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Development of a Problem-Based Learning Module on Elements, Compounds, and Mixtures to Enhance Eighth-Grade Students' Critical Thinking Skills

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Abstract: This study aimed to develop and evaluate a Problem-Based Learning (PBL) science module supplemented with Mind Maps on the topic of elements, compounds, and mixtures to enhance the critical thinking skills of eighth-grade students. The research objectives were to: 1) describe the module's characteristics, 2) examine its feasibility, and 3) test its effectiveness. The development followed the Borg and Gall procedure, comprising ten systematic steps. The module's feasibility was assessed using the Aiken's V validity test, while its impact on critical thinking skills was analyzed using ANCOVA. The results demonstrated that: 1) The developed module possesses distinctive characteristics, integrating PBL with Mind Maps, which promotes active student engagement and provides direct learning experiences to foster critical thinking. 2) The module is highly feasible for classroom use, supported by a strong Aiken's V validity value of 0.85. 3) The module is statistically effective in improving students' critical thinking skills. This conclusion is substantiated by the ANCOVA test results, which showed a highly significant value of $p < 0.001$, confirming a notable enhancement in critical thinking abilities after the implementation of the module. The study successfully validates the module as a viable and effective learning tool.

Keywords: Critical thinking; Modul; Problem-Based Learning.

Introduction

Entering the era of the Industrial Revolution 4.0, the world is undergoing a significant transformation in technology, digital systems, and artificial intelligence, which directly impacts the demand for 21st-century skills. The essential skills for facing this era include critical thinking, collaboration, communication, creativity, citizenship, and character. Indonesia has entered the Industrial Revolution 4.0 since the 2010s, marked by increased connectivity, interaction, and the development of digital systems, artificial intelligence, and virtual reality (Ekasari et al., 2021).

The challenges of the Industrial Revolution 4.0 must be balanced with strengthening student competencies, particularly critical thinking skills, which form the foundation for navigating the complexities of the modern world. By developing these skills early, students can become resilient individuals capable of making decisions and solving problems rationally and objectively. Critical thinking is the ability to think logically, reflectively, and productively in assessing situations to make wise decisions (Cahyani et al., 2021). According to Facione (2015), critical thinking encompasses interpretation, analysis, evaluation, inference, explanation, and self-regulation.

The low critical thinking skills of students in Indonesia are a primary obstacle to improving the quality of competent human resources. This is evident from the 2018 Programme for International Student Assessment (PISA) results, which showed that the average scores for Indonesian students were 371 in

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reading, 379 in mathematics, and 396 in science, all significantly below the OECD averages of 487, 489, and 489, respectively. These scores indicate that most Indonesian students can only solve low-level questions that emphasize memorization and comprehension, rather than analysis or evaluation, which reflect higher-order critical thinking skills.

Further findings reveal that the low achievement across various critical thinking aspects indicates the need for more systematic improvement efforts. The percentage results from a critical thinking skills profile test showed analysis at 59.85% (Low), explanation at 50% (Low), evaluation at 68.94% (Low), self-regulation at 47.72% (Low), interpretation at 51.52% (Low), and inference at 81.82% (High) (Fadwa et al., 2024). Although inference is the highest among the aspects, none has reached the high category, signifying that students' deep-thinking abilities remain limited. This weakness reflects that students are not yet optimally able to interpret information, explain ideas logically, evaluate arguments, regulate their own thought processes, or analyze data accurately. The relatively better inference ability is not supported by other critical thinking aspects; thus, it is insufficient to demonstrate comprehensive and effective critical thinking.

This condition was also found at SMP Negeri 1 Musuk, where students' critical thinking skills have not developed optimally. Teacher interviews indicated that these skills are not evenly distributed among students. The teaching materials used still focus on exercise books, which do not fully develop students' critical thinking abilities. This is exacerbated by teachers' lack of understanding of how to teach critical thinking skills.

The low level of critical thinking skills is suspected to be caused by several factors, including minimal active student engagement, limited teaching materials, and a lack of innovative learning models. The predominantly one-way learning process, which involves little student discussion and deep exploration, needs to be changed to provide students with broader opportunities for critical thinking. Low student engagement, a lack of teaching materials, and insufficient teacher creativity in applying learning models are also causes of this low skill level (Luzyawati, 2017).

The gap between 21st-century learning goals and the reality in the field indicates the need for intervention in the form of developing contextual, applicable teaching materials that can optimally enhance the student's role. One alternative learning approach considered effective for improving critical thinking skills is the Problem-Based Learning (PBL) model. PBL is an appropriate choice as it fosters curiosity, encourages exploration, and cultivates the ability to solve problems independently. Constructivism-based learning strategies like PBL have proven effective in enhancing students' critical thinking skills (Prasmala et al., 2022).

In addition to the learning approach, the media used in the learning process also determines the success of developing student skills, one of which is through the use of learning modules. Learning modules not only facilitate student autonomy in learning but also strengthen their self-control in formulating learning strategies suited to their abilities. Learning modules provide opportunities for students to learn independently according to their own pace (Agustina et al., 2022).

The use of mind maps as a visual aid has also been proven to support the development of critical thinking skills through the systematic organization of information. Mind maps are an important tool in the learning process, particularly in supporting critical thinking skills. They make it easier for students to organize information and find relationships between concepts, which supports higher-order thinking skills like analysis, evaluation, and synthesis. Visualizing ideas through mind maps encourages structured thinking, strengthens understanding, and facilitates memory and application of concepts in different contexts. For science subjects like Elements, Compounds, and Mixtures, which contain many interrelated and abstract concepts, the use of mind maps is highly relevant for facilitating a more systematic understanding. According to Buzan (2007), a mind map is a visual technique that can help students structure ideas, understand concepts, and connect information systematically.

Integrating the PBL model with learning modules and the use of mind maps can develop students' critical thinking skills. This combination of approaches provides a more meaningful learning experience and allows students to develop critical thinking abilities independently and sustainably. Therefore, developing a PBL and mind map-based module is considered a solution for enhancing students' critical thinking skills.

Method

This study employed a Research and Development (R&D) approach, adapting the systematic process from industrial product development to an educational context (Gall et al., 1996). The specific model followed was the 10-stage procedure by Gall et al. (1996), which was implemented to develop and validate a Problem-Based Learning (PBL) and Mind Map-based module designed to enhance the critical thinking skills of eighth-grade students on the topic of Elements, Compounds, and Mixtures.

The research flow, illustrating the interconnected stages of development, evaluation, and revision, is presented in Figure 1.

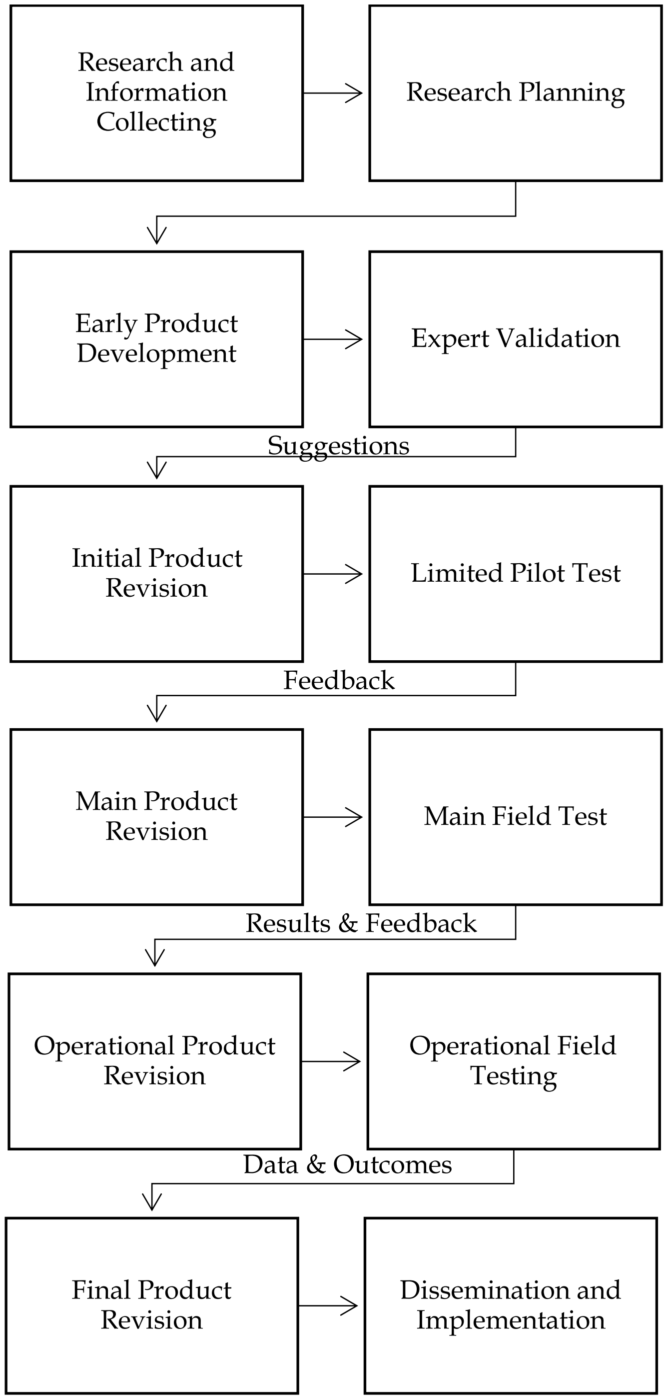

Figure 1. Research and Information Collecting

This preliminary stage involved a comprehensive literature review on critical thinking, PBL, and mind maps. Furthermore, initial field studies were conducted, including an assessment of students' existing critical thinking skills and structured interviews with science teachers to identify specific needs and challenges in the classroom.

Research Planning

The planning phase focused on defining the module's foundational structure based on the Indonesian national curriculum (BSKAP Regulation No. 033 of 2024). The team established the Learning Outcomes *(Capaian Pembelajaran)*, Learning Pathways *(Alur Tujuan Pembelajaran)*, and Learning Objectives *(Tujuan Pembelajaran)* for the "Elements, Compounds, and Mixtures" topic. Module specifications and a content outline were then drafted accordingly.

Early Product Development

A preliminary prototype of the PBL-Mind Map module was developed. This included crafting all standard components of a teaching module, such as the cover, introduction, learning activities, exercises, answer keys, and glossary.

Expert Validation

The initial prototype underwent a rigorous feasibility assessment by a panel of four experts: a content specialist, an instructional design expert, a media expert, and an assessment instrument expert. This stage focused on validating the product's theoretical and design soundness before it was tested with students.

Initial Product Revision

The module was revised based on the quantitative scores and qualitative recommendations provided by the expert validators. This step ensured the product was robust and ready for initial practical testing.

Limited Pilot Test

The revised module was tested with a small group of 15 eighth-grade students. The goal was to gather feedback on its practicality, usability, and initial user engagement. Qualitative responses from the students were collected.

Main Product Revision

All feedback from the limited pilot test was incorporated into a second round of revisions. An improvement matrix was created to systematically address all issues related to language clarity, instruction, and layout, resulting in a more refined version for larger-scale testing.

Main Field Test

This stage involved testing the module's feasibility and refining the research instruments over four class sessions with 34 students. The focus was on evaluating the module's implementation in a real classroom setting and conducting an item analysis on the assessment tools.

Operational Product Revision

A final round of revisions was conducted based on the outcomes and observations from the main field test to prepare the module for the effectiveness trial.

Operational Field Testing

A quasi-experimental study using a pre-test-post-test non-equivalent control group design was conducted to empirically test the module's effectiveness in enhancing students' critical thinking skills.

Final Product Revision

The module was finalized by incorporating the last suggestions from the operational field test, ensuring it was a validated and effective educational product.

Dissemination and Implementation

The final stage involved disseminating the research findings and the developed module by publishing the results in a Sinta 2-indexed scientific journal.

Result and Discussion

The preliminary study was conducted through direct classroom observation and an initial assessment of students' critical thinking skills. Observations took place during science teachers' administration of daily examinations, covering the entire process from preparation to completion, followed by interviews with the science teachers. The observational findings revealed that students' knowledge attainment was primarily limited to factual and conceptual knowledge, representing lower cognitive levels such as remembering, identifying, and recalling information. In contrast, procedural and metacognitive knowledge were generally categorized as moderate based on interview data. Procedural knowledge, which relates to how students solve everyday life problems, showed a significant connection with their critical thinking abilities. Interviews with science teachers indicated that students' critical thinking skills were at a moderate level, as demonstrated by their questioning activity during class, the quality of questions they posed, and the notable number of students who remained passive during questioning sessions. To verify these findings, critical thinking skills were formally assessed using a school population sample, with the baseline assessment results presented in Table 1.

Table 1. Initial Critical Thinking Skills of Students

Pretest critical thinking skill		
Score/percentage	Criteria	Frequency
81-100	Very high	0
61-80	High	1
41-60	Moderate	17
21-40	Low	13
0-20	Very low	2
Total	33	

The pretest results on students' critical thinking skills reveal that the majority (17 out of 33 students) demonstrated only moderate proficiency. Thirteen students scored in the low proficiency category, indicating persistent difficulties in critically analyzing the instructional material. Furthermore, two students fell into the very low proficiency category, suggesting severely limited critical thinking abilities that require targeted instructional intervention.

Notably, only one student achieved high proficiency, while none reached the very high proficiency level (81-100 score range). These findings collectively demonstrate that students' critical thinking skills prior to the implementation of the Problem-Based Learning (PBL) and Mind Mapping module require substantial improvement. The negligible percentage of high-performing students underscores the urgent need for innovative, interactive teaching strategies focused on real-world problem-solving to enhance these essential cognitive skills.

The characteristics of the Problem-Based Learning module for elements, compounds, and mixtures were developed through the following stages: research and information collecting, planning, developing a preliminary product form, preliminary field testing, main field testing, and operational field testing. The obtained characteristics include: 1) Based on Problem-Based Learning; 2) Implementing an inquiry approach (observing; questioning and predicting; planning and conducting investigations; processing, analyzing data and information; evaluating and reflecting; as well as communicating results); 3) Integrating mind maps in learning; 4) Potentially empowering students' critical thinking skills; 5) Providing interactive learning experiences.

The Problem-Based Learning (PBL) model represents a constructivist approach designed to enhance students' critical thinking and problem-solving skills. This study examines the systematic implementation of PBL syntax in teaching "Elements, Compounds, and Mixtures" using the instructional module titled "The Smallest Components of Living Things and Non-Living Objects" for Phase D learners (8th grade junior high school). The following details the implementation of each PBL phase in the learning process.

The learning sequence commenced with a contextual problem presentation. Educators displayed aquarium water condition images and guided students to observe school pond ecosystems. Students engaged in reflective questioning such as, "Have your pet fish ever died? Why?" This activity aimed to cultivate curiosity and establish real-world material connections. Hmelo-Silver (2004), emphasizes that problem orientation constitutes a crucial PBL element for fostering early cognitive engagement and motivation.

Following problem comprehension, students formed small discussion groups (4-5 members) to formulate investigative questions. Teachers facilitated Q&A sessions to stimulate hypothesis development regarding pond water composition. At this stage, students began constructing inquiry procedures with teacher guidance. Arends (2012) highlights that group organization is essential for developing collaborative skills and creating accountable, active learning structures.

During core activities, students conducted direct environmental observations, collecting data on encountered elements, compounds, and mixtures. Findings were organized in tables detailing: substance names, classification, element/compound symbols, constituent components, and ichthyological impacts. Savery (2016) affirms this phase as the PBL cornerstone, promoting autonomous knowledge discovery through active investigation.

The observational data and group analysis results were presented through classroom presentations. Students explained substance classification, mixture separation methods, and the relationship between chemical components and fish health. Teachers provided differentiated guidance for students encountering difficulties. Bell (2010) asserts that results presentation serves as an opportunity to develop scientific communication skills and build student confidence.

The final stage involved intergroup reflection and evaluation. Students exchanged feedback and revised their conclusions accordingly. Teachers guided the scientific reasoning process and facilitated whole-class learning synthesis. Barrows (1996) emphasizes the crucial role of reflection in PBL for deepening understanding and developing higher-order thinking skills.

The implementation of PBL syntax in teaching Elements, Compounds, and Mixtures through this instructional module demonstrated positive impacts on student engagement. Participants became more active, thought critically, and achieved contextual material understanding. Furthermore, the learning process gained greater significance through direct connections to environmental and everyday life contexts.

Module Feasibility

The feasibility test results based on module characteristics are presented in Table 2.

Table 2. Feasibility Test Results of the Learning Module Based on Characteristics

Assessment aspect	Aiken V value	Criteria (V=0.75)
Self instructional	0.80	Valid
Self contained	0.88	Valid
Stand alone	0.85	Valid
Adaptive	0.84	Valid
User friendly	0.85	Valid

The feasibility of the Problem-Based Learning (PBL) module for teaching critical thinking skills in the topic of Elements, Compounds, and Mixtures was established through expert validation. The assessment was based on the BSNP (2014) criteria for instructional materials, which include: self-instruction, self-contained, stand-alone, adaptive, and user-friendly. According to Azwar (2012), the Aiken's V index was used to measure the alignment between items and specific validation indicators. An Aiken's V value of 0.85 indicates a highly feasible category (Azwar, 2012), confirming that the module is suitable for research implementation.

The module was designed with self-instruction capabilities, allowing students to learn independently without direct teacher guidance. Its structured and systematic design enables students to follow learning steps sequentially (Prastowo, 2019). The PBL-based framework helps students develop critical thinking and problem-solving skills autonomously (Rusman, 2015). Additionally, the use of simple and clear language ensures that instructions are easily understandable, enhancing student comprehension (Majid, 2014).

A self-contained module ensures that all relevant material is accessible without requiring additional resources. This design supports effective self-directed learning, allowing students to grasp concepts comprehensively (Ali et al., 2010). The module provides complete content, from fundamental concepts to evaluations, reducing reliance on external textbooks (Sugianto et al., 2022). Furthermore, the webbed-based integrated learning model presents interdisciplinary connections holistically, helping students understand the relationships between Physics, Biology, and Chemistry (Jemeo et al., 2024).

A stand-alone module allows students to learn independently without supplementary materials. Research by Padsing (2021), confirms that PBL-based stand-alone modules enable students to fully understand material without external dependencies. The inclusion of visual aids (images, illustrations) enhances contextual and conceptual understanding, facilitating an integrated and effective self-learning experience. Additionally, Silberman et al. (2021), found that stand-alone modules improve student comprehension by allowing them to learn at their own pace, fostering independent learning skills and motivation.

An adaptive module adjusts content based on technological advancements and student interests. Studies by Contrino et al. (2024) show that adaptive learning systems allow students to access materials at their own pace while providing continuous feedback for deeper understanding. Yaseen et al. (2025) further highlight that adaptive learning technology enhances engagement by personalizing learning experiences according to individual needs and learning styles.

A user-friendly module features an intuitive interface and simple language, enabling independent learning without additional guidance. Sari et al. (2024), emphasize that clear, easy-to-understand language and commonly used terms contribute to user-friendliness in e-modules. Additionally, Firdaus et al. (2024) demonstrate that modules with well-designed user interfaces and experiences improve student creativity and comprehension.

The feasibility assessment of the PBL-based module on Elements, Compounds, and Mixtures confirms its suitability based on expert and practitioner evaluations. Thus, the developed module effectively facilitates abstract concept mastery and self-directed learning.

Effectiveness of the Learning Module

The effectiveness of the PBL and Mind Map-based module in enhancing students' critical thinking skills was evaluated through field testing (Fidan & Tuncel, 2019). A pretest–posttest design was employed: students took a pretest to assess initial critical thinking levels, they engaged in module-based learning activities, and a posttest was administered to measure improvement in critical thinking skills related to Elements, Compounds, and Mixtures. The results determine whether the module successfully enhances students' critical thinking abilities in the subject matter.

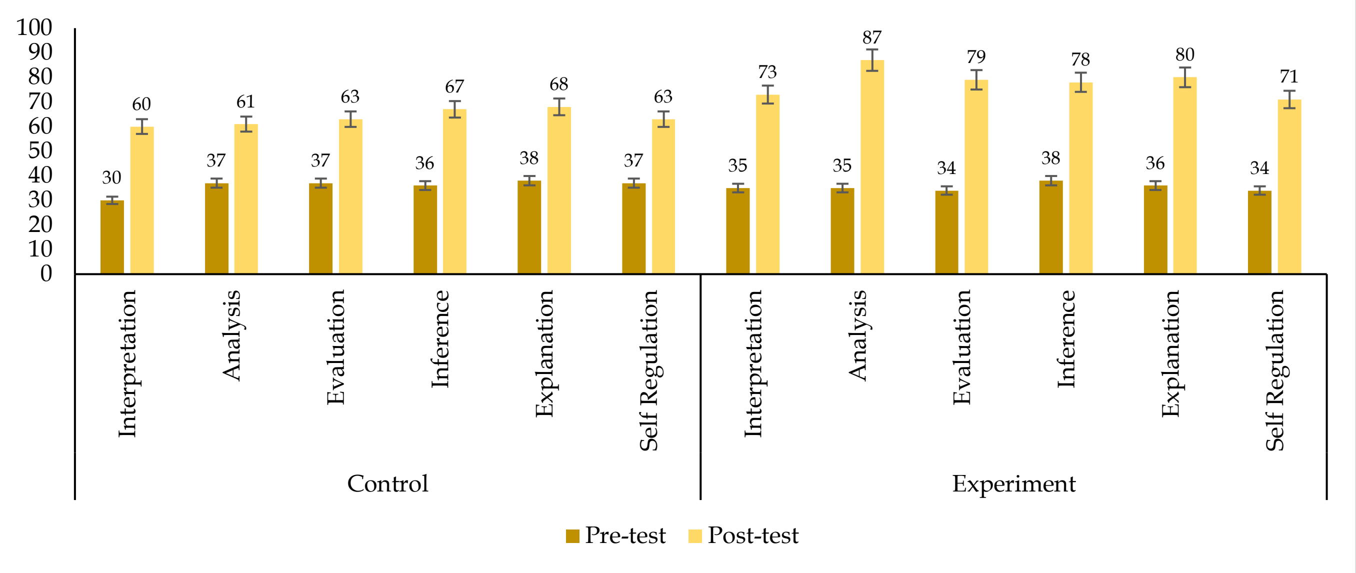

Figure 2. Graph of Students' Critical Thinking Skills Results

The comparative analysis of pre-test and post-test scores between control and experimental groups presented in Figure 2 demonstrates that the implementation of Problem-Based Learning (PBL) and Mind Mapping modules significantly enhances students' critical thinking skills in the subject of Elements, Compounds, and Mixtures. The graphical data reveal substantial improvements across all critical thinking dimensions in the experimental group, including interpretation 73, analysis 87, evaluation 79, inference, explanation, and self-regulation. Notably, the experimental group's analysis score of 87 markedly surpassed the control group's performance of 61, indicating that the PBL methodology effectively promotes active problem analysis and independent solution identification.

Further examination shows the experimental group's superior performance in interpretation 73 versus and 60 and evaluation 79 versus and 63 compared to controls, suggesting deeper conceptual understanding through PBL-based instruction. While both groups exhibited score improvements, the experimental group's significantly better outcomes highlight the comparative limitations of conventional teaching methods in developing critical thinking competencies.

The incorporation of Mind Mapping techniques facilitated structured concept visualization, enabling students to establish logical and systematic connections between learned concepts (Hidayatullah et al., 2020). This pedagogical approach particularly enhanced students' ability to analyze and explain complex chemical concepts. The combined PBL and Mind Mapping intervention proved substantially more effective than traditional methods, especially in developing analytical and interpretative skills among eighth-grade students.

Subsequent analysis of pre-test and post-test scores through ANCOVA calculations quantified the module's effectiveness in enhancing critical thinking skills, with detailed ANCOVA results presented in Table 3. These findings collectively support the adoption of this integrated instructional model for teaching chemical concepts in secondary education.

Table 3. ANCOVA Test Results

Source	F	Sig.
Corrected Model	38.644	<0.001
Intercept	143.604	<0.001
pretest	4.608	0.036
treatment	73.745	<0.001
R Square = 0.543		

The analysis revealed that the pretest yielded an F-value of 4.608 with a significance value (Sig) of 0.036. As the significance value is below the 0.05 threshold (α = 0.05), we conclude that the pretest significantly influenced posttest outcomes. This indicates that students' initial performance (pretest) contributed to their posttest scores, necessitating statistical control to obtain more objective treatment measurements.

The treatment factor showed an F-value of 73.745 with a highly significant p-value < 0.001. This strong significance (well below the 0.05 threshold) demonstrates that the intervention significantly affected posttest results. Specifically, the PBL and Mind Mapping module implemented in the experimental group substantially improved learning outcomes compared to conventional methods. The overall Corrected Model produced an F-value of 38.644 ($p < 0.001$), confirming the model's effectiveness in explaining posttest score variations after controlling pretest influences.

The analysis yielded R^2 = 0.543 and adjusted R^2 = 0.529, indicating that 54.3% of posttest variance was explained by the model (incorporating both pretest scores and treatment effects). The remaining 45.7% of variance stems from factors beyond this study's scope.

These results suggest that the PBL and Mind Mapping approach enhances students' conceptual understanding and critical thinking skills more effectively than conventional instruction. The significant improvement in higher performance categories demonstrates that experimental group students not only achieved better content mastery but also applied learned concepts more effectively. We therefore conclude that the PBL and Mind Mapping module positively contributes to student learning outcomes, particularly in developing critical thinking skills and deep conceptual understanding. The developed instructional module is presented in Figures 3.

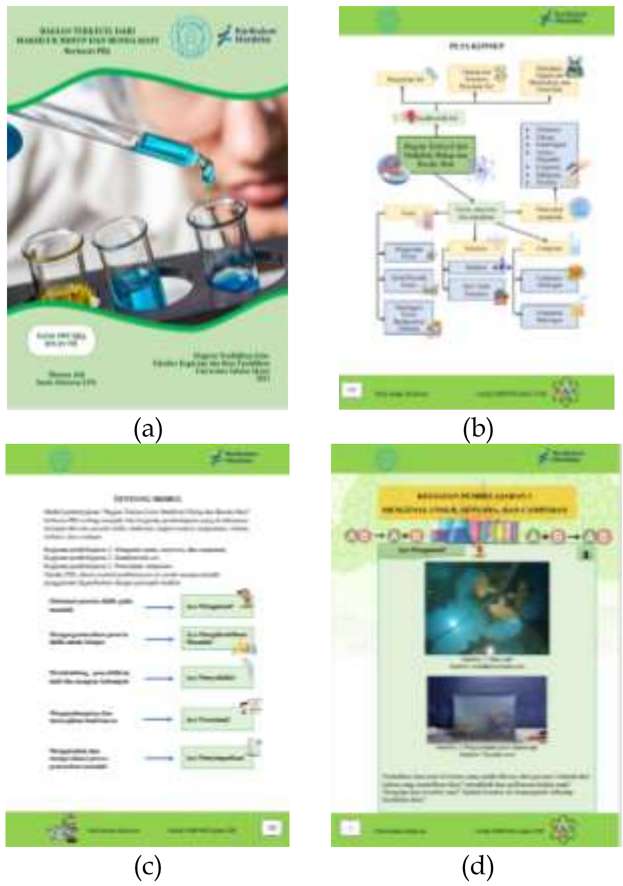

Figure 2. Display of Modul based PBL: (a) Module cover; (b) Concept maps; (c) About the module; and (e) Learning activities

Conclusion

The developed Problem-Based Learning (PBL) and Mind Map-based module for teaching Elements, Compounds, and Mixtures is effective in enhancing students' critical thinking skills. This conclusion is supported by the module's feasibility, as indicated by an expert validation score of 0.85, and a statistically significant effect of the treatment on posttest scores ($F = 73.745$, $p < 0.001$).

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Author Contributions

Conceptualization, investigation, D.R. and H.T.; methodology, W.D.; software, formal analysis, data curation, writing—original draft preparation, writing—review and editing, visualization, D.R.; validation, A.F. and W.D.; resources, H.T. and D.R.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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