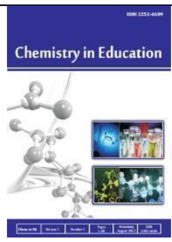
Chemined 14 (1) (2025)

Chemistry in Education

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



Chemical Bond Based E-Worksheet Design Problem-Based Learning With Approaches Differentiation To Improve Learning Outcomes Student

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ARTICLE INFO

Article history:
Received: April 2025
Approved: June 2025
Published: July 2025

Kata Kunci:
E-worksheet, Ikatan Kimia, Problem-Based Learning

Keywords:
E-worksheet, Chemical Bond, Problem-Based Learning

DOI: 10.15294/chemined.v14i1.23391

ABSTRAK

Penelitian ini bertujuan untuk mengembangkan dan mengevaluasi e-worksheet berbasis Problem Based Learning (PBL) dengan pendekatan diferensiasi pada materi Ikatan Kimia guna meningkatkan hasil belajar peserta didik di SMA Negeri 1 Ungaran. Model pengembangan yang digunakan adalah 4D (Define, Design, Develop, Disseminate), namun dibatasi hingga tahap Develop. E-worksheet dirancang berdasarkan studi literatur dan hasil observasi lapangan, mengikuti sintaks PBL yang mencakup lima tahapan: stimulasi, identifikasi masalah, pengumpulan data, analisis data, dan generalisasi. Produk dilengkapi dengan soal latihan dan panduan praktikum untuk mendukung pembelajaran aktif dan keterampilan berpikir kritis. Hasil validasi oleh ahli materi dan media menunjukkan tingkat kesepakatan yang tinggi dengan nilai Cohen's Kappa sebesar 0,853 dan 0,634. Uji keefektifan menunjukkan peningkatan hasil belajar peserta didik secara signifikan, dengan rata-rata skor pretes 46 dan postes 86, serta nilai N-Gain sebesar 0,848 yang tergolong dalam kategori tinggi. Temuan ini menunjukkan bahwa e-worksheet berbasis PBL dengan pendekatan diferensiasi efektif dalam meningkatkan pemahaman konsep dan hasil belajar peserta didik.

ABSTRACT

This study aims to develop and evaluate a Problem-Based Learning (PBL)-based e-worksheet with a differentiated instruction approach for the topic of Chemical Bonding, aimed at improving students' learning outcomes at SMA Negeri 1 Ungaran. The development model applied was the 4D model (Define, Design, Develop, Disseminate), limited to the Develop phase. The e-worksheet was designed based on literature review and classroom observations, incorporating the five stages of PBL: stimulation, problem identification, data collection, data analysis, and generalization. It includes guided exercises and practical instructions to support active learning and critical thinking skills. Validation results from content and media experts indicated high agreement, with Cohen's Kappa values of 0.853 and 0.634, respectively. The effectiveness test showed a significant improvement in learning outcomes, with an average pre-test score of 46 and post-test score of 86, and an overall N-Gain score of 0.848, categorized as high. These findings suggest that the PBL-based e-worksheet with differentiated instruction is effective in enhancing students' conceptual understanding and academic performance in chemistry.

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

INTRODUCTION

Education serves as a crucial pillar for a nation's long-term investment, playing a significant role in shaping quality human resources and strengthening national character. A well-structured learning environment should encourage students to actively develop self-regulation, personality, intelligence, moral values, and essential skills through conscious and systematic efforts. Education must be implemented in a democratic, fair, and non-discriminatory manner (Aspi & Syahrani, 2022). One of the initiatives taken by the Indonesian government to enhance the quality of education is curriculum reform (Monica, 2023). The main goal of curriculum implementation is to strengthen human resources and improve education quality from primary to higher education levels, as it significantly contributes to the success of national development programs (Vhalery et al., 2022).

Chemistry, as a science subject, emphasizes learners' active construction of knowledge. Learning is more effective when students build understanding through guided inquiry and meaningful learning materials rather than solely relying on teachers (Satura et al., 2021). Differentiated instruction is a teaching strategy that aims to meet the diverse needs, personalities, and characteristics of students (Wijaya et al., 2022). In chemistry education, differentiated instruction demands particular attention due to the abstract nature of many chemistry concepts, which often pose difficulties for students (Rahma & Aini, 2023).

The Problem-Based Learning (PBL) model has been identified as a promising solution to address these learning difficulties in a differentiated learning environment (Atikah et al., 2024). Implementing PBL alongside differentiation strategies can significantly enhance student learning outcomes (Pahdianti et al., 2023). According to Haryani & Atmaja (2024), PBL not only improves conceptual understanding but also promotes problem-solving, collaboration, and critical thinking skills. Through this approach, students are encouraged to design experiments and analyze data, thereby learning to draw evidence-based conclusions. Learning outcomes reflect the level of achievement students reach after a period of instruction and are directly influenced by the quality of their learning efforts (Yandi et al., 2023). Therefore, effective teaching methods and appropriate instructional media are essential to optimize these efforts.

One such instructional medium is the student worksheet. Worksheets provide structured guidance and serve as independent learning tools to enhance students' comprehension, skills, and attitudes (Kristyowati, 2018). They must also align with students' readiness levels to ensure effectiveness (Cholifah & Novita, 2022). In the digital era, the integration of technology into education is vital. E-worksheets created using platforms like Liveworksheets can increase student engagement, confidence, and motivation (Andriyani et al., 2020; Salsabila et al., 2023).

Chemistry instruction should engage students in higher-order thinking, such as critical, analytical, and creative reasoning. PBL supports this by situating learning within meaningful problem-solving contexts. However, challenges remain, particularly the lack of supportive media—especially in teaching abstract concepts such as chemical bonding. Based on interviews with chemistry teachers at SMA Negeri

1 Ungaran, traditional methods such as lectures and textbook-based questioning still dominate, but these have proven insufficient in improving students' conceptual understanding. The main barriers include limited prior knowledge, weak mathematical skills, and difficulty visualizing molecular structures. Additionally, current teaching materials are conventional and fail to address diverse student needs.

Aligned with the "Merdeka Belajar" (Freedom to Learn) policy, differentiated instruction offers a promising solution by presenting interactive, contextually relevant materials tailored to students' interests and abilities. Therefore, this study aims to develop a PBL-based e-worksheet integrating differentiation strategies as an alternative learning medium to enhance students' conceptual understanding of chemical bonding in a more flexible, engaging, and effective manner.

METHODS

This study employed a research and development (R&D) methodology, aiming to create a product—an electronic worksheet (e-worksheet)—based on field trials and expert validation, followed by revision and refinement. The development model adopted in this study was the 4-D model, which includes four stages: Define, Design, Develop, and Disseminate (Monica, 2023). However, the implementation of the model in this research was limited to the first three stages (3D), namely Define, Design, and Develop.

The research was conducted in September 2024 at SMA Negeri 1 Ungaran. The purpose of this study was to develop and evaluate the feasibility, effectiveness, and student responses to a Problem-Based Learning (PBL)-oriented e-worksheet on chemical bonding that integrates a differentiated instruction approach. This instructional tool was designed to enhance student learning outcomes in the topic of chemical bonding.

In the Define stage, the research focused on analyzing initial conditions through literature review, curriculum analysis, and observations to identify the learning needs and characteristics of students. The Design stage involved constructing the structure of the e-worksheet, integrating PBL syntax and differentiated learning tasks tailored to students' readiness levels. The Develop stage consisted of developing the e-worksheet prototype, validating it through expert reviews, revising it based on feedback, and conducting a limited trial in a classroom setting.

The e-worksheet content was structured to follow the five core steps of PBL: stimulation, problem statement, data collection, data analysis, and generalization. It was differentiated according to student readiness, interests, and learning styles. Differentiation by readiness grouped students into three categories (beginner, intermediate, and advanced), each receiving appropriately challenging tasks. Differentiation by learning style included visual, auditory, and kinesthetic elements. Differentiation by interest was addressed by allowing students to produce output aligned with their preferences, such as written reports, musical creations, or graphic visuals.

Product validation was carried out by subject-matter and media experts using Cohen's Kappa to assess inter-rater reliability. Learning effectiveness was measured using pre-test and post-test comparisons and N-gain analysis. Student responses were collected using a questionnaire focusing on content quality, visual design, usefulness, and engagement. This multifaceted approach ensured the developed e-worksheet was pedagogically sound, effective, and well-received by students with varying educational needs.

RESULT AND DISCUSSION

This study was conducted in September 2024 at SMA Negeri 1 Ungaran. The research employed a 4D development model, limited to the first three stages: Define, Design, and Develop. The purpose of this study was to evaluate the feasibility, effectiveness, and student responses toward a Problem-Based Learning (PBL)-based e-worksheet on chemical bonding, integrated with differentiated instruction, designed to enhance students' learning outcomes on the topic of chemical bonding.

The PBL-based e-worksheet was developed based on a review of relevant literature and classroom observations. As emphasized by Kristyowati (2018), such e-worksheets can be utilized independently by students to improve their understanding, skills, and attitudes. The e-worksheet offers several advantages, including facilitating the implementation of learning activities aligned with instructional content and teaching methods (Selmin et al., 2022). However, as a learning resource, its design must be aligned with students' skill needs (Cholifah & Novita, 2022). Student engagement in the learning process is also crucial, and through the teacher's facilitation, students can be encouraged to participate actively (Sudiartha, 2022).

The developed product follows the PBL learning syntax, which includes five stages: stimulation, problem statement, data collection, data analysis, and generalization. The e-worksheet is intended to foster students' active participation, develop critical thinking skills, and support learners in analyzing data, solving problems, and making evidence-based decisions. Structurally, the e-worksheet is divided into three major sections: the introductory section, the main content, and the closing section. The introductory section includes the cover, preface, table of contents, laboratory rules, safety instructions, user guide, and the learning flow and objectives. The main section contains learning units organized according to the PBL syntax, along with practice questions and practical activity guides. The final section includes a glossary, references, report templates, and author information.

The implementation of the e-worksheet was carried out with students in class XI-2 at SMA Negeri 1 Ungaran, applying a problem-based learning model with a differentiated approach. Students were grouped based on their learning readiness to ensure learning experiences that suited their needs. The results showed an improvement in both student learning outcomes and conceptual understanding of chemical bonding. The product was proven effective in supporting practical chemistry instruction by providing a more structured and meaningful learning experience.

During the development stage, several critical steps were undertaken to transform the concept into a PBL-based e-worksheet with differentiated instruction. This stage not only focused on producing a digital learning tool but also ensured its alignment with student needs, learning objectives, and the principles of effective instruction. The first step in the development process was to design the foundational framework of the e-worksheet, incorporating key components such as learning objectives, problem-based learning activities, and differentiated tasks tailored to students' varying levels of ability. This began with constructing a systematic structure for the e-worksheet, comprising an introduction, learning goals, learning activities, and evaluation segments. Each activity was designed to stimulate students' analytical thinking through contextual, real-life questions relevant to their daily experiences.

The second step involved integrating the differentiated instruction approach into the e-worksheet. In this approach, questions and activities were structured with varying levels of difficulty to accommodate three distinct learning groups: beginner, intermediate, and advanced. The beginner group focused on fundamental comprehension and basic concepts, such as understanding Lewis structures and the properties of simple compounds. The intermediate group was given more complex tasks, including in-depth analysis of bond formation and compound characteristics. Meanwhile, the advanced group was directed toward analyzing chemical phenomena with a more critical and applied approach, such as investigating the effect of ionization energy on inter-element interactions. The third step was validation and revision. The developed e-worksheet was validated by subject matter experts and media experts to ensure the content aligned with chemistry curriculum standards and met students' learning needs. The results of this validation process served as the foundation for refining and finalizing the e-worksheet before its implementation in classroom instruction.

The final stage of development resulted in an interactive, problem-based chemistry bonding e-worksheet that was also adaptive to students' diverse learning needs. With its flexible and differentiated design, the e-worksheet is expected to improve students' conceptual understanding, enhance their analytical skills, and promote more meaningful learning experiences. This aligns with the findings of (Lestari et al., 2025), who emphasized the importance of structured digital learning tools in supporting interdisciplinary understanding and critical thinking development in chemistry education. The subsequent phase involved product trials with students to gather feedback regarding the developed e-worksheet. The trial was conducted with 17 students from Grade XI at SMA Negeri 1 Ungaran. This phase aimed to assess the effectiveness of the learning media and the degree of student acceptance toward the PBL-based chemistry bonding e-worksheet.

The content validation by subject matter experts aimed to evaluate the e-worksheet based on the relevance of its content to the learning objectives, the completeness and depth of material, and its alignment with the curriculum. The validation results revealed that the PBL-based e-worksheet incorporating differentiated instruction showed a high level of alignment with instructional goals, content depth, and curricular standards. The analysis using Cohen's Kappa yielded a coefficient of 0.853, categorized as very strong, indicating a high level of agreement between the two expert reviewers. This finding is consistent with Isma et al., (2024), who reported that PBL-based e-worksheets utilizing differentiated instruction exhibit high validity, thereby confirming the effectiveness of combining PBL and differentiation in enhancing the quality of instructional media across disciplines.

Media expert validation focused on evaluating the visual design, navigation, and interactivity of the e-worksheet. The assessment included aspects such as display clarity, ease of use, and the compatibility of supporting technologies. The validation revealed that the media met the required standards for instructional effectiveness and learner engagement. Cohen's Kappa coefficient was 0.634, indicating a moderately high level of agreement. Although there were differing perceptions regarding elements like layout and readability, overall, the e-worksheet fulfilled the criteria for technology-based instructional materials. These results align with the studies by Herawati et al., (2024) and Nawati et al., (2023), which emphasize that technology-integrated instructional resources are essential in fostering student interest and learning motivation. In summary, the media expert validation confirmed that the e-worksheet is suitable for classroom implementation, with minor revisions suggested to enhance its consistency and overall effectiveness.

The test instrument used to measure students' problem-solving abilities was also subjected to rigorous evaluation to ensure its validity, reliability, and sensitivity. The validity test aimed to determine the appropriateness and accuracy of each test item in assessing the concepts addressed in the PBL-based e-worksheet with differentiated instruction. Two expert reviewers evaluated 15 items based on content quality, readability, and alignment with PBL principles. The analysis using Cohen's Kappa resulted in a coefficient of 0.526, indicating a moderate level of agreement. Thus, while the test instrument was deemed valid, several items required refinement to improve clarity and precision.

Table 1. Test Instrument Validity Using Anates

Item Number	r_{hitung}	r_{kritis}	Description
1	0,638	0,463	Valid
2	0,499	0,463	Valid
3	0,737	0,463	Valid
4	0,579	0,463	Valid
5	0,630	0,463	Valid
6	0,610	0,463	Valid
7	0,764	0,463	Valid
8	0,713	0,463	Valid
9	0,620	0,463	Valid
10	0,552	0,463	Valid
11	0,526	0,463	Valid
12	0,688	0,463	Valid
13	0,697	0,463	Valid
14	0,530	0,463	Valid
15	0,559	0,463	Valid

The test items covered the entire range of content delivered through the e-worksheet, ensuring that the instrument effectively measured students' understanding of chemical concepts taught using the PBL and differentiated instruction approach. Overall, the results of the validity analysis indicated that the instrument was appropriate for assessing students' problem-solving abilities within the context of PBL-based chemistry learning. The validated and revised test instrument was subsequently piloted on a small scale involving 32 students from class XII-3 at SMA Negeri 1 Ungaran. The post-test items were analyzed using the Anates application to assess their validity and reliability, ensuring that each item met the required standards. Once confirmed to be valid and reliable, the test instrument was deemed ready for use in the implementation phase. The post-test validity results are presented in Table 1.

The validity analysis results indicated that all test items had r-calculated values greater than the r-critical value (0.463), thus confirming that the items were valid and appropriate for assessing students' abilities. The Anates analysis revealed a mean score of 7.06 with a standard deviation of 4.60, indicating a relatively even distribution of scores. The correlation between pre-test and post-test scores was 0.78, demonstrating a strong relationship between the two variables. The reliability test produced a coefficient of 0.87, indicating a high level of consistency and stability in the test results.

In terms of item difficulty, most questions fell into the moderate category, with a few classified as difficult, providing a sufficient range to effectively assess students' abilities. Furthermore, the discrimination indices of the items ranged from good to excellent, suggesting that the instrument could effectively distinguish between high- and low-performing students. Overall, the instrument was proven to be valid, reliable, and effective for measuring students' learning outcomes. With its high validity and reliability, the instrument is suitable for evaluating the effectiveness of the implementation of the PBL-based e-worksheet with a differentiated approach, in line with Kaka et al. (2024), who stated that reliability is considered high if the r_{11} coefficient ≥ 0.70.

The effectiveness of the e-worksheet was measured through a comparison of pre-test and post-test results. The test consisted of 15 multiple-choice items designed to assess students' problem-solving abilities. The results showed a significant increase in post-test scores compared to the pre-test, as illustrated in Figure 1.

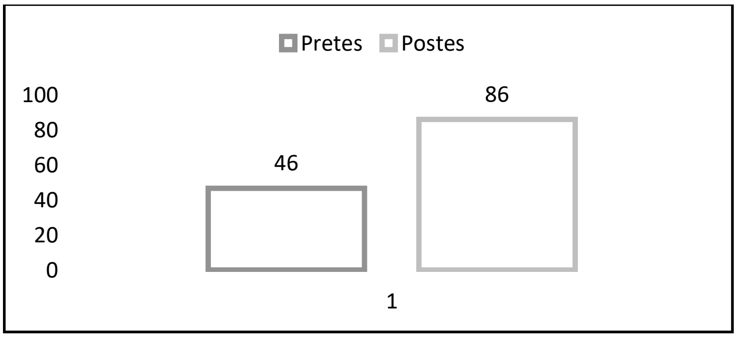

Figure 1. Pre-test and Post-test Score

Based on the collected data, the average pre-test score of students was 46, while the average post-test score was 86. This result indicates a significant improvement in students' scores after the implementation of the e-worksheet. The observed increase suggests that students' problem-solving abilities improved following the use of the e-worksheet during instruction. Nevertheless, to more accurately assess the extent of this improvement, an N-gain analysis was conducted to provide a clearer picture of the effectiveness of the developed e-worksheet in enhancing student learning outcomes. The N-gain analysis was employed to calculate the degree of learning improvement among students. The results of the analysis demonstrated that the e-worksheet was effective in improving students' problem-solving skills. The detailed N-gain values are presented in Table 2.

Table 2. N-Gain Score

Readiness-Based Group	*N-Gain*	Category
Beginning Group	0,80	High
Intermediate Group	0,74	High
Advanced Group	0,60	Moderate

The effectiveness of the PBL-based e-worksheet with a differentiated instruction approach was measured using the N-Gain analysis across three student readiness groups. The Beginning Group demonstrated an N-Gain score of 0.80, categorized as high, indicating that the e-worksheet was highly effective in enhancing the understanding of students with lower readiness levels. The Intermediate Group obtained an N-Gain score of 0.74, also within the high category, suggesting a significant positive impact on students with moderate learning readiness. Meanwhile, the Advanced Group showed an N-Gain score of 0.60, which falls into the medium category, indicating a noticeable improvement, albeit lower than the other groups. Overall, the average N-Gain was 0.848, signifying that the PBL-based e-worksheet was highly effective in improving students' conceptual understanding across all readiness levels, particularly among those in the Beginning and Intermediate Groups. These findings align with the study by Rohim et al., (2024), which emphasized that identifying learners' needs based on readiness levels is essential for aligning instructional material difficulty with students' capabilities.

In the context of Problem-Based Learning (PBL), the learning process emphasizes students' active engagement in solving contextual problems rather than relying solely on direct instruction. Based on the assessment data reflecting the total scores and percentages achieved by each group, a relationship can be analyzed between students' learning outcomes, the implementation of PBL, and the level of difficulty experienced by each readiness group. These relationships are illustrated in Figure 2.

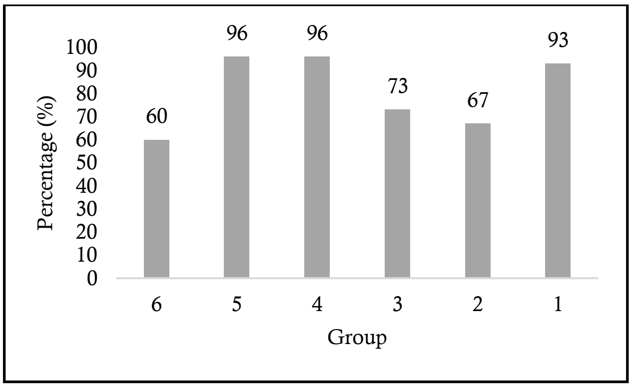

Figure 2. Mastery Percentage of E-Worksheet Implementation by Student Readiness Group

Most student groups demonstrated a solid understanding of the subject matter. Groups 4 and 5 achieved the highest performance, followed closely by Group 1 with similarly strong scores. Groups 3 and 2 fell within the moderate category, indicating the need for further improvement. Meanwhile, Group 6 showed the lowest performance, highlighting the necessity for additional instructional strategies to strengthen their conceptual understanding. Process differentiation was applied by considering students' learning readiness, identified through diagnostic tests and final semester summative assessments. This analysis aimed to categorize students into three readiness-based groups—beginning, intermediate, and advanced—as illustrated in Figure 3.

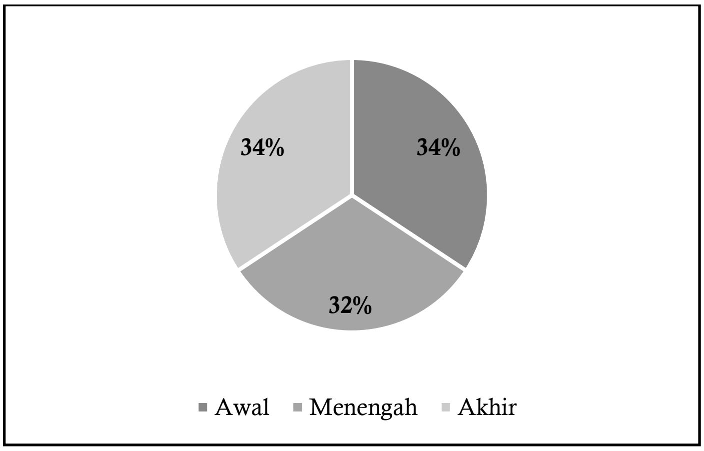

Figure 3. Distribution of Students' Learning Readiness Groups

Based on the analysis of 35 students, 34% were classified in the beginner group, 32% in the intermediate group, and 34% in the advanced group. During the learning process, students in the beginner group received full guidance from the teacher throughout the investigation and completion of the e-worksheet. Students in the intermediate group received proportional guidance according to their needs, while those in the advanced group were able to study independently with minimal supervision due to their higher ability to comprehend the material. Content differentiation was applied by providing e-worksheets designed to accommodate students' learning needs based on their learning styles. The e-worksheet integrates content and learning resources tailored for visual, auditory, and kinesthetic learners, as illustrated in Figure 4.

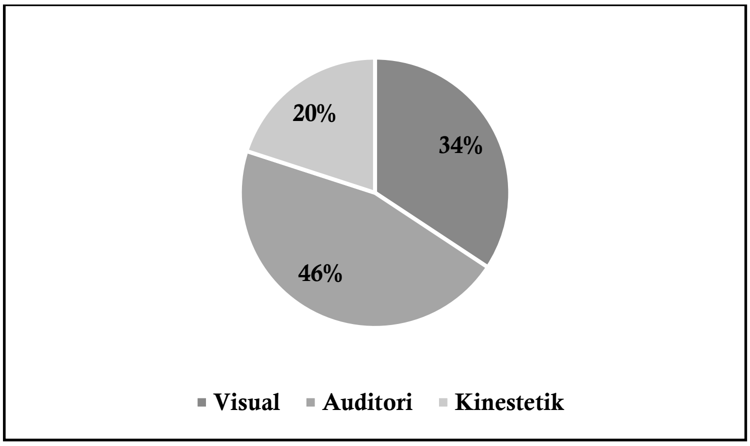

Figure 4. Distribution of Students' Learning Styles

The analysis results revealed that among the 35 students, 46% exhibited a kinesthetic learning style, 34% preferred a visual learning style, and 20% identified as auditory learners. For students with visual learning preferences, the e-worksheet provided access to text-based and visual learning resources. Meanwhile, auditory and kinesthetic learners were supported with instructional videos that integrated sound and movement to facilitate better comprehension of the material. This content differentiation strategy enabled students to access learning materials aligned with their individual learning styles, thereby reducing learning barriers. Interest-based differentiation was implemented based on the results of a student learning interest questionnaire. The analysis of students' learning interests is presented in Figure 5.

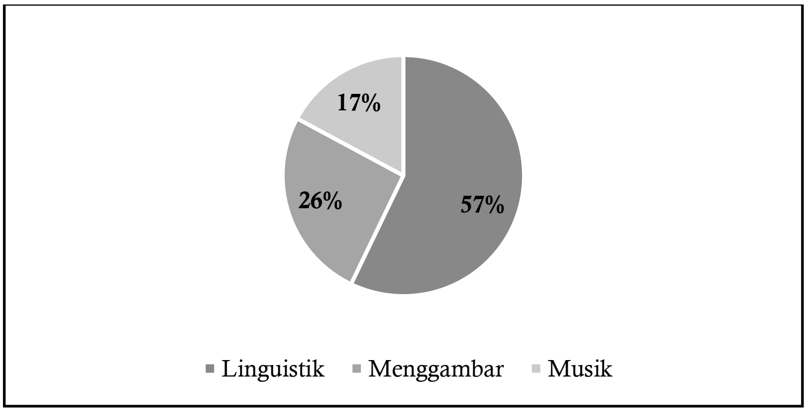

Figure 5. Distribution of Students' Learning Interests

In the final stage of learning, namely the fourth phase of Problem-Based Learning (PBL), students were encouraged to create a product aligned with their individual interests and related to the topic of reaction rates. Students with a linguistic interest produced written outputs such as articles or papers, while those interested in music created learning products in the form of singing videos or animated musical presentations. Meanwhile, students with an inclination towards visual arts developed posters or infographics. This approach allowed students to express their understanding of the subject matter through their personal interests, thereby enhancing both motivation and academic achievement. Affective and psychomotor assessments conducted during PBL revealed varying levels of achievement, reflecting the strengths and challenges encountered throughout the learning process. These results are presented in Figure 6.

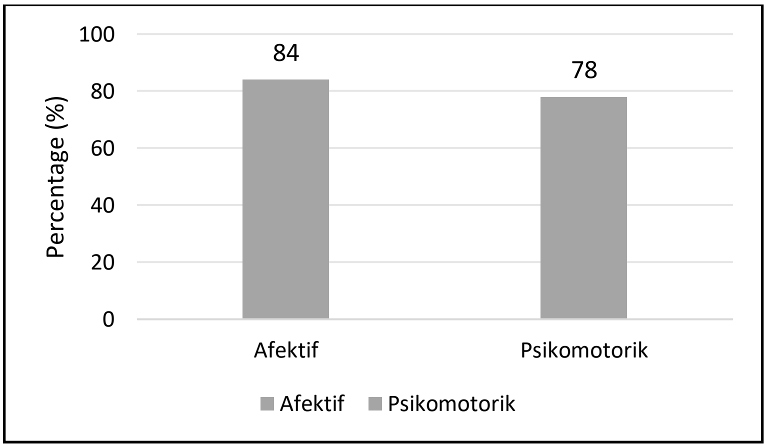

Figure 6. Distribution of Students' Affective and Psychomotor Assessment Scores

The affective achievement score of 84% indicates that students demonstrated a positive attitude during the learning process, including cooperation, discipline, and responsibility. Students with the highest scores exhibited strong emotional engagement, suggesting that the Problem-Based Learning (PBL) approach was effective in fostering social interaction and collaborative learning. The psychomotor achievement score of 78% reveals that most students were able to apply physical skills in practice, although this score was slightly lower than the affective domain. This finding highlights the challenge of translating theoretical concepts into hands-on activities, where some students still require additional guidance. There was a noticeable tendency for students with high affective scores to also achieve good psychomotor performance, although other factors—such as practical experience and self-confidence—also influenced skill acquisition. Overall, PBL proved effective in supporting the development of both affective and psychomotor domains. However, differentiated guidance is crucial to meet the diverse needs of students, particularly in skill training and strengthening social interaction.

Student responses to the e-worksheet were measured using a questionnaire distributed via Google Forms after the learning session. The questionnaire assessed three main aspects: visual design, content quality, and usability. The analysis revealed that the majority of students provided positive feedback, particularly regarding the visual aspect, which was perceived as engaging and easy to understand. The complete data on students' responses is presented in Table 7.

Table 7. Students' Responses to the E-Worksheet

No.	Aspect	Percentage (%)	Category
1	Content Quality	81	Excellent
2	Visual Appearance	79	Excellent
3	Usefulness	81	Excellent
4	Learning Interest	76	Good
5	Ease of Use	76	Good
	Average	**78,6**	Excellent

The content quality aspect received a score of 81%, categorized as very good, suggesting that the presented material effectively met learning needs and was aligned with instructional objectives. Similarly, the visual appearance (79%) and usefulness (81%) aspects also fell under the very good category, demonstrating that the e-worksheet's design was visually engaging and helped students better understand the subject matter. The aspects of learning interest (76%) and usability (76%) were rated as good, indicating that although the e-worksheet successfully captured students' attention, there is still room to enhance interactivity and ease of use to maximize its educational potential. Overall, with an average score of 78.6%, the e-worksheet was considered effective in supporting problem-based learning. While these results are promising, further development should focus on improving user interactivity and the overall user experience to make the tool more comfortable and motivating for students. These findings are consistent with Safitri et al. (2022), who reported that student responses to PBL e-worksheets were very positive, as they felt more challenged to solve contextual problems. Moving forward, enhancements could be directed toward refining usability and strategies for increasing student interest to enrich the learning experience. Moreover, the implemented differentiation design should continue to be adapted to ensure that all students benefit optimally from the learning media.

CONCLUSION

The findings of this study indicate that the PBL-based chemistry bonding e-worksheet with a differentiated learning approach demonstrates high validity, as reflected by Cohen's Kappa values of 0.853 for content experts and 0.634 for media experts, indicating strong inter-rater agreement. The implementation feasibility, with an acceptance rate of 78.5%, confirms that the e-worksheet effectively supports students' conceptual understanding and active engagement. The use of the e-worksheet significantly improved student learning outcomes, with an increase in average scores from 46 (pre-test) to 86 (post-test), and an N-Gain of 0.848, categorized as high. These results suggest that the PBL-based e-worksheet with differentiated instruction is highly effective in enhancing students' conceptual understanding of chemical bonding, particularly among learners with varying levels of learning readiness.

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