



Development of a Contextual Problem-Based Learning Worksheet Using the Haze Phenomenon to Enhance Understanding of Gas Laws among Chemistry Education Students

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Abstract

Understanding gas laws in physical chemistry often challenges students due to their abstract nature. The recurring haze phenomenon in South Sumatra provides a relevant environmental context to connect theory to daily life. This study aimed to develop a contextual Problem-Based Learning (PBL) student worksheet (LKM) using the haze phenomenon to improve students' understanding of gas laws in Chemistry Education at Sriwijaya University. The research applied the ADDIE development model combined with Tessmer's formative evaluation, including expert review, one-to-one, small-group, and field testing. Expert validation of content, design, pedagogy, and PBL aspects yielded an average Aiken's V of 0.902 (high validity), and reliability analysis showed Cronbach's $\alpha = 0.796$, indicating good internal consistency. The worksheet's practicality reached 97% in the one-to-one trial and 96% in the small-group trial, both categorized as very practical. Field testing revealed a pretest mean of 77.24 and a posttest mean of 98.62, with an N-gain of 0.94 (94.14%) and a paired t-test of $t = -7.109$, $p < 0.001$, confirming significant improvement in students' conceptual understanding. These findings suggest that integrating local environmental issues through contextual PBL worksheets fosters meaningful learning, reflective thinking, and environmental awareness in physical chemistry education.

Keywords: Contextual learning, problem-based learning, student worksheet, haze phenomenon, gas laws

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INTRODUCTION

Physical Chemistry I is a compulsory 3-credit course for prospective chemistry teachers in the Chemistry Education Study Program at Universitas Sriwijaya. Upon completing this course, students are expected to achieve several competencies: (1) the ability to understand and explain the fundamental concepts of thermodynamic laws and their applications; (2) the ability to solve problems related to equations of state, thermodynamic laws, entropy, and chemical equilibrium; and (3) the ability to analyze energy changes in chemical systems based on thermodynamic principles. These competencies enable prospective teachers to design chemistry learning using various approaches, strategies, methods, and techniques in accordance with national education standards and the integration of science and technology, thereby helping students achieve the intended learning objectives (Eviota & Liangco, 2023).

However, the learning of Physical Chemistry I, particularly on the topic of the gas laws, remains dominated by traditional approaches emphasizing rote memorization and mathematical manipulation of formulas. Concepts such as the relationships among pressure, volume, temperature, and the number of moles are often taught in isolation,

disconnected from real phenomena that occur in daily life (Muliyati et al., 2024). As a result, students experience difficulties in understanding the physical meaning of gas parameters and in applying these ideas to environmental or observable phenomena. This indicates a low level of cognitive engagement and weak critical thinking skills, which ultimately leads to a lack of relevance between chemistry learning and real-life contexts (Solé et al., 2024).

Mastery of gas laws is fundamental because it serves as a prerequisite for understanding other physical chemistry concepts, such as thermodynamics and chemical equilibrium (Zikri et al., 2022). Difficulties in comprehending gas behavior may hinder students' ability to apply scientific reasoning across broader chemical contexts, which is crucial for future chemistry teachers. Therefore, it is essential to design learning tools that bridge abstract content with concrete, observable phenomena. Real-world events such as haze, changes in air pressure at high altitudes, and gas expansion due to temperature variations in South Sumatra provide authentic and locally relevant contexts for teaching the gas laws (Novitasari et al., 2024). Integrating such contextual issues is not merely an instructional choice but a pedagogical necessity to foster deeper conceptual understanding.

Integrating contextual issues such as the haze phenomenon can enhance students' cognitive engagement because it situates abstract gas law concepts within familiar, observable events. According to cognitive and constructivist learning theories, meaningful learning occurs when new information is linked to prior experiences, increasing motivation and facilitating conceptual change (Cakir, 2022). Furthermore, contextualized problem-solving promotes scientific literacy as students interpret data, analyze environmental causes, and propose evidence-based solutions to authentic problems.

Problem-Based Learning (PBL) and contextual learning are both rooted in constructivist learning theory, which posits that knowledge is actively constructed through learners' experiences and interactions with their environment (Jumaah, 2024; MacLeod et al., 2022). Within this framework, students engage in authentic problem solving that fosters higher-order thinking, reflection, and the ability to transfer concepts to new contexts (Gradini et al., 2025). Therefore, developing a PBL-based worksheet that integrates contextual issues aligns with the constructivist principle that understanding emerges through active engagement with real-world experiences.

The geographical conditions of South Sumatra, characterized by periodic haze caused by land fires and significant temperature variations between lowland and highland regions, such as along the Palembang–Pagar Alam route, offer strong potential as contextual foundations for gas law instruction (Hayasaka, 2023). These environmental phenomena reflect the application of gas law principles such as Boyle's Law, Charles's Law, and the Ideal Gas Equation in real atmospheric dynamics. Thus, it is important to design a contextual PBL worksheet that incorporates these local phenomena, enabling students not only to understand the concepts theoretically but also to reason, analyze, and calculate changes in gas properties based on authentic data (Pramudiyanti et al., 2023).

Although numerous studies have implemented PBL or contextual approaches in chemistry education, few have directly integrated local environmental phenomena, such as the haze events in South Sumatra, as a contextual basis for learning gas laws. Previous studies (Winarsi et al., 2024) have shown that PBL significantly enhances conceptual understanding and problem-solving skills. Similarly, (Afrida, 2024) and (Aprilia et al., 2024) highlighted that contextual approaches improve students' comprehension of chemical concepts. Studies by Noyan and Suharman developed physical chemistry worksheets based on green chemistry and case-based learning, which proved valid and effective in enhancing understanding and participation (Noyan, 2023). However, most of

these studies remain generic and lack a direct connection to students' immediate environmental contexts.

Based on this review, there remains a gap in the development of instructional tools that combine PBL with local contextual issues in physical chemistry learning. The absence of such tools limits students' ability to connect theory with real-life phenomena and to develop critical and reflective thinking skills. Therefore, the main problem addressed in this study is the lack of a contextual PBL-based student worksheet (LKM) that integrates local environmental phenomena, specifically haze, as an entry point for understanding gas laws. This study aims to develop such a worksheet and assess its validity, practicality, and effectiveness. The development model employed in this research combines the ADDIE framework with Tessmer's formative evaluation, including expert review, one-to-one, small group, and field testing.

METHODS

This study, conducted at Universitas Sriwijaya (June–September 2025), employed the ADDIE model integrated with Tessmer's formative evaluation to develop a contextual PBL worksheet on gas equations (Figure 1). Participants included 29 Physical Chemistry I students for effectiveness testing, 30 external students for instrument trials, 41 past students for practicality questionnaires, and selected peers for one-to-one and small group evaluations (Eviota & Liangco, 2023).

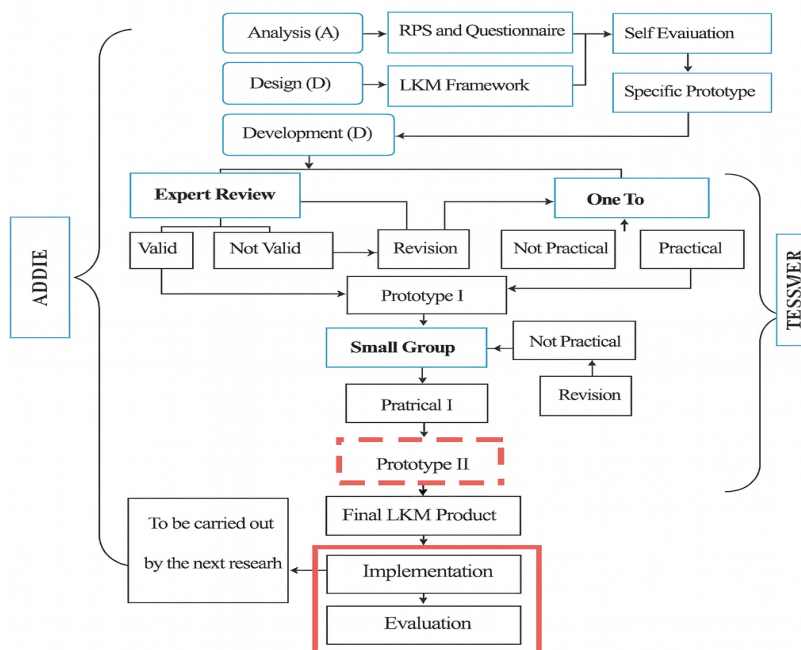


Figure 1. The ADDIE Model with Tessmer's Formative Evaluation

The analysis phase comprised a comprehensive needs assessment involving: (1) an online questionnaire for the 2022 cohort to identify difficulties regarding gas topics; (2) a curriculum review of Physical Chemistry I to ensure alignment; and (3) instructor interviews addressing instructional challenges, misconceptions, and PBL suitability (Suharman et al., 2024).

In the design phase, instructional materials were developed by aligning PBL syntax with the Physical Chemistry I course structure (Nor et al., 2022). The worksheet

components facilitated problem orientation, exploration, reasoning, and reflection. Following self-evaluation, the prototype was validated by three experts across design, PBL structure, content, and pedagogy. Inter-rater reliability analysis yielded Cohen’s Kappa coefficients ranging from 0.560 to 0.750 (Tan et al., 2024).

One-to-one (n=3), varying abilities) and small group (n=9) evaluations assessed clarity and readability, resulting in Prototype II. Subsequently, a limited field test with 30 students (2023 cohort) examined the worksheet’s effectiveness in the Chemistry Education context (Rianti et al., 2021)

The test instrument was piloted on 30 students, showing valid item correlations (Pearson $r=0.479-0.768$, $p<0.01$) and adequate reliability (Cronbach’s $\alpha=0.796$) (Tan et al., 2024). Expert feasibility (content, design, pedagogy) was assessed using Likert-scale questionnaires and analyzed via the percentage formula:

$$P = \frac{\sum x}{\sum xi} \times 100\%$$

Description:

P = percentage of validity

$\sum x$ = total expert assessment score for each aspect

$\sum xi$ = total maximum score for each aspect

The results of the feasibility percentage calculation were then classified into categories according to Table 1.

Table 1. Validity Percentage Categories (Eviota & Liangco, 2023)

Percentage Range (%)	Category
85.01 – 100	Very Valid
70.01 – 85.00	Valid
50.01 – 70.00	Less Valid
01.00 – 50.00	Not Valid

During one-to-one and small group trials, students assessed the worksheet’s (LKM) readability, clarity, and practicality. Practicality scores were calculated using the formula:

$$Practicality\ Score = \frac{Obtained\ Score}{Maximum\ Score} \times 100\%$$

The obtained scores were then converted into practicality categories as presented in Table 2.

Table 2. Practicality Categories (Pitri et al., 2025)

Achievement Level (%)	Category
81 – 100	Very Practical
61 – 80	Practical
41 – 60	Fairly Practical
21 – 40	Less Practical
0 – 20	Not Practical

Worksheet effectiveness (n=29) was analyzed using a paired sample t-test on pretest-posttest scores (Aprida & Mayarni, 2023). Learning improvement was subsequently calculated using the normalized gain formula:

$$\langle g \rangle = \frac{\langle \%Sf \rangle - \langle \%Si \rangle}{(100 - \langle \%Si \rangle)}$$

Description :

g = average normalized gain score

S_f = final score (posttest)

S_i = initial score (pretest)

100 = maximum score

This analysis aimed to determine the improvement of students' understanding after using the LKM. Furthermore, the N-gain was converted into gain index categories. The criteria for students' gain scores are presented in Table 3.

Table 3. N-gain Categories (Christman et al., 2024)

N-gain Value	Category
$g > 0.70$	High
$0.30 \leq g \leq 0.70$	Medium
$g < 0.30$	Low

RESULTS & DISCUSSION

Lecturer interviews revealed that instruction relies heavily on theoretical textbooks (e.g., Atkins, Moore), lacking contextual application. The recurring South Sumatra haze is a relevant local phenomenon linking pressure, temperature, and pollutants, which has notably not been utilized. Integrating this context into PBL worksheets is therefore anticipated to facilitate meaningful cognitive anchoring and knowledge transfer (Juliantari & Wibawa, 2024; Juliantari & Wibawa, 2024).

Student questionnaires revealed a significant gap between resource availability and conceptual comprehension. Despite high enthusiasm (97.6%) and accessibility (100%), only 34.1% of students reported adequate understanding. Structural issues were prominent, with 78% finding the material difficult to follow and 65.9% noting a lack of alignment with PBL characteristics. Difficulties peaked in the Gas State Equation topic (75.6%), where limited real-life connections were identified (61%). These findings highlight a clear instructional mismatch. The unanimous demand (100%) for contextual PBL worksheets supports (Lubis et al., 2023) and (Zikri & Wardana, 2025), confirming that such materials improve the comprehension of abstract concepts through real-world connections.

While the Merdeka Curriculum-based Physical Chemistry I course covers gas laws, students often perceive these concepts as abstract. Integrating the local South Sumatra haze phenomenon into PBL worksheets addresses this by providing an authentic, constructivist context. This approach enhances conceptual reasoning and scientific literacy, aligning with the curriculum's emphasis on active, applicable learning (Qomariah et al., 2023; Sial et al., 2024).

The LKM integrates core gas law theories (Rowland, 1963) with PBL pedagogy (Chang & Overby, 1986), progressing from ideal assumptions to real gas deviations. It covers three subtopics: ideal gas, real gas, and the South Sumatra haze, connecting theoretical concepts to measurable environmental variables. By embedding this authentic, ill-structured problem, the worksheet fosters scientific reasoning and environmental literacy, consistent with contextual PBL frameworks (Amalia et al., 2024).

The LKM development adhered to Tessmer's formative evaluation stages to ensure validity, practicality, and effectiveness. Initial self-evaluation and peer reviews prompted specific revisions: a South Sumatra haze-themed cover, simplified title, structured answer spaces, and enhanced color layout. These improvements optimized the LKM for PBL

pedagogical alignment and cognitive accessibility (Haryati et al., 2025). During development, the LKM was refined to align content with PBL outcomes using authentic, contextual scenarios. Expert and one-to-one evaluations assessed accuracy, language, and feasibility, ensuring the LKM's validity, practicality, and theoretical alignment with Physical Chemistry I requirements (Eviota & Liangco, 2023). At the validation stage, quantitative data from Likert-scale questionnaires and qualitative data from validator feedback were collected. The validation results were analyzed using Aiken's V formula, as shown in Table 4.

Table 4. Results of Design Validation Calculation

Item	Rater		S1	S2	ΣS	n(c-1)	V
	I	II					
Items 1-15	69	67	54	52	106	120	0,90

Expert validation indicated high design validity with an Aiken's V value of 0.90 and substantial inter-rater agreement with a Kappa value of 0.737. These results confirm that the LKM possesses the necessary layout clarity and visual structure to facilitate learning effectively. The findings align with (Rahmi & Azrul, 2021) and (Çırakoğlu et al., 2022), who emphasize that robust visual design involving appropriate typography and spacing is critical for reducing cognitive load and strengthening information processing. Consequently, the visual presentation of the LKM is sufficiently effective to support students in building a conceptual understanding of gas laws. The material validation results are detailed in Table 5:

Table 5. Results of Material Validation Calculation

Item	Rater		S1	S2	ΣS	n(c-1)	V
	I	II					
Items 1-8	36	35	28	27	55	64	0,859

Two subject-matter experts assessed the haze-contextualized PBL Worksheet (LKM), resulting in a high material validity score with an Aiken's V of 0.859. This confirms that content accuracy and depth align well with Physical Chemistry I learning objectives. The logical sequencing and integration of contextual haze cases were deemed appropriate for supporting conceptual understanding. Additionally, inter-rater consistency showed substantial agreement with a Cohen's Kappa of 0.750, indicating reliable expert judgment. As noted by (Parmiti & Sudatha, 2023), Such validity and stability are crucial for instructional materials. Thus, the LKM is materially valid and pedagogically robust, effectively linking gas law concepts with real environmental issues to strengthen scientific literacy.

The pedagogical assessment by two experts yielded a high Aiken's V value of 0.89 and a substantial inter-rater agreement (Kappa) of 0.75. These metrics confirm that the LKM meets pedagogical feasibility criteria and aligns well with PBL principles. High validity is evidenced by clear objective alignment, communicative language, and material that stimulates curiosity. Furthermore, the LKM fosters critical thinking through independent problem-solving activities, while illustrations enhance readability. These findings corroborate (Khan et al., 2025) and (Nilson & Goodson, 2021), who emphasize the importance of clear objectives and coherent content presentation. Consequently, the LKM is valid in both content and pedagogy, effectively supporting contextual learning. The pedagogical validation results are detailed in Table 6.

Table 6. Results of Pedagogical Validation Calculation

Item	Rater		S1	S2	$\sum S$	n(c-1)	V
	I	II					
Items 1-16	76	70	60	54	114	128	0,890

The contextual Problem-Based Learning (PBL) Student Worksheet (LKM) on the haze phenomenon for understanding gas laws among Chemistry Education students at Universitas Sriwijaya was assessed by two expert validators and obtained an average Aiken's V value of 0.94, categorized as high, with a Kappa inter-rater agreement of 0.56, indicating moderate agreement. The LKM meets the eligibility criteria for PBL syntax and reflects problem-based learning principles through authentic contextual problems, guided investigation with trigger questions, and opportunities for students to report and conclude findings collaboratively. These results confirm that the LKM effectively supports contextual, scientific, and critical thinking, aligning with previous findings on the importance of structured problem formulation and investigative stages in PBL (Nariman, 2021; Salsabila & Asih, 2024). The results of the PBL material validation sheet assessment using Aiken's V formula are presented in Table 7.

Table 7. Results of PBL Validation Calculation

Item	Rater		S1	S2	$\sum S$	n(c-1)	V
	I	II					
Items 1-11	53	51	42	40	82	88	0,931

Based on the assessment of two expert validators for the Problem-Based Learning (PBL) aspect, the contextual PBL Student Worksheet (LKM) on the haze phenomenon for understanding gas laws among Chemistry Education students at Universitas Sriwijaya obtained an average Aiken's V value of 0.931, indicating high validity. The LKM meets PBL syntax criteria and demonstrates real contextual problems, guided investigation with trigger questions, and opportunities for students to compile reports and draw conclusions, fostering critical and collaborative thinking. These results confirm that the LKM effectively supports contextual, scientific, and reflective learning, in line with the principles of problem-based learning (Salsabila & Asih, 2024).

The high category of the LKM is reflected in its capacity to orient students toward real-world problems like the haze phenomenon and guide investigations through structured inquiries. By facilitating result presentation and conclusion formulation, the worksheet promotes critical and collaborative thinking. This aligns with (Nariman, 2021), who emphasizes that PBL effectiveness hinges on clear problem formulation and structured investigation. Consequently, the LKM validly applies PBL syntax to support contextual learning that fosters scientific and reflective thinking. The expert validation scores are presented in Table 8.

Table 8. Average Validation Score Results

Assessment Aspect	Aiken's V Coefficient	Category
Design	0,90	High
Material	0,859	High
Pedagogical	0,891	High
PBL	0,932	High
Average Score	0.895	High

The practicality of the Contextual PBL Student Worksheet (LKM) on the haze phenomenon for understanding gas laws was confirmed through a one-to-one trial with three students, yielding scores of 69, 69, and 67, which correspond to an average practicality of 97% and a “very practical” category. Students reported that the LKM was clear, well-structured, and easy to follow, with minor suggestions for font and color improvements. These results align with (Fitria & Afdaleni, 2024) and (Tegmark et al., 2022), who highlight that readability, visual appeal, and communicative language enhance practicality, and with (Maftuh et al., 2023), who note that contextual materials support conceptual understanding. Overall, the LKM effectively combines content alignment and engaging visuals, making it highly practical for classroom use.

The small group trial involving nine Chemistry Education students demonstrated that the PBL Worksheet (LKM) possesses high practicality and effectively supports learning. Feedback indicated that the material was clear, systematic, and successfully connected gas law concepts with real-world haze phenomena. Minor suggestions regarding uniform fonts, softer colors, and a flipbook format were noted to further enhance engagement. These results align with (Amanda et al., 2025), confirming that the practicality of a learning tool relies heavily on its ease of use and effectiveness in facilitating student comprehension.

The practicality questionnaire yielded an average score of 96%, categorized as “very practical.”(Amraini et al., 2025), indicating that the LKM is easy to understand and supports independent learning. Student feedback suggested minor improvements in color harmony and image use. These results align with (Fitria & Afdaleni, 2024), who emphasized that appealing design and clear content enhance motivation and engagement. Overall, the developed PBL-based Physical Chemistry I LKM is valid, highly practical, and ready for final implementation as Prototype III. As shown in Figure 2, the field trial consisted of a pretest, LKM implementation, and posttest.



Figure 2. Field Trial Implementation

The following table (Table 9) presents the calculation results of students’ pretest and posttest scores using the N-gain formula :

Student	N-Gain	% N-Gain	Category
Average	0.941	94.14%	High

The field test for Class A students showed a significant improvement in learning outcomes, with the average pretest score of 77.24 increasing to 98.62 in the posttest. The paired-sample t-test confirmed a statistically significant improvement ($t = -7.109$, $df = 28$, $p < 0.001$). The worksheet items were valid, with Pearson correlations ranging from 0.479 to 0.768 ($p < 0.01$), and the instrument was reliable with a Cronbach's alpha of 0.796. Expert validation using Aiken’s V also confirmed high validity: 0.90 for design, 0.875 for material, 0.891 for pedagogical aspects, and 0.943 for PBL syntax, while inter-rater

reliability (Kappa) ranged from 0.560 to 0.750. These results indicate that the developed LKM effectively supports learning and meets quality standards in design, content, pedagogy, and PBL implementation (Li et al., 2023; Tan et al., 2024).

The findings demonstrate that the PBL approach using a real-world haze context promotes active, critical, and engaged learning, strengthens conceptual understanding, and develops problem-solving and scientific thinking. The LKM's systematic development following the ADDIE model ensured iterative refinement, integrating contextual problems, guided investigations, and collaborative reporting. Overall, the final contextual PBL LKM is valid, reliable, practical, and highly effective for broader classroom implementation in Physical Chemistry and related courses (Abuhassna et al., 2024; Adeoye et al., 2024).

CONCLUSION

This study successfully developed a contextual Problem-Based Learning (PBL) Student Worksheet (LKM) on the haze phenomenon to enhance understanding of gas laws among Chemistry Education students at Universitas Sriwijaya, using the ADDIE model integrated with Tessmer's formative evaluation. The developed worksheet demonstrated high validity ($V = 0.902$), strong reliability (Cronbach's $\alpha = 0.796$), very high practicality (97%–96%), and significant effectiveness (N-gain = 0.94, paired t-test $p < 0.001$), confirming its feasibility as an instructional tool. By embedding real-world environmental contexts, the worksheet supports constructivist and situated learning, linking abstract gas law concepts to students' experiences while fostering critical thinking, scientific literacy, and environmental awareness in line with the Merdeka Curriculum. Although the study was limited to one institution with a small sample, the findings provide a replicable model for developing valid, practical, and effective chemistry learning materials. Future research should test the worksheet across broader settings, assess long-term learning retention, and adapt the approach to other chemistry topics such as thermodynamics or chemical equilibrium.

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