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PBL-Based Online Worksheet on Green Chemistry to Enhance Students' Literacy and Numeracy Skills

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ABSTRACT

The limited availability of digital learning tools that effectively integrate green chemistry concepts while enhancing scientific literacy and numeracy presents a challenge in science education. Chemistry learning that integrates environmental issues, particularly the concept of green chemistry, requires contextual and innovative teaching materials to support the enhancement of students' scientific literacy and numeracy skills. This study aimed to develop a problem-based learning (PBL) online student worksheet on green chemistry to enhance students' scientific literacy and numeracy. The research employed a research and development (R&D) approach using the ADDIE model and involved 24 randomly selected students from SMA Negeri 4 Lhokseumawe. Data were collected using expert validation sheets, student response questionnaires, and pre- and post-test instruments. The validation results indicated that the online worksheet was highly feasible (media: 96.88%, content: 96.39%, Aiken's V = 0.95). User responses were very positive (82.42%), and the questionnaire instruments demonstrated high validity (Aiken's V = 0.97). The N-Gain scores revealed moderate improvement in both scientific literacy (0.6061) and numeracy (0.6106), reflecting strengthened critical thinking, data interpretation, and problem-solving skills. This study contributes by providing a replicable model of an online worksheet that integrates environmental issues into chemistry learning, enriches digital learning resources, and supports the mastery of 21st-century competencies in science education. Therefore, the development of this PBL-based online student worksheet is considered feasible, practical, and effective in enhancing students' scientific literacy and numeracy skills.

ARTICLE INFORMATION

Keywords:
green chemistry; online student worksheet; problem-based learning; science literacy, science numeracy;

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INTRODUCTION

Green chemistry, as outlined in the twelve principles of Anastas and Warner (2000), emphasizes waste prevention, renewable feedstocks, energy efficiency, and the reduction of hazardous substances, aiming to design environmentally benign products and processes that support global sustainability (Ganesh et al., 2021; Rathi et al., 2023; Zuin et al., 2021; Koulougliotis et al., 2024). Embedding green chemistry in secondary education fosters environmentally conscious citizens equipped with critical thinking, problem-solving, and responsible environmental action, aligning with the Education for Sustainable Development (ESD) framework (Sánchez et al., 2024; Sihombing et al., 2024; Burmeister et al., 2012; UNESCO, 2018; Wilhelm et al., 2019; Kioupi & Voulvoulis, 2022). Effective pedagogical strategies include inquiry-based, problem-based, and context-based learning, along with case-based modules that integrate hands-on activities, such as atom economy calculations and eco-friendly product design, which enhance engagement and motivation (Koulougliotis et al., 2024; Ballard & Mooring, 2021). Incorporating green chemistry into education advances the Sustainable Development Goals, particularly SDG 4 (Quality Education) and SDG 12 (Responsible

Consumption and Production), by enhancing scientific literacy, promoting sustainable behavior, and fostering environmental stewardship (Mitarlis et al., 2023; UNESCO, 2018).

However, despite its significance, green chemistry is not yet widely embedded in educational practice. This is partly due to the lack of appropriate instructional models, insufficient teacher training and professional development (Gunbatar et al., 2025; Idul & Walag, 2024; MacKellar, 2020), and using sustainability-oriented tools like the SDGs Game encourages interdisciplinary learning and helps students grasp the complexity of global issues, which aligns with the goals of green chemistry education (Andreoni & Richard, 2023). To overcome these barriers, problem-based learning (PBL) has emerged as an effective pedagogical strategy that enhances students' engagement with real-world, contextual problems, promoting inquiry-based learning and collaborative knowledge construction (Hmelo-Silver, 2004; Wiono & Siregar, 2024; Zuin et al., 2021). When combined with contextual teaching and learning (CTL), PBL can foster higher-order thinking skills, creativity, scientific reasoning, and environmental awareness (Adah, 2023; Chen et al., 2020; Winarti et al, 2024; Byrkun & Liashenko, 2024; Carvalho et al., 2023; Günter et al., 2017). These integrated pedagogical approaches also provide authentic, interactive experiences that deepen students' engagement with green chemistry content (Ghaisani & Setyasto, 2023). International research consistently underscores the effectiveness of PBL in developing scientific literacy and 21st-century competencies. A meta-analysis of PBL implementations in secondary science education demonstrates significant improvement in science literacy and related skills (Aripin et al., 2024). Additionally, PBL has proven effective in green chemistry education at the secondary level, producing measurable learning gains (Sari & Wahyuni, 2024).

Scientific literacy and numeracy are essential competencies in 21st-century science education, equipping students to make informed decisions and solve real-world problems (OECD, 2019; Amini & Sinaga, 2021; Deda et al., 2023; Carreiras et al., 2015). However, local data from SMA Negeri 4 Lhokseumawe show that only 28.89% of students met minimum competency standards for literacy and numeracy in 2023; although improved in 2024 (65.12% literacy, 63.63% numeracy), performance remains suboptimal (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2023; 2024). Contributing factors include limited use of contextual learning models, lack of engaging instructional media, and students' low self-efficacy in science and mathematics (Hartono et al., 2023; Kamal et al., 2024; Mangkuwibawa et al., 2024). Classroom observations further indicate that students struggle to articulate scientific ideas, experience extended response times in writing tasks, and exhibit low reading fluency (Khoir et al., 2022). Recent studies emphasize that students' STEM literacy, particularly in environmental contexts like global warming, remains low, with science literacy being the weakest component. Furthermore, misconceptions and difficulties in data interpretation and analytical reasoning were frequently observed (Illahi et al., 2023; Paspania & Susilawati, 2024).

Science learning in secondary education should address not only the mastery of scientific concepts but also accommodate students' diverse abilities, readiness, and interests through differentiated instruction (Smale-Jacobse et al., 2019; Tundreng et al., 2025). Embedding sociological pedagogy perspectives in instructional design can further connect science learning with real-world social and environmental challenges (Giroux, 1988). This study introduces an innovative instructional intervention: a student worksheet based on PBL, delivered online and integrated with content related to green chemistry. Chemistry education that emphasizes higher-order thinking skills and real-life context continues to face challenges, one of which is the limited availability of interactive learning materials that foster students' scientific literacy and numeracy. Recent studies have shown that interactive media developed through PBL approaches can significantly improve students' science literacy (Mufidah & Dwiningsih, 2024; Nilawati et al., 2025; Mahyuny et al., 2022). Mufidah and Dwiningsih (2024) designed a problem-oriented e-worksheet on chemical equilibrium, whereas

Nilawati et al. (2025) focused on materials related to quantum numbers and electron configurations. Both studies reported improvements in students' critical thinking and science literacy. However, these studies have yet to integrate sustainability issues or address science numeracy skills fully. The current study extends this line of research by embedding green chemistry contexts into the development of a PBL-based online worksheet, aiming to enhance not only students' science literacy but also their science numeracy. This dual focus addresses a gap in previous research, which has largely overlooked the importance of quantitative reasoning in environmental and chemical education (Fatmawati & Shofiyah, 2022; Amini & Sinaga, 2021).

The novelty of this research lies in the strategic combination of PBL and environmental chemistry, implemented through digital technology—an approach that remains underutilized in secondary science education in Indonesia (Khairunnisa et al., 2023). This integration is designed to simultaneously foster critical thinking, contextual relevance, and environmental awareness, addressing both cognitive and affective dimensions of science learning (Amini & Sinaga, 2021; Deda et al., 2023). The following are scientific contributions of this study: (1) it provides empirical evidence on the impact of combining PBL and green chemistry on students' scientific literacy and numeracy, and (2) it proposes a replicable contextual learning model to enhance 21st-century competencies in science education (Suryaningsih & Nurlita, 2021; Mangkuwibawa et al., 2024). Differentiated instruction is recognized as an effective approach in secondary education, enabling teachers to tailor content, process, and product according to students' needs and readiness (Putra, 2023; Smale-Jacobse et al., 2019). In the context of science learning, integrating sociological pedagogy helps students critically examine environmental and societal issues, aligning with the goals of sustainability-oriented education (Giroux, 1988).

METHOD

This study employed a quantitative research design with an R&D approach, utilizing the ADDIE development model, which comprises five stages: analysis, design, development, implementation, and evaluation (Sugiyono, 2022; García et al., 2023). The ADDIE model procedure was adapted from Cahyadi (2019). In the analysis stage, the curriculum review, student characteristics, and relevant literature on green chemistry were examined to inform the design of the online student worksheet using a liveworksheet. The design phase outlined learning objectives, content, interactive activities, and assessment instruments. During development, the student worksheet prototype was created using Microsoft Word and Canva then uploaded to the Liveworksheet platform. Content and media experts validated the product, followed by revisions. The implementation phase involved a limited trial (8 students) and a field trial (20–35 students), both using a one-group pretest-posttest design, to assess learning gains and practicality. The instructional design incorporated principles of differentiated instruction to ensure accessibility and engagement for students with varied backgrounds and learning profiles (Tundreng et al., 2025).

The study was conducted at SMA Negeri 4 Lhokseumawe in the second semester of the 2024/2025 academic year (January–May 2025). The subjects were tenth-grade students, while the object was an online PBL-based student worksheet designed to improve science literacy and numeracy. The population consisted of all tenth-grade students (three heterogeneous classes), with class X.2 selected randomly as the sample. Ethical clearance for this research was obtained from the Postgraduate School, Universitas Syiah Kuala, following approval by the Research Ethics Committee. Research implementation permission was granted by SMA Negeri 4 Lhokseumawe through Letter of Approval No. 421.3/325/SMAN-4/IV/2025. Informed consent was obtained from all participants prior to data collection, ensuring voluntary participation, the right to withdraw at any time, and the confidentiality of all personal information. This study adhered to the ethical principles in educational

research, including respect for autonomy, beneficence, and justice. Data were collected using validation sheets, response questionnaires, and pre- and post-test items. Content and media experts assessed the feasibility of the student worksheet (Nieveen, 2019), while teachers and students evaluated its practicality via questionnaires (Subali, 2014). Validated pre-test and post-test items were used to measure the effectiveness of the student worksheet in enhancing science literacy and numeracy based on green chemistry indicators (Wulandari & Sholihin, 2016). The science literacy indicators are presented in Table 1. Referring to the PISA data and the 2025 science literacy indicators, school learning should focus on enhancing comprehensive science literacy by training students to observe, investigate, and evaluate data for scientific decision-making. The indicators of science numeracy are presented in Table 2.

Table 1. Science Literacy Indicators

Aspect of Science Literacy	Indicator
Content Knowledge	Explaining phenomena scientifically
Procedural Knowledge	Constructing and evaluating designs for scientific inquiry, as well as critically interpreting data and scientific evidence
Context	Investigating, evaluating, and using scientific information for decision-making and action

Table 2. Science Numeracy Indicators

Science Numeracy Competency	Description
Understanding Quantitative Data	The ability to read, interpret, and evaluate data in the form of tables, graphs, or diagrams.
Mathematical Modeling	The skill to create mathematical representations of scientific phenomena.
Quantitative Problem Solving	The ability to use mathematical operations to solve scientific problems.
Proportional Reasoning	The skill in understanding and applying proportional relationships between variables.
Risk Interpretation and Evaluation	The ability to assess probabilities and the impact of an event or experiment.

Data collection techniques included written tests (pre-test and post-test) and questionnaires for students, teachers, and experts. The test consisted of 10 standardized essay items validated to measure the improvement in science literacy and numeracy following the use of the online PBL-based student worksheet. Questionnaires were administered to content and media experts to evaluate the feasibility of the content, language, visual appearance, and media navigation, using a four-point Likert scale and an open-ended response column. Quantitative data were analyzed using the feasibility percentage formula (Sugiyono, 2022). Validation results were averaged and categorized according to the feasibility percentage range in Table 3.

Table 3. Feasibility Percentage Distribution

Feasibility Percentage (%)	Score Scale	Description
76 – 100	4	Highly Feasible
56 – 75	3	Feasible
40 – 55	2	Less Feasible
0 – 39	1	Not Feasible

(Sugiyono, 2019)

The questionnaire for teachers and students assessed the practicality and effectiveness of the student worksheet in terms of attractiveness, ease of navigation, content relevance, and its influence on motivation and critical thinking skills. These data were processed quantitatively using percentages and categorized into four quality levels: very good, good, fair, and poor, as shown in Table 4 (OECD, 2022). Interpretation of scores ranged from 76–100 (very positive), 56–75 (positive), 40–55 (less positive), and 0–39 (negative), determining the quality and level of revision needed.

Table 4. Qualitative Percentage Criteria of the User Response Questionnaire

Score Range (%)	Qualitative Criteria
76 – 100	Very Good or Very Positive
56 – 75	Good or Positive
40 – 55	Fair or Less Positive
0 – 39	Poor or Negative

(Sugiyono, 2019)

The data analysis techniques included several steps to assess the validity, reliability, item difficulty, and discrimination power of the science literacy and numeracy skill test instruments. Validity was tested using the product-moment correlation to determine how well each item represented the measured construct (Sugiyono, 2022; Yusrizal, 2020), while reliability was calculated using the KR-20 formula to assess internal consistency. Item difficulty was measured by comparing the number of correct answers to the total number of participants, and discrimination power was based on score differences between high and low groups. All quantitative analyses were performed using the *proanal* test software developed by Khaldun (2017), which automatically calculates validity, reliability, and item characteristics. To assess the feasibility and practicality of the learning media, Aiken's V index and inter-rater reliability (IRA) were used, calculated through Cohen's Kappa, intraclass correlation coefficient (ICC), and percentage agreement (PA). Aiken's V index was used to determine content validity (Retnawati, 2016), while IRA values were interpreted based on ICC (Tong et al., 2020) and PA (Viviers et al., 2017). The effectiveness of the student worksheet in improving students' science literacy and numeracy was evaluated using the normalized gain (N-Gain) by comparing pre-test and post-test scores (Masnur, 2021; Novita et al., 2019), categorized into high (≥ 0.7), medium ($0.3 \leq G < 0.7$), and low (≤ 0.3) improvement levels.

RESULTS AND DISCUSSION

The ADDIE development model comprises five primary stages: analysis, design, development, implementation, and evaluation. The results of the development research are presented as follows. The analysis stage involved a literature review and needs assessment. The literature review emphasized the importance of integrating green chemistry into the school curriculum to equip students to address global issues such as pollution and climate change (Zuin et al., 2021; Ganesh, 2021). In line with this, the low levels of student literacy and numeracy remain a critical challenge (Deda et al., 2023; Cheung et al., 2021; Fatmawati & Khotimah, 2023), making the development of an online PBL-based student worksheet highly relevant. Previous studies have shown that problem-based learning enhances students' critical and independent thinking skills (Hmelo-Silver, 2004; Novia et al., 2023), and 21st-century learning media, such as online student worksheets, offer innovative solutions in chemistry education (Suryaningsih & Nurlita, 2021). The needs assessment involved

curriculum analysis, learner characteristics, teacher readiness, and learning infrastructure at SMA Negeri 4 Lhokseumawe.

The implemented *Merdeka Curriculum* includes learning outcomes aligned with the development of an online student worksheet for green chemistry topics. However, teachers have not yet developed a PBL-based student worksheet due to time constraints and challenges in designing contextual problems. Students also face limitations in accessing quality learning resources and visual media to support understanding of abstract chemistry concepts, including green chemistry. The development of an online PBL-based student worksheet is imperative to ensure flexible, contextual, and sustainable access to science learning. Empirical studies have demonstrated that an environmentally oriented PBL-based student worksheet is effective in fostering science literacy (Mumtaza & Zulfiani, 2023; Rohmaya et al., 2023; Georgiou & Kyza, 2023) and addressing the scarcity of digital teaching materials that impede the enhancement of literacy and numeracy skills (Kamal et al., 2024). Its implementation is supported by several enabling factors, including curriculum alignment, the availability of ICT infrastructure, and robust empirical evidence of PBL's success in improving science literacy and numeracy. Conversely, challenges persist, such as teacher workload, limited instructional time, the complexity of designing authentic problem scenarios, insufficient availability of high-quality digital learning resources, and the risk of cognitive overload in the absence of adequate scaffolding. Taken together, the model's effectiveness is underpinned by its integration of green chemistry contexts, its capacity to facilitate authentic and problem-centered learning experiences, and its strategic incorporation of technological tools aimed at cultivating 21st-century competencies within the framework of sustainable science education (Purnama & Suparman, 2020).

The second stage is the design phase, which includes: (1) organizing the content of the PBL-based student worksheet systematically using Canva to make it visually appealing, and (2) uploading it in PDF format to the Liveworksheets platform for interactive online use. A portion of the online student worksheet design results is shown in Figure 1.

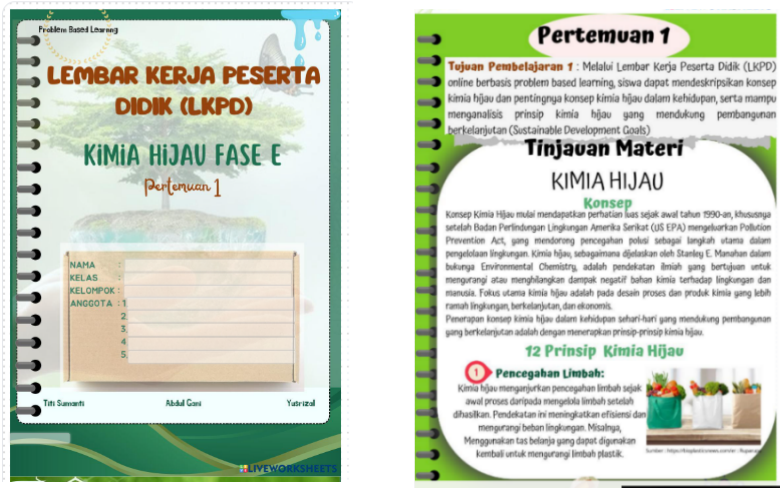

Figure 1. Display of Online Student Worksheet Design from Canva and Liveworksheet

The online student worksheet is structured with the following components: (1) student worksheet identity; (2) competencies based on learning outcomes; (3) contextual introduction based on green chemistry issues and global warming; (4) literacy sheet containing popular scientific readings; (5) numeracy activities involving environmental data/graph analysis; (6) group work guide based on PBL syntax; (7) reflection and conclusion; and (8) video links and digital sources. The attractive visual design, contextual content, and interactive features are designed to enhance the

ability to read scientific information, analyze data, and solve problems collaboratively, aligning with 21st-century learning demands (Suryaningsih & Nurlita, 2021; Kamal et al., 2024). The student worksheet can be accessed via the following link: https://bit.ly/LKPDonlinekimiahijaupbl_1.

During the development stage, the validity of the online student worksheet was evaluated prior to implementation. Two subject-matter experts and one education practitioner from Universitas Syiah Kuala, along with two media experts, assessed aspects such as content, motivation, pedagogy, appearance, navigation, and system functionality, in collaboration with SMA Sukma Bangsa Lhokseumawe. Validation results showed high feasibility: 96.39% for content and 96.88% for media, both categorized as "highly feasible." Improvements were made based on feedback, including alignment of objectives, illustrations, references, and language use (Nieveen, 2019; Wulandari et al., 2025). Validity and reliability were confirmed through Aiken's V and Inter-Rater Agreement (IRA). Aiken's V reached 0.956 (media) and 0.926 (content), with IRA values of 0.771 and 0.750, respectively, indicating strong agreement beyond chance (Azwar, 2015).

Table 5. Validity and Reliability Results of Aiken's V and IRA Index

Category	Aiken's V Index	Validity Standard	Inter-Rater Agreement (IRA)	Reliability Standard
Media	0.956	Valid	0.771	Good Reliability
Content	0.926	Valid	0.750	Good agreement beyond chance

Suggestions were incorporated into revisions of objectives (ABCD and HOTS format), evaluation items, and multimedia elements (Wulandari et al., 2025; Suryaningsih & Nurlita, 2021).



Figure 2. Adjustment of Green Chemistry Principles: Illustration Before and After Revision

To ensure the practicality of the instrument's quality, student and teacher response questionnaires were validated. Results indicated very good validity, with 100% (student) and 98.21% (teacher) accuracy, confirmed by Aiken's V (0.94 and 1.0) and IRA (0.609 and 0.6), indicating consistent and reliable judgment (Azwar, 2015; Nieveen, 2019; Nurjanah, 2023). Field trials showed strong positive responses with practicality scores of 82.42% (students) and 96.41% (teachers). Literacy and numeracy test items also demonstrated strong validity, with averages of 0.680 (literacy)

and 0.731 (numeracy), and high reliability scores of 0.916 and 0.936, respectively. Most items were of medium difficulty. Based on discrimination analysis, seven literacy and nine numeracy items were selected, and 10 representative items were used for pre-test and post-test (Friatma & Anhar, 2019).

Table 6. Validity and Reliability of Practicality Test Instruments Based on Aiken's V and IRA

Category	Aiken's V Index	Validity Standard	IRA	Reliability Standard
Student Response Questionnaire	0.94	Valid	0.609	Good agreement beyond chance
Teacher Response Questionnaire	1	Valid	0.6	Good agreement beyond chance
Average	0.97	Valid	0.705	Good agreement beyond chance

The development of an online PBL-based student worksheet is crucial to ensure flexible, contextual, and sustainable science learning. Empirical evidence demonstrates that PBL integrated with environmental and green chemistry contexts significantly enhances science literacy and numeracy while addressing the scarcity of digital learning tools (Mumtaza & Zulfiani, 2023; Rohmaya et al., 2023; Georgiou & Kyza, 2023; Kamal et al., 2024). Key enablers include curriculum alignment, adequate ICT infrastructure, and strong prior validation of PBL's pedagogical efficacy. However, constraints such as limited preparation time, challenges in designing authentic problems, and insufficient digital resources may hinder implementation. This model's effectiveness stems from its integration of problem-centered learning with technological tools, promoting higher-order thinking and 21st-century competencies within the framework of sustainable science education (Purnama & Suparman, 2020).

The implementation of the PBL-based online student worksheet was conducted with class X-2 students of SMA Negeri 4 Lhokseumawe over three sessions, involving 24 students. The primary objective of this implementation was to assess the effectiveness of the student worksheet in enhancing science literacy and numeracy. The learning process utilized digital devices, such as smartphones or laptops, to access the online student worksheet, followed by the administration of pre-test and post-test essay-based questions on the topic of green chemistry. Figure 3 shows the results of the science literacy pre-test and post-test.

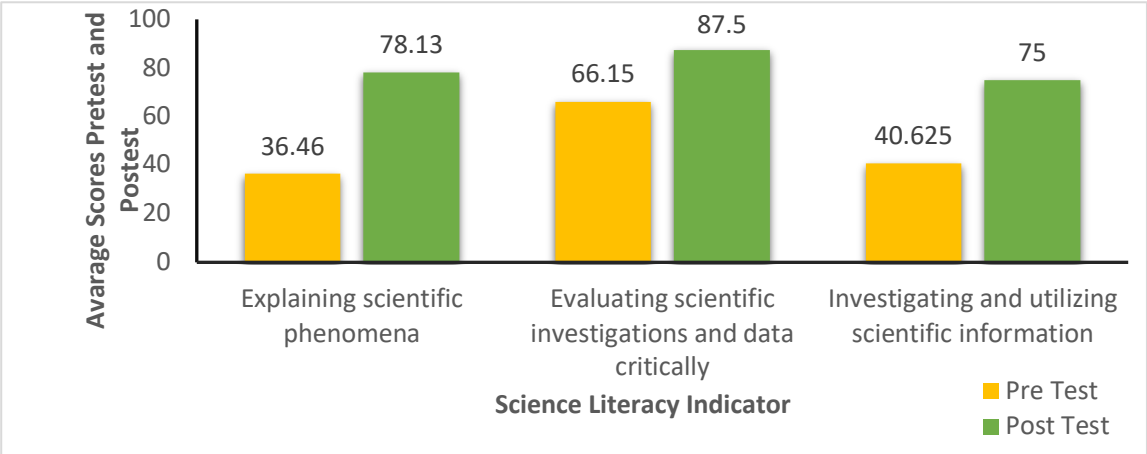

Figure 3. Comparison of Average Pre-test and Post-test Scores in Science Literacy

The implementation results showed a significant increase in students' science literacy after using the PBL-based online student worksheet. The average pre-test score of 47.74 increased to 80.21 in the post-test. All literacy indicators improved: the ability to explain phenomena rose from 36.46 to 78.13; to evaluate scientific investigations from 66.15 to 87.5; and to use scientific information from 40.625 to 75. These findings indicate that the PBL-based online student worksheet effectively promotes critical, reflective, and contextual understanding of scientific concepts. PBL has been proven to moderately to highly improve students' scientific problem-solving skills and science literacy (Adawiyah & Mahmuddin, 2023).

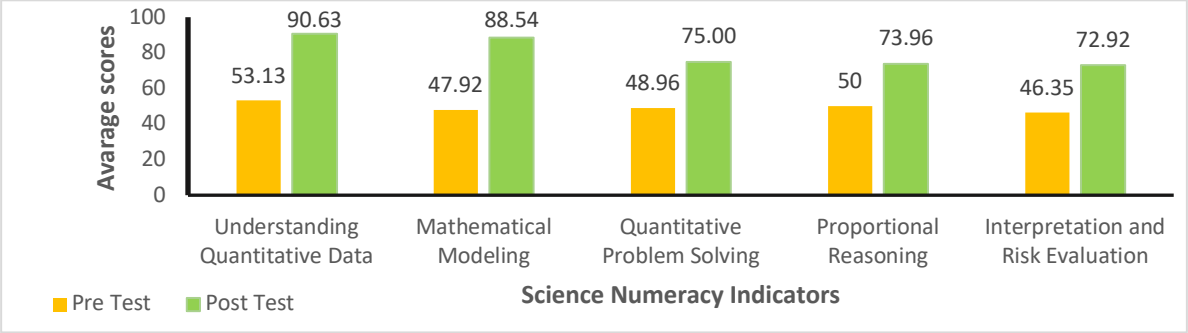

Figure 4. Comparison of Average Pre-test and Post-test Scores in Science Numeracy

According to Figure 4, the use of a PBL-based online student worksheet had a positive impact on students' science numeracy. The initial average score of 49.27 increased to 79.38 after the learning process. All numeracy indicators improved: quantitative data understanding increased from 53.13 to 90.63, mathematical modeling improved from 47.92 to 88.54, quantitative problem solving rose from 48.96 to 75, proportional reasoning increased from 50 to 69.79, and risk evaluation improved from 46.35 to 72.92. This improvement shows that the problem-based approach in the online student worksheet effectively strengthens critical and numerical thinking skills in an applicable green chemistry context. These results support meta-analysis findings that PBL is effective in enhancing problem-solving and numeracy skills in science education (Raman et al., 2024; Ritonga & Anas, 2022). In the evaluation stage, the effectiveness of the PBL-based online student worksheet was measured using N-Gain analysis on pre-test and post-test scores of 24 tenth-grade students at SMA Negeri 4 Lhokseumawe.

Table 7. N-Gain Test for Students' Science Literacy

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation	Category
N gain_score	24	-0.12	0.91	0.6061	0.2000	Moderate (Significant)
N gain_percent	24	-12.48	90.90	60.61	20.0000	

Table 8. N-Gain Test for Students' Science Numeracy

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation	Category
Ngain_score	24	0.19	1.00	0.6106	0.25239	Moderate (Significant)
Ngain_percent	24	18.75	100.00	61.06	25.23937	

The results in Tables 7 and 8 show average N-Gain scores of 0.6061 for science literacy and 0.6106 for science numeracy, both classified as moderate, indicating improved learning outcomes after using the online student worksheet. To assess practicality, a limited trial involving four teachers showed that the developed online student worksheet achieved a very high practicality score of

95.31%. This includes high ratings in media, content, student engagement (each 93.75%), and efficiency of use (100%). These results indicate that the student worksheet is highly acceptable and practical for classroom use, supporting its potential for broader implementation in digital science education (Yusrizal, 2020). Students completed a response questionnaire covering media, content, effectiveness, and motivation. Results indicated highly positive responses from all 24 students, with an average score of 79.30%. The highest ratings were for effectiveness (80.90%), followed by motivation (80.56%), content (78.13%), and media (77.60%). All aspects were rated as very positive, indicating the student worksheet is practical and feasible for classroom implementation. This aligns with studies showing PBL significantly increases students' motivation and engagement in chemistry based on quantitative surveys and interviews (Arsyad et al., 2024). The positive responses from both teachers and students are consistent with previous findings that differentiated instruction enhances learning engagement and achievement in diverse classrooms (Smale-Jacobse et al., 2019; Tundreng et al., 2025). Moreover, the integration of green chemistry principles reflects the essence of sociological pedagogy, which emphasizes connecting science learning to authentic societal and environmental contexts (Giroux, 1988).

This study presents a novel instructional approach that integrates a PBL framework with online student worksheets, embedding green chemistry content to enhance both scientific literacy and numeracy. The evaluation showed moderate improvements in students' science literacy (N-Gain = 0.6061) and numeracy (N-Gain = 0.6106), while practicality scores from teachers (95.31%) and students (79.30%) indicated strong usability, engagement, and motivation. These findings suggest that integrating problem-centered, contextual tasks fosters active knowledge construction and enhances both literacy and numeracy, consistent with constructivist learning principles (Jonassen, 2014; Karpudewan et al., 2015). These findings suggest the PBL-based student worksheet effectively enhances literacy and numeracy through contextual problem-solving. This is consistent with research reporting science literacy gains of 65.83% (moderate N-Gain) and higher-order thinking skills of 82.16% using a PBL module on buffer solutions (Sugiharti et al., 2025). Likewise, green chemistry-oriented studies have shown that PBL improves science literacy, with N-Gain ≈ approximately 0.55 (Fauziah, 2019; Yuafian & Astuti, 2020).

Key enabling factors include curriculum alignment with the Merdeka Curriculum, sufficient ICT infrastructure, and iterative validation by content and media experts. Potential inhibitors are limited teacher preparation, varying levels of digital literacy among students, and the cognitive demands of self-directed problem-solving, which have been highlighted in prior studies on digital PBL implementations (UNESCO, 2018). Compared to prior research that focused solely on scientific literacy (Mufidah & Dwiningsih, 2024), critical thinking skills (Nilawati et al., 2025), or reaction rate materials (Safitri et al., 2021), this study broadens the scope by simultaneously addressing multiple learning outcomes. It also extends Jayanti's (2023) findings on PBL worksheets in biology to green chemistry, demonstrating similar benefits in promoting scientific literacy and numeracy when learning is contextualized around environmental and sustainability issues. Overall, the validated and reliable instruments support replicability, and embedding environmental and sustainability contexts encourages the development of 21st-century competencies. This digital PBL-based instructional model provides an evidence-based, scalable approach to fostering reflective, contextual, and solution-oriented scientific understanding, addressing the limitations of conventional paper-based or digital worksheets while offering practical implications for classroom implementation.

CONCLUSION

The development of a PBL-based online student worksheet on green chemistry has proven to be valid, practical, and effective in enhancing students' science literacy and numeracy. Validation

results showed that the content and media were highly feasible, with Aiken's V scores of 0.926 (material) and 0.956 (media), and IRA scores of 0.750 and 0.771, indicating good agreement beyond chance. The limited trial involving teachers revealed that the developed online student worksheet achieved a very high practicality score, with an average of 95.31%. This score encompassed four key aspects: media (93.75%), content (93.75%), student engagement (93.75%), and efficiency of use (100%). In terms of practicality, the response questionnaires from students also indicated a very positive reception, with an average score of 79.30%. The highest aspect was effectiveness (80.90%), followed by motivation (80.56%), content (78.13%), and media (77.60%). These results show that the online student worksheet was engaging, user-friendly, and relevant to students' learning needs. Effectiveness testing, as measured through N-Gain analysis, showed a significant improvement in learning outcomes. The N-Gain scores for science literacy and science numeracy were 0.6061 and 0.6106, respectively, both categorized as moderate. This demonstrates that the online student worksheet effectively supported students in understanding scientific phenomena, analyzing data, and solving quantitative problems. The student worksheet is recommended as an innovative, context-based digital learning resource that embeds green chemistry principles to cultivate environmentally literate learners. For teachers, it provides a robust tool to foster critical thinking, problem-solving, and sustainability-oriented learning. For school principals, its adoption in curriculum design can accelerate digital transformation and environmental awareness across the school community. For policymakers, scaling such approaches can advance national STEM education goals, promote 21st-century competencies, and align science education with sustainability imperatives. Ultimately**,** the integration of this student worksheet represents a strategic step toward building a future-ready generation capable of addressing global environmental challenges through scientific literacy and numeracy.

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