Enhancing Critical Thinking and Learning Achievement in Chemical Bonding Through Problem-Based Chemistry Module with Concept Mapping

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Abstract

The development of innovative problem-based teaching materials is a strategic effort to enhance students' critical thinking skills and learning achievement, particularly in understanding abstract concepts such as chemical bonding. This study aims to describe the results of the development stage, the feasibility, and the effectiveness of a problem-based chemistry module assisted by concept mapping in improving the critical thinking skills and learning achievement of high school students on the topic of chemical bonding. The study employed a Research and Development (R&D) method using the Borg and Gall model, modified into nine stages, and was tested in two private schools in Surakarta. Validation results indicated that the module was considered highly valid by experts and practitioners, with scores of 0.95 for content, 0.98 for presentation, 0.96 for language, and 0.94 for media aspects. The feasibility of the module, based on student responses, reached an average of 82.12%, and teacher responses 85.42%, both categorized as very good. The effectiveness of the module was demonstrated by the increase in pretest and posttest results, with N-gain scores of 0.37 (moderate category) for critical thinking skills and 0.69 (moderate category) for learning achievement. Therefore, the problem-based chemistry module assisted by concept mapping is considered feasible and effective for use in teaching chemical bonding at the high school level.

Keywords: *Chemistry Module, Problem-Based Learning, Critical Thinking, Chemical Bonding, Concept Mapping.*

A. INTRODUCTION

Improving the quality of education in Indonesia is an inevitable demand in facing the challenges of the 21st century. Educational transformation is the key to enhancing the quality of Human Resources (HR) to be able to compete globally. Ki Hajar Dewantara explained that education is a comprehensive learning process that teaches individuals to learn and develop throughout their lives. Therefore, educational transformation refers to a series of changes undertaken to ensure that every individual can continue to grow and learn lifelong.

The results of the Programme for International Student Assessment (PISA) tests have become a major concern in efforts to improve education quality and prepare Indonesian human resources to compete in the era of globalization. The trend in Indonesian students' PISA performance from 2000 to 2018 consistently placed Indonesia at the lower ranks with scores below the international average. The latest data from PISA 2022 show that Indonesia's ranking improved by 5–6 positions compared to 2018, although the average score decreased by 12–13 points in reading,

mathematics, and science. These PISA test results are one of the external factors driving curriculum changes in Indonesia.

Table 1. Trends in Indonesian Students' PISA Performance from 2000–2018

No.	Year	Rank	Number of Participating Countries	Score	International Average Score
1	2000	39	41	367	500
2	2003	39	39	360	500
3	2006	50	57	391	500
4	2009	61	65	371	496
5	2012	64	65	375	494
6	2015	63	70	386	490
7	2018	72	78	379	489
8	2022	69	80	369	477

Source: OECD (2003, 2004, 2007, 2010, 2014, 2016, 2019, 2022)

Since Indonesia's first participation in PISA, the curriculum has undergone several reforms, from the Competency-Based Curriculum (KBK) 2004, the 2006 School-Based Curriculum (KTSP), the 2013 Curriculum, to the latest Merdeka Curriculum. These curriculum changes aim to improve the quality of education, with the expectation that better education quality will align with improved PISA scores (Kemendikbud, 2023). Other external factors influencing curriculum changes in Indonesia include the dynamic developments among nations, rapid technological advancements, and political and intellectual perspectives on education outcomes.

Entering the 21st century and the era of the Industrial Revolution 5.0, education must equip students with 21st-century competencies, known as the 4Cs: Critical Thinking and Problem Solving, Communication, Creativity and Innovation, and Collaboration skills. Among these, critical thinking is a particularly essential competency. Critical thinking is crucial in daily life because it enables individuals to evaluate, analyze, and filter information carefully before making decisions or forming opinions. According to Facione (2015), critical thinking encompasses key skills such as interpretation, analysis, evaluation, inference, explanation, and self-regulation. Susanti et al. (2022) emphasized that activities such as posing 5W+1H questions, active listening, and considering various possible solutions can foster students' critical thinking skills.

Along with the transition from the 2013 Curriculum to the Merdeka Curriculum, innovations in teaching components continue to evolve, including learning models, teaching materials, and learning media. Learning modules and the Problem-Based Learning (PBL) method remain highly relevant for enhancing 21st-century competencies. Learning modules facilitate independent and enjoyable learning, while PBL is recommended in both the 2013 Curriculum and the Merdeka Curriculum (E-Journal TSB, 2023). Research has shown that developing PBL-based chemistry modules is effective in enhancing students' critical thinking skills, particularly in the topic of redox reactions.

In chemistry education at Phase F, chemical bonding is one of the essential topics taught during the first semester. In the Merdeka Curriculum, the chemical bonding topic is included in the Learning Outcomes (Capaian Pembelajaran), covering element stability, Lewis structures, ionic and covalent bonds, and polar and nonpolar covalent compounds (Kemendikbud, 2023). Based on interviews with Grade XI students from two private senior high schools in Surakarta, 87.5% of students reported difficulties in learning chemical bonding. These difficulties can be categorized into three main aspects: the abstract nature of the content, lack of connection to real-life contexts, and the complex structure of the concepts.

To bridge the challenges in teaching chemical bonding and enhance students' critical thinking skills, it is necessary to implement teaching methods and materials that integrate critical thinking strategies. Therefore, this study develops a problem-based chemistry module supported by concept mapping to improve students' critical thinking skills and academic achievement in chemical bonding.

Concept mapping is an effective learning tool for enhancing students' critical thinking skills because it helps them visualize the relationships among concepts, facilitating deeper understanding and analysis. Darnella et al. (2020) found that using concept mapping significantly improved students' critical thinking skills in the topic of the locomotor system, with an 87% mastery rate compared to 76% in conventional methods. Research by Labibah and Ernawati also indicated that concept mapping strategies positively influenced science learning outcomes, especially for students with high critical thinking abilities. Furthermore, Mardhiyati et al. (2021) revealed that students taught using concept mapping strategies showed a significant increase in critical thinking skills compared to control groups. Thus, various studies confirm that concept mapping plays an important role in enhancing students' critical thinking abilities by helping them organize and connect concepts systematically and deeply.

The module developed in this study incorporates concept maps at the end of each learning activity, helping students organize and relate concepts more systematically and profoundly. In addition, the module uses Socratic questioning in the "Critical Thinking" activities to encourage students to reflect on their learning processes based on critical thinking indicators (Repository UNSRI, 2023). Therefore, this study offers an innovation in chemistry learning that addresses students' difficulties in understanding chemical bonding while enhancing their critical thinking competencies.

B. METHOD

This study employed the Research and Development (R&D) method based on the Borg and Gall development model, which aims to produce a specific product through needs analysis and test its effectiveness so that it can function optimally (Sugiyono, 2012). The development model was modified into nine steps, as follows:

1. Preliminary Stage

   Conducting initial research and data collection through field studies and literature review to understand the needs and development context.

2. Development Stage
   Designing the product, which includes:
   - Selecting the module format.
   - Preparing the first draft of the module.
   - Validating the design by four experts (media, language, content, and instructional design) and practitioners using the BSNP standard module validation sheet.
3. Draft Revision
   Revising the first draft based on input and suggestions from experts and practitioners.
4. Initial Field Trial
   Using questionnaires to obtain feedback from 2 teachers and 10 students on the developed module draft.
5. Product Revision Based on Initial Field Trial
   Refining the product based on the evaluation results of the initial field trial.
6. Limited Field Trial
   Using questionnaires to collect data from 2 teachers and 32 students to assess the revised module.
7. Product Revision Based on Limited Field Trial
   Improving the product based on feedback received during the limited field trial.
8. Wider Field Trial
   Testing the effectiveness of the product through:
   - Data collection using questionnaires from 65 students and 3 teachers.
   - Critical thinking skill tests using instruments provided by a psychological service.
   - Academic achievement tests on the topic of chemical bonding using validated and tested instruments.
     Effectiveness testing was carried out using a pre-test and post-test group design, with the following treatments:
   - The experimental class used a problem-based chemistry module supported by concept maps.
   - The control class used a conventional chemistry module (not problem-based and without concept maps).
9. Final Product Revision
   The final product was refined based on suggestions and input from experts, teachers, and students.

C. RESULT AND DISCUSSION

1. Preliminary Study

The results of the preliminary study at two private high schools in Surakarta are presented in Table 2. Based on the data, it is necessary to develop a problem-based chemistry module assisted by concept maps on the topic of chemical bonding to

improve academic achievement and foster critical thinking skills.

Table 2. Summary of Preliminary Research Based on Field Surveys

Aspect	Average (%)
Perception of chemical bonding as difficult	86.67
Test scores above 75	71
Use of PBL syntax in learning	0
Use of concept maps in learning	50
Student engagement in literacy activities	50

Based on the data, it can be concluded that there is a need for the development of a problem-based chemistry module assisted by concept maps on the chemical bonding topic to enhance student achievement and critical thinking skills.

2. Module Design Planning

Module design planning includes:

a. Selecting the Module Format

The module format adapts the format from the Ministry of National Education (Depdiknas, 2008), consisting of three main sections: introduction, content, and closing. The module is further adapted to the characteristics of problem-based learning (PBL).

b. Drafting the First Version of the Module

The preparation of the first draft follows these steps:

1. **Determining the Material**
   The material covered in this module is Chemical Bonding, part of the Grade 10, Semester 1 curriculum under the Independent Curriculum.
2. **Formulating Material Points**
   The material points are divided into three learning activities:
   Learning Activity 1: Abundance of Elements in Nature
   Learning Activity 2: Element Stability
   Learning Activity 3: Types of Chemical Bonds
3. **Preparing Module Components**
   The components include the title, description, instructions for working on the module, exercises, and images related to real-life situations.
   The draft design is based on field needs and validated by three experts and two practitioners. Validation results are presented in Table 3.

Table 3. Overall Assessment by Validators Based on BSNP Standards

BSNP Aspect	Average Score	Remark
Content	0.95	Valid
Presentation	0.98	Valid
Language	0.96	Valid
Media	0.94	Valid

Learning tools used were also validated and are presented in Table 4.

Table 4. Overall Assessment by Validators on Learning Tools

Device	Average Score	Remark
Teaching Module	0.96	Valid
Concept Map	0.93	Valid
Learning Objectives Flow	0.97	Valid
Knowledge Test	0.93	Valid
Skills Observation	1.00	Valid
Attitude Questionnaire	1.00	Valid

Based on the validation results with valid criteria and feedback from validators, the module draft is ready to be developed.

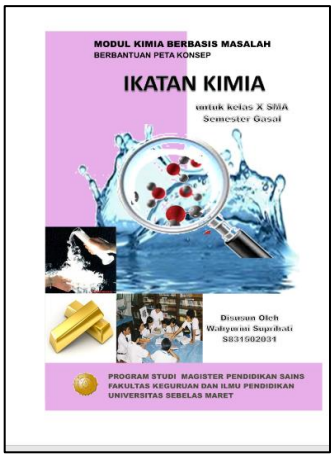
3. **Development Stage**

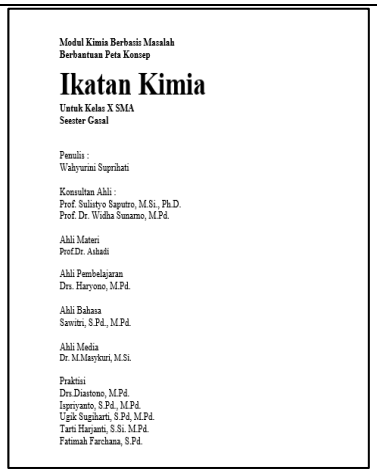
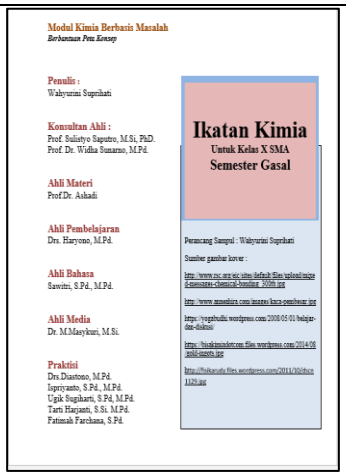
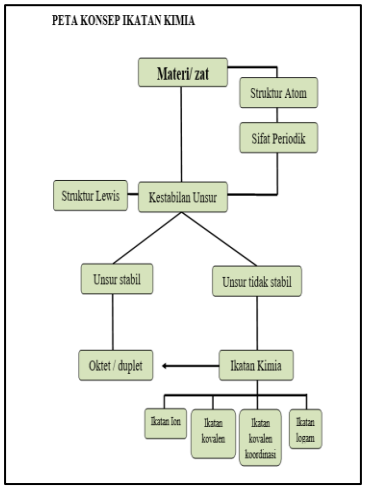
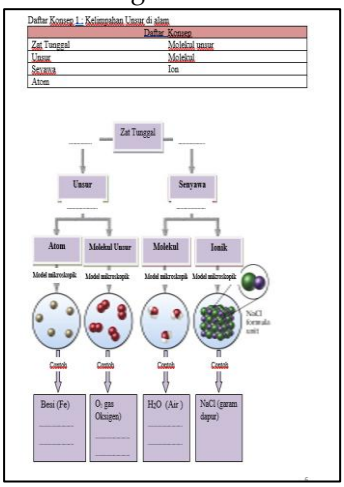
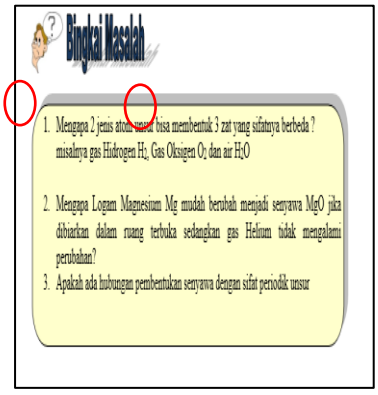
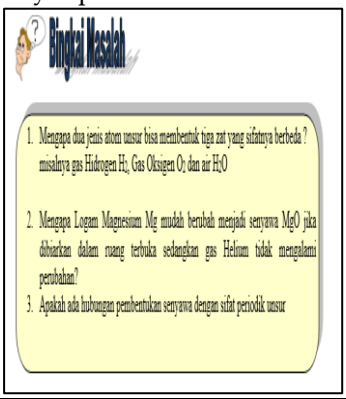
At this stage, improvements were made to Draft I of the module based on suggestions and feedback from media, language, learning experts, and practitioners (teachers), resulting in Draft II, which is ready for small-scale trials. Revisions to Draft I are shown in Table 5.

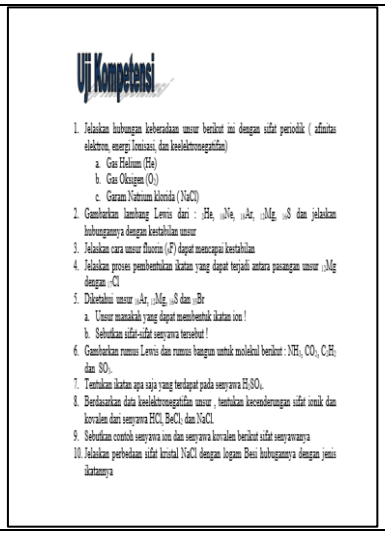
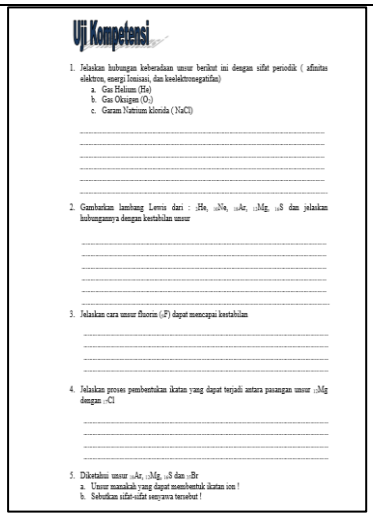
4. **Product Testing**

The product was tested three times to assess module feasibility, with improvements made after each trial based on feedback.

Table 5. Revisions to the Module Draft

Validation Source	Improvement Suggestions	After Repair
Media Expert	Improve the background color type, logo placement and clarity of the module identity. 	Revised results of the module cover. 
	Francis page design plus image sources	Cover quote source on francis page and validator added.

Validation Source	Improvement Suggestions	After Repair
		
Learning Expert	It is not a concept map but a position map. 	Concept maps are created at the end of each learning activity, complete with a list of concepts. Each concept has a connecting word 
Linguist	Write in letter form. 	Already repaired 
	Correct punctuation and spacing	Already repaired
Education Practitioner	In the Competency Test, descriptive questions are given spaces (dots) to be filled in.	Already repaired

Validation Source	Improvement Suggestions	After Repair
		

Responses from initial, limited, and broad field trials are presented in Tables 6, 7, and 8.

Table 6. Initial Field Trial Responses

No.	Aspect	Student Score (%)	Category	Teacher Score (%)	Category
1	Content	79.17	Good	75.00	Good
2	Language	79.70	Very Good	83.33	Very Good
3	Presentation	82.02	Very Good	83.33	Very Good
4	Graphics	72.50	Good	75.00	Good
	Average	78.34	Good	79.17	Good

Table 7. Limited Field Trial Responses

No.	Aspect	Student Score (%)	Category	Teacher Score (%)	Category
1	Content	80.47	Very Good	79.33	Good
2	Language	81.67	Good	87.50	Very Good
3	Presentation	83.50	Very Good	87.50	Very Good
4	Graphics	77.78	Good	83.33	Very Good
	Average	80.85	Very Good	84.38	Very Good

Based on the data from Tables 6 and 7, response results improved after each trial. Some revisions were made to the module after each trial according to respondents' suggestions.

4. **Broad Field Trial**

A broad field trial was conducted to test the effectiveness of the product using questionnaires and tests, as shown in Tables 8 and 9.

Table 8. Questionnaire Results in Broad Field Trial

No.	Aspect	Student Score (%)	Category	Teacher Score (%)	Category
1	Content	83.33	Very Good	81.05	Very Good
2	Language	82.50	Very Good	87.50	Very Good
3	Presentation	84.20	Very Good	87.70	Very Good
4	Graphics	79.70	Good	85.53	Very Good
	Average	82.12	Very Good	85.42	Very Good

Table 9. Learning Achievement and Critical Thinking Skills Test Results in Broad Field Trial

Aspect	Pretest	Post test	N-gain
Critical Thinking Skills			
a. Experimental Group	5.70	8.52	0.37
b. Control Group	6.20	8.17	0.17
Learning Achievement			
a. Experimental Group	26.83	77.07	0.69
b. Control Group	27.34	67.75	0.56

The broad-scale trial results show that the problem-based chemistry module assisted by concept maps is feasible for use in learning. Both the experimental and control groups showed increased critical thinking skills and academic achievement (moderate N-gain category), with greater improvement in the experimental group. This module proved effective in enhancing students' critical thinking and learning outcomes in chemical bonding material. This study is supported by previous research. Wang and Zhao (2023) found that a problem-based approach fosters students' reflective thinking in understanding chemical concepts, while Xie et al. (2023) and Kim and Lee (2023) reported that concept maps help organize complex ideas and enhance analytical skills.

Additionally, studies by Huang et al. (2023), Chen & Wu (2024), and Sun et al. (2023) revealed that the use of visual media such as concept maps improves information retention, conceptual understanding, and knowledge transfer. Problem-based modules have also been proven to enhance critical thinking skills, learning motivation, and higher-order thinking skills, as stated by Ariffin et al. (2023), Tan & Goh (2024), and Martínez-Sierra & García-González (2023).

Further support comes from Li & Zhang (2024), Yu & Park (2024), and Zhao et al. (2023), who emphasized that the use of concept maps strengthens metacognitive abilities and accelerates students' knowledge construction. Research by Hernández-Gómez & Luna-Márquez (2024), Singh & Kaur (2024), and Putri & Pratama (2024) confirmed that this approach is more effective than lecture-based methods, increasing class discussion activity and mastery of the material. Studies by Nguyen and Pham (2025), Alvarado and Muñoz (2024), and Khalid and Ahmed (2025) also indicated that integrating concept maps into learning clarifies inter-concept relationships, enriches learning experiences, and develops analytical, evaluative, and creative thinking skills.

Table 10. Normality Test Results

Test	Experimental Group		Control Group	
	Sig.	Decision	Sig.	Decision
Knowledge	*0.200*	*Ho accepted*	*0.200*	*Ho accepted*

Table 11. Homogeneity Test Results

Test	Sig.	Decision	Conclusion
Knowledge	0.232	Ho accepted	Variance is homogeneous

Table 12. T-Test Results

School	Sig. (2-tailed)	Decision	Conclusion
Knowledge	0.003	Ho rejected	Module is effective

Students were more motivated to study using the module because they could practice independently at home and assess their learning outcomes through tasks and exercises provided in the module. The feedback feature also allowed them to evaluate their progress. According to the principles of learning by Depdiknas (2008), knowing the learning outcomes achieved encourages students to continuously pursue learning goals.

D. CONCLUSION

Based on the research results, it can be concluded that the problem-based chemistry module assisted by concept maps on the topic of chemical bonding has been successfully developed through a series of revisions based on feedback from expert consultants and validators, and has been tested on small, medium, and large scales. The module was declared feasible for use, as indicated by the average response scores of 82.12% from students and 85.42% from teachers, both falling into the "very good" category. In addition, the module was proven effective in improving students' critical thinking skills and academic achievement, as reflected by the higher N-gain scores in the experimental group compared to the control group.

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