

Problem-Based Learning Worksheets Integrating Computational Thinking and 21st-Century Interdisciplinary Themes for Real-Life Problem Solving

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Abstract: Problem solving is an essential competency in 21st-century mathematics education. However, implementing Problem-Based Learning (PBL) still faces challenges in using authentic problems and has rarely integrated Computational Thinking (CT) and 21st-century interdisciplinary themes systematically. This study aimed to develop a PBL-based student worksheet that integrates CT and 21st-century interdisciplinary themes to support students' real-life problem-solving. The study employed the ADDIE model, consisting of the analysis, design, development, implementation, and evaluation stages. The developed worksheet was validated by experts, evaluated for practicality through teacher and student responses as well as learning implementation, and tested for effectiveness using a posttest-only control group design. The results showed that the worksheet has three main characteristics: integrating CT into every phase of PBL, using 21st-century interdisciplinary themes as authentic problem contexts, and including learning activities that systematically guide students through the real-life problem-solving process. The evaluation results indicated that the worksheet was valid, practical, and effective. Its effectiveness was demonstrated by students' real-life problem-solving performance, which was significantly better than that of students receiving standard PBL instruction, and by the achievement of classical learning mastery, with at least 80% of students meeting the predetermined mastery criterion.

Keywords: 21st century interdisciplinary themes, computational thinking, problem-based learning, problem solving.

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■ INTRODUCTION

Problem solving is a central demand of 21st-century life, since many of the problems students will eventually face cannot be resolved through a single discipline. To solve problems effectively, students need to recognize a range of real-life contexts, an ability that in turn supports the innovation and creativity they will need in the future (Adeoye & Jimoh, 2023). This expectation carries into secondary education, National Council of Teachers of Mathematics (NCTM) sets out problem-solving standards spanning early schooling through secondary level, covering the

construction of new mathematical knowledge through problem solving, solving problems both within and beyond mathematics, applying appropriate strategies, and reflecting on the process itself (NCTM, 2000). However, student problem-solving ability remains far from optimal in practice (Asih & Ramdhani, 2019; Nugroho & Sari, 2021), placing considerable responsibility on teachers to train students to tackle non-routine problems both inside and beyond the classroom (Ahdhianto et al., 2020).

PBL follows this same process, and its effectiveness in improving students' problem-

solving ability is well documented (Amalia et al., 2017; Hudha et al., 2023; Marchy et al., 2022). PBL presents students with a problem to solve by drawing on prior or newly acquired knowledge (Ahdhianto et al., 2020). Its benefits extend beyond problem solving itself: PBL has also been linked to stronger long-term retention (Li & Tsai, 2017), higher motivation (Argaw et al., 2017), and improved critical thinking (Sari et al., 2022). Students' problem-solving ability in PBL is closely associated with the use of metacognitive strategies, particularly planning, monitoring, and evaluating the problem-solving process (Hmelo-Silver, 2004). In practice, however, students rarely manage this independently; without additional scaffolding, misconceptions and breakdowns in the process are common (Hmelo-Silver & DeSimone, 2013), and the problem-solving process itself often becomes an obstacle for students (Yu et al., 2015).

CT offers one way to support this process. CT has been shown to contribute positively to student learning (Sukirman et al., 2024), and Wing (2006) describes its essential move as turning a problem that looks unsolvable into one whose solution is already within reach. As a problem-solving process, CT involves formulating the problem, organizing data logically, representing it through abstraction, automating a solution, reflecting on its efficiency, then generalizing and transferring the approach to new problems (Dong et al., 2019). This study operationalizes CT through Dong et al.'s (2019) PRADA framework: pattern recognition, abstraction, decomposition, and algorithms, which together help students identify what matters in a problem, break down its complexity, recognize recurring patterns, and construct a solution step by step. CT therefore can strengthen the problem-solving process at the core of PBL by offering students a systematic way of thinking as they understand, analyze, and solve problems.

Sharpening how students solve a problem, however, does not resolve a separate issue: real-world problems rarely respect disciplinary boundaries. The problems society faces typically involve economic, environmental, health, civic, and global dimensions at once. Hence, classroom contexts need to reflect that same complexity if students are to become accustomed to connecting mathematical concepts with real situations. The Partnership for 21st (2011) groups this territory under 21st century interdisciplinary Themes: global awareness; financial, economic, business, and entrepreneurial literacy; civic literacy; health literacy; and environmental literacy. Bringing these themes into mathematics instruction shifts learning beyond exercise-solving toward understanding and decision-making grounded in real-life conditions.

This interdisciplinary framing fits naturally with PBL, which is already anchored in authentic problems. Arends (2012) notes that even when PBL centers on a single subject, the problems it uses still need to be factual enough to draw in content from multiple fields. Achieving this consistently, however, requires a tool that can guide student activity through the PBL syntax while keeping the problems genuinely contextual, and a worksheet is a natural candidate for that role.

Even where PBL is already common in mathematics classrooms, the quality of the problems used remains a persistent issue. Mumu et al. (2025) found that teachers tend to rely on routine, procedural problems instead of the constructive problems that PBL is meant to run on, problems that actually demand exploration, reasoning, and investigation. CT as a skill worth cultivating has drawn separate research attention, from number-pattern tasks (Julianti et al., 2022) to PISA-style space and shape problems (Suntaryati et al., 2023). A review by Maharani (2020), however, found a gap between knowledge and practice: teachers understand the

concept of CT but struggle to integrate it into their teaching. Elsewhere, CT training has been shown to improve performance on Bebras tasks, a competition built around CT skills (Syamsy & Sholikhah, 2023), and Setyawan & Astuti (2021) developed CT-based calculus materials that proved valid and practical. However, their effectiveness for problem solving had not yet been tested. Although these studies point to the benefits of CT and have produced CT-based teaching materials, integrating CT into PBL to advance real-life problem solving remains limited, particularly when combined with 21st-century interdisciplinary themes.

To address these gaps, the present study develops a PBL-based worksheet that integrates CT and 21st-century interdisciplinary themes to support real-life problem solving. The study addresses two research questions (RQ): 1) What are the characteristics of the developed PBL worksheet? and 2) To what extent is the worksheet valid, practical, and effective for real-life problem solving? Based on the second research question, the implementation stage tested the hypothesis that students using the developed PBL worksheets would differ significantly in their real-life problem-solving skills from those using standard PBL worksheets.

■ **METHOD**

Research Design

This development study used the ADDIE model as a systematic framework for building PBL worksheets that integrate CT and 21st century interdisciplinary themes. The model is well suited for producing instructional aids (Branch, 2010; Idris & Rus, 2023). ADDIE is a product development paradigm built around five interrelated stages: Analyze, Design, Develop, Implement, and Evaluate. Each stage has its own purpose, procedures, and deliverables, and each feeds into the next, keeping the development process systematic and continuous (Aldoobie, 2015; Branch, 2010).

The study followed these five phases. The analyze stage involved examining the curriculum and the characteristics of the systems of linear inequalities in two variables material, alongside a literature review on PBL, CT, 21st century interdisciplinary themes, and real-life problem solving to establish the conceptual foundation for the worksheet. The design stage focused on drafting the worksheet, setting learning objectives, building PBL-based learning activities that integrate computational thinking and 21st century interdisciplinary themes, and developing the research instruments and assessment design. Following Branch (2010), this stage produced a design brief that guided the subsequent development process. In the development stage, the design was turned into a worksheet prototype. This involved writing the worksheet content, having it validated by experts, revising it formatively based on validator feedback, and running a limited trial until the worksheet was judged fit for use. Branch (2010) describes this stage as generating and validating learning resources, while Aldoobie (2015) emphasizes that it centers on producing the product, refining it through feedback, and testing it on a small scale before broader implementation. In the implementation stage, the experimental class used the worksheet, while the control class used a standard PBL worksheet. Data were collected at this stage through a real-life problem-solving test and observation of how the lesson was carried out. The final stage, evaluation, assessed the worksheet's quality based on implementation results through an effectiveness analysis, with final revisions made as needed. Branch (2010) notes that evaluation covers both product quality and the development process itself.

Participants

Participants were involved in the develop and implement stages. During development, three validators validated the worksheet prototype. It was then assessed by two teacher-users and

trialed on a limited scale with ten students to gather feedback on the clarity of the content, its presentation, and ease of use. During implement, two intact tenth-grade classes from a public senior high school in Central Java, Indonesia, took part in the study. The school had arranged the classes to maintain a relatively balanced distribution of students' academic abilities. To assess comparability before the intervention, the study used students' mathematics scores from the previous semester as an indicator of prior mathematics achievement. An independent-samples t-test showed no statistically significant difference in prior mathematics achievement between the two classes ($p = 0.628$). However, no pretest of real-life problem-solving performance was given, so the initial equivalence of the two classes on this specific outcome could not be statistically verified. One class, with 32 students, served as the experimental group and used the PBL worksheet integrating CT and 21st-century interdisciplinary themes. The other class, with 35 students, served as the control group and used a standard PBL worksheet. An observer was present throughout the implementation to monitor how the lessons were carried out. Before data collection, permission was obtained from the school and the mathematics teacher. At the beginning of the implementation, students were informed about the study, the learning activities, and the use of their data for research purposes.

Instruments

This study employs three primary instruments for data collection. First, an expert validation sheet assesses the worksheet's content suitability before field testing. This instrument comprises 16 statements covering five aspects: alignment of content with the curriculum, characteristics of PBL, integration of CT, didactic quality and thought processes, and language and presentation. The validation process involves three experts using a four-point Likert scale.

Second, practicality was assessed through questionnaires and classroom observation. The questionnaires captured teachers' and students' views of the worksheet, particularly its ease of use and suitability for learning. They consist of 18 statements covering five indicators: (1) ease of use, (2) implementation of PBL, (3) support for real-life problem solving, (4) support for computational thinking and 21st-century interdisciplinary themes, and (5) language and presentation. An implementation observation sheet was also used to examine how the planned learning activities were carried out in the classroom.

Third, a real-life problem-solving test was used to assess students' ability to solve a contextual mathematical problem. The test consists of one complex problem that requires students to identify relevant information and variables, construct a mathematical model, determine the solution region, test and select solutions that meet the given constraints, and interpret the result in relation to the problem context. Students' responses were scored using a rubric covering these five aspects. The test and its scoring rubric were reviewed by validators, resulting in an average Aiken's V coefficient of 0.84. Empirical item analysis was conducted using corrected item-total correlations. The coefficients for the five scoring aspects ranged from 0.313 to 0.686, all exceeding the 0.30 criterion recommended for adjusted item-total correlations (Boateng et al., 2018). The test showed acceptable internal consistency (standardized Cronbach's $\alpha = 0.715$), based on the > 0.70 criterion proposed by George and Mallery (2024).

Data Analysis

Data analysis was carried out to evaluate the validity, practicality, and effectiveness of the worksheet. Content validity was analyzed using the Content Validity Index (CVI) based on the assessments of three validators, following Yusoff

(2019). Practicality determined from teachers' assessments, student responses during the limited trial, and observations of lesson implementation.

The average scores obtained were then interpreted using practicality criteria adapted from Akbar (2016) as presented in Table 1.

Table 1. Practicality criteria

Average Score Interval	Category	Description
1.00–1.60	Not practical	Not suitable for use
1.61–2.20	Less practical	Not suitable for use
2.21–2.80	Moderately practical	Usable after major revision
2.81–3.40	Practical	Usable after minor revision
3.41–4.00	Highly Practical	Suitable for use

Students' responses were independently scored by two raters based on the five scoring aspects. Inter-rater reliability for each scoring aspect was assessed using a two-way mixed-effects intraclass correlation coefficient (ICC) with absolute agreement and single measures (Hallgren, 2012). When the two raters assigned different scores, the final score was determined through consensus. Effectiveness was analyzed using the Mann-Whitney U test to compare real-life problem-solving scores between the experimental and control classes at posttest, since the data were not normally distributed. Because this study used a posttest-only design, the comparison reflects differences in outcome scores following the intervention rather than within-group gains. The worksheet was also classified as effective if at least 80% of students in the experimental class reached the school's minimum passing score of 70 (Leton et al., 2025).

■ RESULT AND DISCUSSION

Characteristics of The PBL Worksheet Integrating CT and 21st Century Interdisciplinary Themes

The first characteristic of the developed worksheet lies in how CT is integrated into PBL. This worksheet treats CT as a thinking strategy

that supports students throughout each stage of PBL. CT is not, in other words, an added activity sitting on top of the lesson; it becomes part of the problem-solving process itself. This integration follows the PRADA framework proposed by Dong et al. (2019), comprising pattern recognition, abstraction, decomposition, and algorithm. CT integration is reflected in the activities students work through across the PBL phases. During orientation, students identify what they know and what they need to solve the problem, break the problem into smaller parts, and select relevant information. They then identify variables, assumptions, constraints, and relationships among the information to construct an initial mathematical model. During investigation, students look for patterns and relationships between variables and use them to develop a systematic solution. When presenting their work, they organize the solution into a logical sequence and interpret the mathematical results in relation to the original problem. In the final phase, students revisit their solution, identify parts that did not work, recognize recurring errors, and reflect on how to improve their strategy. These four components were mapped onto the five PBL syntax stages set out by Arends (2012), and this mapping is presented in Table 2.

Table 2. Mapping of CT integration into PBL syntax

PBL Syntax	CT components integrated			
	Pattern Recognition	Abstraction	Decomposition	Algorithm
Orient students to the problem	-	•	•	-

Organize students for study.	-	•	•	-
Assist independent and group investigation.	•	-	-	•
Develop and present artifacts and exhibits.	-	•	-	•
Analyze and evaluate the problem-solving process.	•	-	•	-

Note. • indicates the CT component integrated into each PBL phase

Table 2 shows that the four CT components are not spread evenly across the five PBL phases. Each phase draws mainly on the component whose cognitive demands match the phase's requirements. Decomposition and abstraction dominate the orientation and organization phases, where the task is to turn an unfamiliar situation into a workable mathematical form. At the same time, pattern recognition and algorithm construction come to the fore once students move into investigation and solution development. This selective, phase-specific mapping fits with the argument that CT develops best when embedded in the practice of a discipline itself, rather than taught as a separate, decontextualized skill (Weintrop et al., 2016). Put differently, the CT component assigned to a given phase is meant to carry out cognitive work the phase already demands, not to introduce an extra task alongside it. This fit is also supported by findings that PBL and CT pair naturally, since both center on the process of problem solving (Ye et al., 2023).

The second characteristic of the developed worksheet is its use of 21st century interdisciplinary themes as the basis for designing problem contexts, rather than as mere opening illustrations. This follows a pattern seen across various contexts of cross-disciplinary theme integration, from environmental issues (Mumu et al., 2021), financial literacy (Sole, 2021), global citizenship (Rim et al., 2025), to cross-subject STEAM projects (Bairy & Inamdar, 2026), all reported to strengthen the authenticity and

relevance of mathematics learning contexts. The same principle is applied here through contexts involving clean water management, financial calculations, a healthy canteen business, and disaster relief logistics distribution.

One example of the contextual problems used in the worksheet is clean water management at school (Figure 1a). Students work with water-use constraints and develop a mathematical model to support decision-making rather than simply calculate a final answer. This environmental context connects mathematical problem solving with a real issue that students may encounter in everyday life (Mumu et al., 2021). The worksheet also varies the level of guidance provided across sections. In the earlier section, key information is explicitly presented to support decomposition (Figure 1b), while a later section asks students to identify the relevant information themselves (Figure 1c). Teaching modules can provide structured guidance and assessment tools to support the learning process (Ajid et al., 2025).

Choosing this kind of context shows that the problems presented go beyond conventional word problems. Instead, they require students to understand a situation, identify its constraints, build a model, and interpret results within the context of real decision-making, which are the defining features of real-life problem solving. The same principle carries through the other contexts in the worksheet, so that mathematics is consistently positioned not as a stand-alone discipline, but as a tool for analyzing and resolving

AYO PAHAM! MASALAH!

Perhatikan lingkungan sekolahmu dalam kehidupan sehari-hari.

Sekolah menggunakan air bersih untuk berbagai keperluan, seperti:

- kegiatan belajar di kelas dan laboratorium
- aktivitas di kantin sekolah
- kebersihan lingkungan (toilet, cuci tangan, penyiraman tanaman, dan lain-lain)

Translate:
Let's Understand the Problem!

Observe your school environment in daily life. The school uses clean water for various purposes, such as:

- *Learning activities in classrooms and laboratories*
- *Activities in the school canteen*
- *Environmental cleanliness (toilets, handwashing, watering plants, etc.)*

1a. Contextual problem presented in the worksheet

AYO MENDEKOMPOSISI SITUASI!

Dari kasus penggunaan air bersih di sekolah, perhatikan dua kalimat berikut:

- 1** Total penggunaan air per hari untuk kebersihan dan untuk kegiatan belajar tidak boleh melebihi 2000 liter.
- 2** Penggunaan air untuk kebersihan tidak boleh lebih sedikit daripada penggunaan air untuk kegiatan belajar.

AYO MENDEKOMPOSISI SITUASI!

Berdasarkan uraian kasus Misi kemanusiaan, kamu perlu mengidentifikasi ketentuan dan informasi penting yang harus diperhatikan sebelum menyusun rencana pengiriman bantuan. Tuliskan informasi penting pada kolom berikut!

1b. Guided decomposition activity (Section 1) 1c. Less-guided decomposition activity (Section 2)

Figure 1. Selected pages from the developed PBL worksheet

cross-disciplinary problems in a logical, responsible way.

The third characteristic of the developed worksheet is how its learning activities are structured to systematically guide students through the full process of real-life problem solving. Miftah and Setyaningsih (2022) similarly incorporated activity and problem sections into their mathematics worksheet. This structure follows Polya's (2004) problem-solving framework: understand the problem, devise a plan, carry out the plan, and look back. A systematic review of PBL studies in K-12 mathematics found that

staged frameworks like this remain the most widely adopted approach in the field, with four-stage and five-stage versions (the latter including an explicit evaluation or reflection stage) standing out as the two most common variants (Ayari et al., 2025). This structure is not a standalone feature. It is simply another lens on the same PBL syntax already mapped to CT components in Table 2. The systematic activity design behind this third characteristic, then, doubles as the operational vehicle for the CT integration described under the first characteristic, rather than two separate design features.

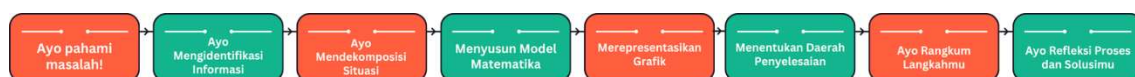


Figure 2. Sequence of learning activities in the worksheet toward real-life problem solving

This staged approach unfolds across the sequence of activities in each worksheet (Figure 2), where students understand the situation, identify key information, build a mathematical

model, represent it graphically, determine the solution region, and then revisit their solution steps as a form of reflection. A reflection activity at the end of the problem-solving process allows

students to revisit their solution and consider the strategies they used. This feature aligns with Kholid et al. (2026), who highlighted reflective worksheets and guided questioning as ways to support students' reflection during mathematical problem solving.

The resulting activity design gives students a complete learning experience, from making sense of a real situation to producing a mathematically justified solution. This integration reinforces the worksheet's underlying goal of helping students build real-life problem-solving ability through a systematic, contextual, and reflective thinking process.

Validity of the Developed Worksheet

At this stage, the product validation process was conducted to ensure that the developed worksheet aligned with the characteristics of PBL, CT, and 21st-century interdisciplinary themes. The worksheet was validated by three experts. The validation scores were analyzed using the CVI to determine the product's validity.

The content validity of the developed worksheet was evaluated using the CVI, including the item-level Content Validity Index (I-CVI) and the scale-level CVI based on the average method (S-CVI/Ave). All three expert validators rated every item as relevant (scores of 3 or 4). Thus, each of the 16 items had an I-CVI of 1.00, indicating complete agreement among the validators on each item's relevance. The S-CVI/Ave, calculated as the average of all I-CVI values, was also 1.00. The I-CVI indicated the relevance of individual items, while the S-CVI/Ave summarized the worksheet's overall content validity.

The validation results showed that the worksheet met the predefined criteria for content and curriculum suitability, PBL characteristics, integration of CT, didactic quality and thinking processes, and language and presentation. This suggests that the content and learning activities

aligned with the worksheet's intended design. Contextual problems are particularly relevant in PBL worksheets, as meaningful contexts can help connect mathematical ideas with students' everyday experiences (Fairus et al., 2026).

Based on expert feedback, the draft worksheet was revised prior to pilot testing. The revisions mainly addressed aspects that received a rating of 3, particularly contextual relevance, scaffolding, alignment with students' thinking abilities, and readability. For example, a problem originally framed around an international humanitarian organization was revised to an Indonesian context to make it more familiar and contextually relevant to students. The level of scaffolding was also adjusted in several activities. In one activity, the values of $x = 0$ and $y = 0$ were initially provided to guide students in determining points for drawing a boundary line. These values were later removed, requiring students to determine the appropriate values themselves. Other revisions included simplifying the language and instructions and refining the visual presentation to improve clarity.

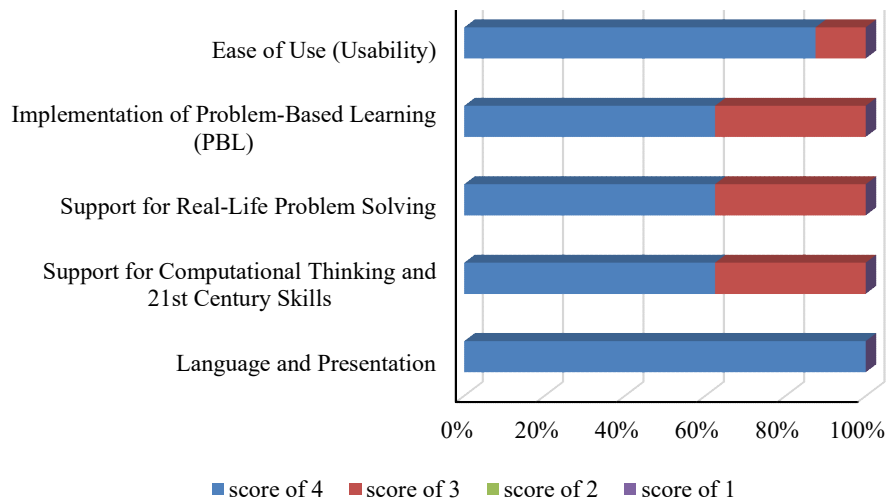
In addition to the quantitative evaluation, the expert validators provided several qualitative comments that informed worksheet refinement before implementation. These comments focused on four main areas: (1) strengthening the structure of students' argumentation, (2) clarifying the positioning and implementation of the PBL syntax, (3) accommodating learner diversity, and (4) incorporating a reflection component. Collectively, these comments reflected a coherent underlying theme. The unclear positioning of the PBL syntax, the limited structured guidance for developing students' argumentation, and the lack of scaffolding for slow learners point to challenges in the early stage of product development, particularly in translating the theoretical framework into an operational instructional design. In other words, although the worksheet's conceptual design was well established, its

practical implementation was not sufficiently explicit to effectively support students with diverse ability levels. Worksheets that are tailored to students' cognitive levels help in constructing and understanding lessons more effectively, leading to better learning outcomes (Muhdhar & Zahroh, 2021)

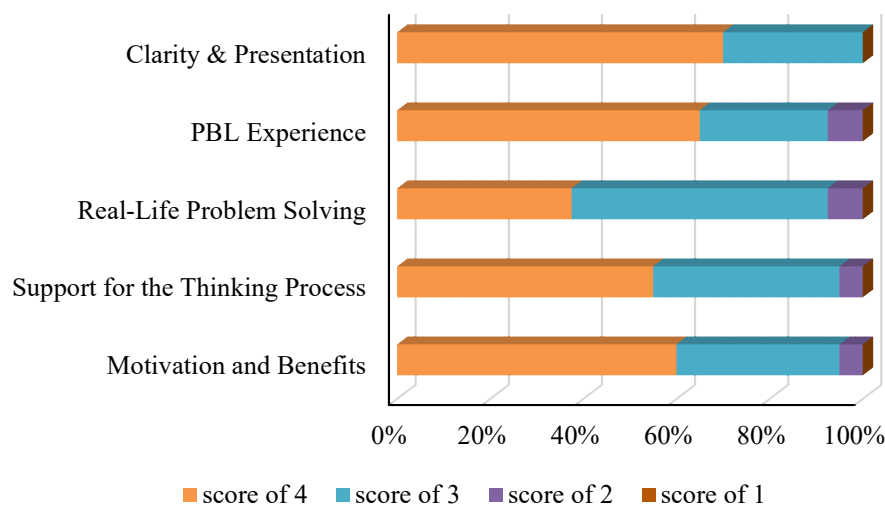
Practicality of the Developed Worksheet

The validated worksheet was implemented in classroom instruction. Students used the worksheet to develop their problem-solving skills. This stage also aimed to evaluate the

worksheet's practicality from both teachers' and students' perspectives. Feedback from teachers and students after implementing the worksheet was collected and analyzed to ensure the product was high quality and beneficial to students. In addition, the worksheet's readability during classroom implementation was assessed to inform further product refinement. The results of the analysis of teachers' responses to the developed worksheet are presented in Figure 3a. Teachers' responses were measured using an 18-item questionnaire covering five evaluation aspects.



(a) Teachers' practicality



(b) Students' practicality

Figure 3. Practicality assessment results: (a) teacher responses and (b) student responses

The results of the analysis of students' responses to the developed worksheet are presented in Figure 3b. Students' responses were measured using an 18-item questionnaire covering five evaluation aspects. The analysis results showed an overall mean score of 3.522, indicating that the developed worksheet was classified as highly practical. Across the five evaluation indicators, four were categorized as highly practical: Clarity and Presentation (mean = 3.70), PBL Experience (mean = 3.575), Support for the Thinking Process (mean = 3.50), and Motivation and Benefits (mean = 3.55). Meanwhile, the Real-Life Problem Solving indicator had a mean score of 3.30, which fell into the practical category, one level below the other four indicators. Within the Real-Life Problem Solving indicator, Item 11 received the lowest mean score among all 18 questionnaire items (3.1), followed by Items 10 and 12, each with a mean score of 3.2. Overall, these findings indicate that the developed worksheet demonstrated a high level of practicality from the students' perspective, with all indicators falling within the practical to highly practical categories.

The practicality evaluation conducted by teachers (mean score = 3.72 out of 4, categorized as highly practical) and students (mean score = 3.52 out of 4, categorized as highly practical) indicates that the developed worksheet is feasible for use under authentic classroom conditions. More specifically, both teachers and students rated the worksheet as practical to highly practical across all evaluation indicators. These findings suggest that, from the teachers' perspective, the worksheet is easy to implement and can be carried out as intended in actual classroom practice. This ease of implementation likely stems from the worksheet's structure, which explicitly labels each stage of the PBL process. The consistent organization of these stages likely reduces teachers' instructional management demands at the beginning of each learning

session, as they can readily align student activities with the PBL syntax without requiring additional interpretation during instruction. Furthermore, teachers perceived that the worksheet effectively supported real-life problem solving, CT, and 21st-century themes.

From the students' perspective, the worksheet was perceived as user-friendly, well organized, and cognitively manageable during learning activities. Its design, which provides separate response spaces for each problem-solving step, including information identification, situation decomposition, coordinate-point tables, graph construction, and final summarization, encourages students to externalize their thinking processes gradually and systematically rather than focusing immediately on obtaining the final answer. Visually engaging and well-structured worksheets can increase student motivation and participation in learning activities (Fauziah & Nurita, 2019).

Effectiveness on Learning Outcomes

At this stage, an effectiveness test was conducted to evaluate the impact of integrating CT dan 21st century interdisciplinary themes into the PBL worksheet on supporting students' problem-solving. The ICC values for the five scoring aspects ranged from 0.841 to 0.893, indicating good inter-rater reliability (Koo & Li, 2016). Before testing for differences, we conducted a Shapiro-Wilk normality test on the posttest scores of both groups. The results indicated that the data for the experimental group (statistic = 0.797; $p < 0.001$) and the control group (statistic = 0.936; $p = 0.043$) were not normally distributed. Based on these results, the analysis proceeded using the non-parametric Mann-Whitney U test.

As shown in Table 3, the Mann-Whitney U test showed a statistically significant difference between the experimental and control groups ($Z = -4.910$, $p < 0.001$). The effect size was calculated from the standardized test statistic

following Rosenthal (1991), yielding $r = 0.60$, which Cohen (1988) classifies as a large effect. This result indicates that students in the experimental group demonstrated substantially higher problem-solving skills than those in the control group. Furthermore, 81.25% of students in the experimental group achieved the minimum

passing score, indicating that the majority attained the expected level of problem-solving skills. The experimental group achieved a mean problem-solving score of 82.63, whereas the control group obtained a mean score of 62.51. The distribution of the posttest results is presented in Figure 4.

Table 3. Mann–Whitney U test results

Comparison	Mann-Whitney U	Z	p	Effect size (r)
Experimental vs. control group	173.00	-4.91	< .001	0.60

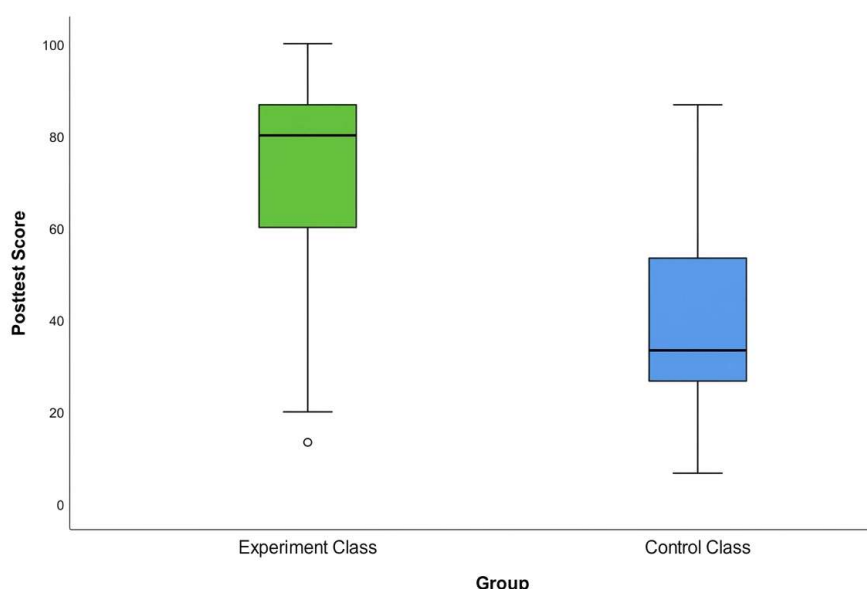


Figure 4. Distribution of post-test scores for students' problem-solving skills in the experimental and control groups

The experimental group had a median score of 88, with an interquartile range (Q1-Q3) of 76-92, whereas the control group had a median of 60 and an interquartile range of 56-72. One lower outlier, with a score of 48, was observed in the experimental group, while no outliers were observed in the control group. These distributions are consistent with the Mann-Whitney U test results, which showed significantly higher problem-solving performance in the experimental group.

The second criterion was analyzed descriptively based on the percentage of students in the experimental group who achieved the

minimum passing score. The results showed that 26 out of 32 students (81.25%) achieved or exceeded the mastery criterion, whereas 6 students (18.75%) did not. This percentage exceeded the 80% effectiveness threshold, indicating that the second criterion was also met. Meanwhile, the control class reached only 22.86% mastery. Based on these two criteria, the developed worksheet was considered effective in supporting students' problem-solving skills.

This achievement can be explained by the structural alignment between the PBL stages adapted from Arends (2012) and the CT

components integrated into the worksheet. During the initial stage, the worksheet guides students to break down complex problems into smaller, more manageable parts before proceeding to subsequent solution steps. This helps students organize the information and relationships in the problem and focus on what to address first (Kumar & Mohd, 2024). Lehmann (2025) reported a similar pattern, finding that students used decomposition mainly during the analysis/plan stage of mathematical problem solving, particularly to break the problem into subgoals.

Effective worksheets are aligned with students' cognitive development by using approaches such as cognitive apprenticeship, higher-order thinking skills, and scaffolding. This ensures that activities are neither too easy nor too difficult, promoting optimal learning and cognitive growth (Oktaviyanti & Dahlan, 2018). Studies show that embedding CT in curricula, especially in STEM and mathematics, improves problem-solving skills and academic achievement (Fuzy & Yahaya, 2024; Kayyis et al., 2025). Az'zahra and Toyib (2026) reported higher mathematical problem-solving scores for students taught through Discovery Learning with an ethnomathematics-integrated worksheet than for those taught through Discovery Learning without ethnomathematics integration.

■ CONCLUSION

This study developed a PBL worksheet integrating CT and 21st century interdisciplinary themes to support real-life problem solving. Its main characteristics include CT integrated into every PBL syntax stage, 21st century interdisciplinary themes used as the basis for authentic problem contexts, and learning activities structured to systematically guide students through the real-life problem-solving process. Evaluation results show that the worksheet met the criteria for validity based on expert assessment, practicality based on teacher and student

responses along with lesson implementation, and effectiveness, demonstrated by students in the class using this worksheet outperforming those in a standard PBL class on real-life problem-solving ability, and at least 80% of students reaching the mastery threshold. The developed worksheet is therefore a viable alternative teaching material for mathematics, supporting instruction that is more contextual and oriented toward solving real-life problems. In practice, teachers can gradually integrate CT into PBL activities by guiding students to break down problems, identify relevant information, recognize patterns or relationships, and develop steps toward a solution. Problems can also draw on 21st-century interdisciplinary themes while using contexts that are relevant to students. The level of guidance in the worksheet should be adjusted to students' needs, providing sufficient support while still allowing them to develop their own solution strategies.

Several limitations should be considered when interpreting these findings. The absence of a pretest meant that the groups' initial real-life problem-solving performance could not be statistically compared. In addition, the assessment relied on a single complex task, limiting the range of problem contexts represented in the test.

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■ AI DECLARATION

This manuscript was proofread and translated using Claude (Anthropic) for language editing, translation, and clarity improvement. All content was reviewed, verified, and edited by the author(s), who take full responsibility for the accuracy and integrity of the final manuscript.

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