Chemined 14 (2) (2025)

Chemistry in Education

https://journal.unnes.ac.id/journals/chemined

A Problem-Based Learning (PBL)-Based Student Worksheet Development on Green Chemistry Topics Through Experimental Activities to Improve Students' Critical Thinking Skills

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ARTICLE INFO

Article history:
Received: July 2025
Approved: December 2025
Published: December 2025

Kata Kunci:
Lembar Kerja Siswa, Keterampilan Berpikir Kritis, Kimia Hijau

Keywords:
Student Worksheet, Critical Thinking Skills, Green Chemistry

DOI: 10.15294/chemined.v14i2.30448

ABSTRAK

Penelitian ini bertujuan mengembangkan Lembar Kerja Peserta Didik (LKPD) berbasis Problem-Based Learning (PBL) pada materi kimia hijau melalui kegiatan praktikum sederhana guna meningkatkan keterampilan berpikir kritis siswa. Pengembangan dilakukan menggunakan model ADDIE (Analyze, Design, Develop, Implement, Evaluate) melibatkan siswa kelas X di SMA Negeri 12 Semarang. LKPD yang dikembangkan berfokus pada praktikum pemurnian minyak jelantah dan pembuatan lilin aromaterapi sesuai prinsip kimia hijau. Instrumen penelitian meliputi lembar validasi ahli, angket respons siswa, dan tes pilihan ganda keterampilan berpikir kritis. Hasil validasi menunjukkan bahwa LKPD memperoleh skor rata-rata 99% dari ahli media dan 90% dari ahli materi, keduanya berkategori sangat valid. Efektivitas LKPD ditinjau melalui pretest dan posttest, dengan peningkatan nilai rata-rata dari 70,98 menjadi 86,26 dan nilai N-Gain sebesar 0,58 yang berkategori sedang hingga tinggi. Sebanyak 84,40% siswa mencapai kategori tinggi dan sangat tinggi dalam keterampilan berpikir kritis. Respons siswa terhadap LKPD sangat positif dengan persentase rata-rata 97%. Temuan ini menunjukkan bahwa LKPD berbasis PBL pada materi kimia hijau valid, efektif, dan mampu meningkatkan proses serta hasil belajar, sekaligus menumbuhkan keterampilan berpikir kritis serta kesadaran lingkungan dan keberlanjutan.

ABSTRACT

This study aims to develop a Problem-Based Learning (PBL)-based Student Worksheet on green chemistry topics through simple experimental activities to enhance students' critical thinking skills. The development process employed the ADDIE model (Analyze, Design, Develop, Implement, Evaluate), involving Grade X students at SMA Negeri 12 Semarang. The worksheet centers on practical experiments involving the purification of used cooking oil and the production of aromatherapy candles, aligned with green chemistry principles. Research instruments included expert validation sheets, student response questionnaires, and multiple-choice critical thinking tests. The worksheet achieved average validity scores of 99% from media experts and 90% from material experts, both of which are categorized as highly valid. Its effectiveness was evaluated through pretest and posttest assessments, revealing an increase in students' mean scores from 70.98 to 86.26, with a normalized gain (N-Gain) of 0.58, classified as moderate to high. Furthermore, 84.40% of students demonstrated high to very high levels of critical thinking skills. Student responses toward the worksheet were highly positive, with an average rating of 97%. These results indicate that the PBL-based worksheet on green chemistry is valid, effective, and significantly supports the learning process and outcomes while fostering critical thinking, environmental awareness, and sustainability.

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p-ISSN 2252-6609
e-ISSN 2502-6852

INTRODUCTION

In an effort to enhance the quality of education, particularly in science learning such as chemistry, educators need to develop creative and innovative teaching methods in accordance with the applicable curriculum. This involves effective planning, implementation, assessment, and supervision. Laboratory work becomes one of the essential methods that allows students to apply the concepts learned through firsthand experience. In this context, laboratory guides and Student Worksheets serve as important informational resources to support the learning process and necessary data analysis (Saputri et al., 2024).

In the execution of chemistry experiments, hazardous chemical waste is often generated, which can have long-term negative environmental impacts. Therefore, there is a need to develop safer and more environmentally responsible laboratory practices. One applicable solution is the concept of green chemistry. This concept focuses on reducing or substituting the use of hazardous substances in chemical processes with more environmentally friendly materials. By applying the principles of green chemistry, students not only learn about chemical theory but also engage directly in a learning process that supports conservation values and environmental awareness. Through this experience, students can understand the importance of protecting the environment and develop a sense of responsibility toward their surrounding ecosystem (Putra, 2022).

Green chemistry is an integral part of the chemistry curriculum aimed at addressing various environmental issues through the use of safer chemicals and efficient processes. This concept implements 12 principles, such as preventing waste formation, maximizing atom economy, and designing processes that use safe chemicals. By applying these principles, green chemistry significantly contributes to environmental sustainability and ecosystem health. Furthermore, these principles encourage innovation in environmentally friendly technologies, focusing on the development of processes and products that minimize the use of hazardous materials and generate less waste. By reducing dependence on non-renewable resources, green chemistry supports long-term sustainability. Thus, the application of green chemistry not only results in safer products but also equips individuals with the knowledge and tools necessary for maintaining environmental sustainability in the future, making chemistry education more relevant and positively impactful (Suci & Zainul, 2023).

Based on observations and interviews with chemistry teachers at SMA Negeri 12 Semarang, it was found that students' critical thinking skills in chemistry learning are still relatively low, marked by minimal active participation in discussions and insufficient ability to explain concepts logically. Teachers also expressed concern that the teaching methods employed have not optimally trained students' higher-order thinking skills, indicating a need for innovative learning that integrates practical approaches and Problem-Based Learning (PBL).

The use of a PBL-based worksheet, combined with simple laboratory activities, is expected to provide a solution to these issues. Previous research has also shown that the application of practical-

based learning models and problem-solving can significantly improve students' learning outcomes and critical thinking skills. Therefore, the development of worksheets aligned with the principles of green chemistry becomes a strategic step to enhance the effectiveness of learning and students' environmental awareness. However, to date, the development of PBL-based worksheets on green chemistry topics through simple laboratory practices that are feasible and effective remains very limited and requires further investigation. Through comprehensive validation and trials, it is hoped that this educational tool can assist learners not only in understanding the material theoretically but also in applying concepts in real-world contexts that support environmental sustainability and the development of their critical thinking skills.

METHODS

This research was conducted at SMA Negeri 12 Kota Semarang, involving a small-scale trial with 20 participants from the eleventh grade and a large-scale trial with 33 participants from the tenth grade. This study is a Research and Development (R&D) project that utilizes the ADDIE design, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. Data collection techniques in this study included observations and direct interviews with teachers as primary informants to obtain preliminary information regarding issues and the needs for the development of learning media, as well as the use of instruments in the form of questionnaires distributed to media experts, subject matter experts, students, and teachers to evaluate the feasibility and effectiveness of the PBL-based Student Worksheets. Additionally, data collection was conducted using tests in the form of multiple-choice questions, which were validated by expert lecturers. Analysis was performed using the formula from Saputra and Sunu (2019) to calculate student scores and determine their critical thinking abilities. The validity test of the questions indicated that all items met high validity and reliability criteria, while the discrimination power of the questions was mostly good, indicating that the items were able to accurately and objectively differentiate students based on their levels of understanding.

RESULT AND DISCUSSION

Result

The results of the study include an analysis of feasibility, effectiveness, student responses, and the quality of the Multiple Choice Test instrument in enhancing students' critical thinking skills.

Analysis of the Feasibility of Student Worksheets and Test Instruments by Expert Validation

The feasibility of the worksheet and test instruments was assessed through validation by experts who possess competence in their respective fields. A total of three validators were involved, all of whom are lecturers from the chemistry department at UNNES. The results of the validation of the worksheet

and test instruments by the validators are presented in Table 1. The validity results of the test instruments are presented in Table 2.

Table 1. Results of the Worksheet Validation by Media Expert Validators

No.	Aspect	Scores	Category
1.	Appearance	8	Highly Valid
2.	Usefulness	16	
3.	Media Materials	8	
Total Score		32	

Based on Table 1, it is known that the results of the worksheet validation in media experts reached a score of 32, or 97% of the minimum score, which was declared valid, namely 70% meeting the criteria.

Table 2. Results of the Worksheet Validation by Subject Matter Expert Validators

No.	Aspect	Scores	Category
1.	Scope Accuracy	8	Highly Valid
2.	Content Quality	14	
3.	Language	7	
4.	PBL Stages	19	
5.	Evaluate	6	
Total Score		54	

Table 2 shows that the results of the worksheet validation by material experts yielded a total score of 54, corresponding to 96% validity, which falls within a very valid category. This indicates that the worksheet has met the minimum criteria of 70%.

Table 3. Results of the Content Validity Analysis of the Test Instruments.

Aspect	Scores	Category
Content Appropriateness	18	Highly Valid
Question Construction	4	
Linguistic Aspects	8	
Total Scores	30	

The reliability analysis of the test instrument is presented in Table 4 below.

Table 4. Reliability of the Test Instrument

Reference Value	Cronbach's Alpha Value	Conclusion
0,7	0,87	Reliable

Effectiveness Analysis

From the reliability analysis of the test instrument conducted on 20 items in this study, a Cronbach's Alpha value of 0.87 was obtained. This value indicates that the instrument has a very high level of reliability, as it meets the applicable standard where a Cronbach's Alpha value above 0.70 is

considered a good indicator of reliability. The results of the pretest and posttest are presented in Figure 1.

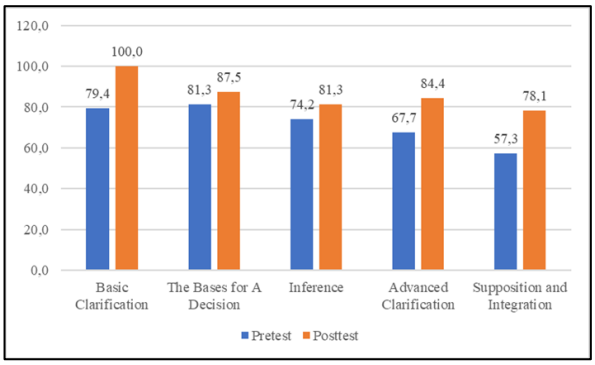

Figure 1. Result of *Pretest* and *Posttest*

Analysis of Students' Critical Thinking Skills on Green Chemistry Materials Through Student Worksheets

In addition to observing the pretest and posttest scores, the improvement in students' critical thinking skills can also be seen from the worksheet used. Refer to the N-Gain test results in Table 5 below.

Table 5. Result of N-Gain Test

	N-Gain Value	**N-Gain Value (%)**
	0,59	59,44
Category	Medium	Quite Effective

Analysis of Student Responses to the Worksheet Questionnaire.

The analysis of student responses from the small-scale trial, distributed to 32 participants, is illustrated in Figure 2.

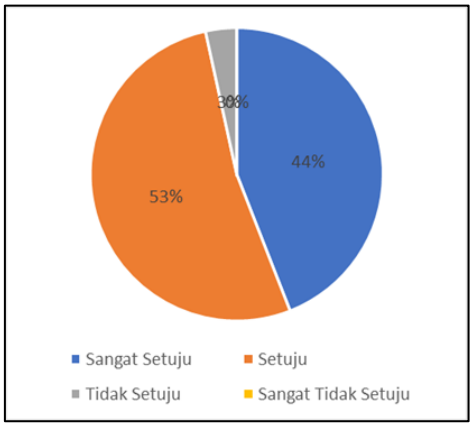

Figure 2. Student Response Questionnaire

Discussion

Analysis of the Feasibility of the Student Worksheets and Test Instruments by Expert Validation.

The feasibility of the worksheet and test instruments was assessed by validating them with competent validators in their respective fields. This approach ensures that the instruments developed can be used for trials in data collection. This is supported by Putri et al. (n.d.), who state that a test instrument must pass expert validity tests before being administered to students. There are five assessment aspects: content quality, PBL stages, appearance, construction, and linguistic aspects, as well as evaluation. A total of three validators were involved, all of whom were from the chemistry department at UNNES.

Based on the results shown in Tables 1, 2, and 3, the worksheet received a score of 32 or 99% from subject matter experts, while media experts scored 54 or 97%, both of which are categorized as highly valid, meeting the minimum criterion of 70% from a total score of 100%. The worksheet meets the criteria for scope accuracy, content quality, language, PBL stages, and evaluation very well and is deemed suitable for use in research. Additionally, the validity test results indicate that all items achieved a validation score of 30 from the experts. This indicates that all items are valid and strongly related to the learning indicators, thus accurately measuring the intended construct. Therefore, this instrument is classified as highly reliable and can provide consistent results when used in repeated measurements.

Analysis of Test Instrument Quality

The reliability analysis presented in Table 4 yields a Cronbach's Alpha value of 0.87, which exceeds the minimum reference value of 0.70. Thus, this instrument is classified as highly reliable, meaning it can provide consistent results when used for repeated measurements. Based on Table 4, it is evident that this test instrument has empirically demonstrated adequate quality as a measurement tool in research, particularly in accurately and objectively reflecting students' conceptual understanding, and can be utilized for both pretest and posttest items.

Effectiveness Analysis

The reliability analysis conducted on 20 items in this study yielded a Cronbach's Alpha value of 0.87. This value indicates that the instrument has a very high level of reliability, as a Cronbach's Alpha above 0.70 is considered a good indicator of reliability according to established standards. Based on the pretest and posttest results of students' critical thinking skills in the large-scale trial, a significant improvement was observed after using the developed worksheet. Measurement based on the five indicators of critical thinking skills—Basic Clarification, The Bases for A Decision, Inference, Advanced Clarification, and Supposition and Integration—showed score increases that reflect the effectiveness of the worksheet. The Basic Clarification indicator increased from 79.4% to 100%, while the Bases for A Decision rose from 81.3% to 87.5%. The Inference indicator also improved from 74.2% to 81.3%, and

Advanced Clarification increased from 67.7% to 84.4%. The highest increase occurred in the Supposition and Integration indicator, rising from 57.3% to 78.1%. Overall, these results demonstrate that the WORKSHEET effectively enhances students' critical thinking skills across all measured aspects.

Furthermore, this high reliability value indicates that the instrument can produce consistent and stable measurement results when used repeatedly under similar conditions. In other words, the scores obtained by students from the items in this instrument can be trusted to objectively reflect students' understanding and skills without significant influence from external factors.

Based on Table 5, an N-gain value of 0.59 or 59.44% was obtained. Referring to the gain score classification criteria, this value falls within the moderate category, indicating that the effectiveness of the worksheet is classified as sufficiently effective, meaning there was a significant improvement in students' critical thinking skills after participating in the learning process using the developed worksheet. This achievement suggests that the worksheet positively contributes to enhancing students' critical thinking skills, although there is still room for improvement to further enhance learning effectiveness.

Analysis of Student Responses to the worksheet Questionnaire

According to Figure 2, it can be observed that the majority of students provided positive responses to the worksheet used. Specifically, 53% indicated "Agree," and 44% indicated "Strongly Agree," while only 3% expressed "Disagree," and none stated "Strongly Disagree." These results indicate that the worksheet was well received by the students in terms of content, appearance, and its benefits in supporting the learning process and enhancing critical thinking skills.

CONCLUSION

The Problem-Based Learning (PBL)-based Student Worksheet developed for green chemistry topics has been proven effective in enhancing the critical thinking skills of tenth-grade students at SMA Negeri 12 Semarang. Through the ADDIE development model, the worksheet met very high validity criteria from both material and media experts, indicating strong content accuracy and design feasibility. The significant improvement in students' critical thinking performance from pretest to posttest further confirms the worksheet's effectiveness. In addition, students expressed highly positive responses, demonstrating that the media is engaging, easy to use, and relevant to their learning needs. Overall, the developed worksheet not only supports the improvement of critical thinking skills but also promotes awareness of environmental conservation and sustainability, making it a valuable instructional resource for green chemistry learning.

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