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AI-Assisted Computational Thinking-Based Digital Worksheet in the Context of Deforestation to Improve Students' Mathematical Problem-Solving Skills

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Abstract

This development research aimed to design an Artificial Intelligence (AI)-assisted, Computational Thinking (CT)-based digital worksheet on the Two-Variable Linear Equation System (SPLDV) topic within a deforestation context, and to examine its validity, practicality, and effectiveness in supporting students' mathematical problem-solving skills. Although CT-based worksheets, AI-assisted learning, and environmental contexts have been studied separately, few studies have integrated these three components simultaneously in SPLDV learning; this study addresses that gap. Using the Design Research–Development Studies approach (preliminary research, prototyping, and assessment phases), the study involved grade VIII students of SMP IT Indo Global Mandiri Palembang, selected through purposive sampling (3 students in the one-to-one trial, 6 in the small-group trial, and 20 in the field test). Data were collected through observation, interviews, questionnaires, and tests, then analyzed descriptively and using the Normalized Gain (N-Gain) test and a paired-sample t-test. The digital worksheet was categorized as very valid (95.55%) and very practical (89.7%). Students' average problem-solving score increased from 42.44 to 76.06 (N-Gain = 0.60, medium category; $t = 11.13$, $p < 0.001$). Within the scope of this single-school trial, the AI-assisted CT-based digital worksheet shows promise as a contextual mathematics teaching material.

Keywords: Digital worksheet; Computational thinking; Artificial intelligence; Deforestation; Mathematical problem-solving

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INTRODUCTION

Mathematics education in Indonesia continues to face the challenge of low critical thinking and mathematical problem-solving skills among students (Sukendra & Sumandya, 2020). Several studies report that students struggle to understand mathematical concepts and to design problem-solving strategies (Utami et al., 2021; Rokhmatillah et al., 2021), a difficulty largely triggered by the abstract nature of mathematics and by the scarcity of learning media that connect mathematics with real-life contexts (Gustin et al., 2020). This condition is compounded by limited innovation in learning methods and weak integration of mathematical material with everyday reality (Maryam & Fauzi, 2024; Istofany et al., 2024), thereby necessitating a more effective learning approach to strengthen students' problem-solving skills (Susanto et al., 2023). Computational Thinking (CT), comprising decomposition, pattern recognition, abstraction, and algorithmic thinking, is regarded as a means of equipping students with a systematic and rational way of solving problems (Ramadoni et al., 2024; Wing, 2006), including contextual problems (Evendi, 2022). One topic that remains difficult for students yet is relevant for a CT-based approach is the Two-Variable Linear Equation System (SPLDV)

(Herdakospian et al., 2024), because solving SPLDV problems requires the ability to translate real situations into mathematical models (Rahmad & Wijaya, 2020). The scarcity of learning media that present SPLDV contextually is one contributing factor to students' low understanding of this topic (Nasution et al., 2023).

Digital worksheets have emerged as one instructional innovation capable of delivering interactive, flexible, and contextual learning (Nuniati et al., 2021; Filjinan et al., 2022), while also helping teachers monitor students' progress in real time (Agustinawati et al., 2024). However, most existing digital worksheets have not integrated Artificial Intelligence (AI), even though AI can provide automated assessment and adaptive feedback (Koe et al., 2025) as well as more personalized learning assistance (Pratiwi & Silalahi, 2021; Fahrudin et al., 2024); ethical challenges related to data use and teachers' technology literacy remain obstacles to its wider adoption (Qomaruzzaman, 2024). Without AI support, students who struggle at the more demanding stages of CT, particularly abstraction and algorithmic thinking, often do not receive timely, individualized feedback, which limits the extent to which a worksheet alone can scaffold their problem-solving process. At the same time, students' low mathematical problem-solving ability is also linked to the lack of meaningful context in the problems they are given (Zulkarnain et al., 2021). Environmental issues such as deforestation are rarely used as a context for mathematics learning, even though their impact on ecosystems makes them highly relevant for introducing authentic problems to students (Giljum et al., 2022). Deforestation is particularly suitable for SPLDV because comparisons between two related quantities, for example, the area of forest lost versus the area replanted, or the cost of two different reforestation schemes, can naturally be represented as two linear relationships that must be solved simultaneously, giving students an authentic modeling task rather than an abstract exercise. Embedding SPLDV in this context can therefore help students see the relationship between mathematical concepts and real problems in their environment (Zulkarnain et al., 2021).

Previous studies have examined the application of CT to a range of mathematical topics, such as linear equations (Otten et al., 2020), social arithmetic (Syafruddin et al., 2022), trigonometry (Sholihah & Firdaus, 2023), and curved-side space (Sarman et al., 2023), as well as deforestation in the context of environmental conservation (Itfan, 2023) and the spatial modeling of deforestation (Batjoli et al., 2025). Other studies have developed CT-based worksheets or e-worksheets (Salwadila & Hapizah, 2024; Azma et al., 2024; Mubharokh et al., 2023; Ostian et al., 2023; Septiana et al., 2024). However, CT-based worksheets, AI-assisted learning, and environmental contexts have generally been examined separately, and studies that integrate these three components simultaneously, particularly within SPLDV learning, remain limited. Most existing CT-based worksheets also provide a fixed sequence of CT-oriented tasks without adaptive support, so that students who struggle at the abstraction or algorithmic-thinking stage receive the same generic prompts as students who do not experience such difficulty. This is the specific limitation that the present study seeks to address: rather than treating CT, AI, and the deforestation context merely as three themes combined, this study positions AI as adaptive scaffolding at the CT stages that are empirically the most difficult for students, while the deforestation context supplies an authentic situation for mathematical modeling that gives meaning to the CT process.

Based on these gaps, this study aims to develop an AI-assisted, Computational Thinking-based digital worksheet on SPLDV material in the context of deforestation and to describe its validity, practicality, and effectiveness in supporting students' mathematical problem-solving skills. The pedagogical novelty of this study lies not only in combining CT, AI, and the deforestation context, but specifically in (1) using AI as adaptive scaffolding at the CT stages that prior studies indicate are most challenging for students, and (2) using deforestation as an authentic two-variable modeling context for SPLDV. This combination is expected to offer an innovative option for contextual mathematics learning in the 21st century while supporting the achievement of the Sustainable Development Goals (SDGs). The scope of this study is limited to grade VIII students of one junior high school and to the SPLDV topic; the findings are intended to demonstrate the feasibility of the developed worksheet within this scope rather than to be generalized beyond it.

METHOD

This study employed a Research and Development (R&D) approach using the Design Research model with a Development Studies approach (Bakker & Korthagen, 2019). This approach was selected because it emphasizes the systematic design, evaluation, and refinement of educational products through iterative formative evaluation before broader implementation. Unlike conventional experimental research, which primarily examines the effectiveness of an intervention, Development Studies focuses on producing educational products that are theoretically grounded, practically applicable, and empirically effective through continuous evidence-based revisions. This approach was considered appropriate because the objective of the study was to develop a Computational Thinking (CT)-based digital worksheet assisted by Artificial Intelligence (AI) for learning Systems of Linear Equations in Two Variables (SPLDV) within the context of deforestation. The integration of CT principles, AI-assisted learning, and contextual mathematical problems required a systematic development process to ensure that the resulting digital worksheet was pedagogically sound, technologically functional, and aligned with curriculum requirements. The overall research design is presented in Figure 1.

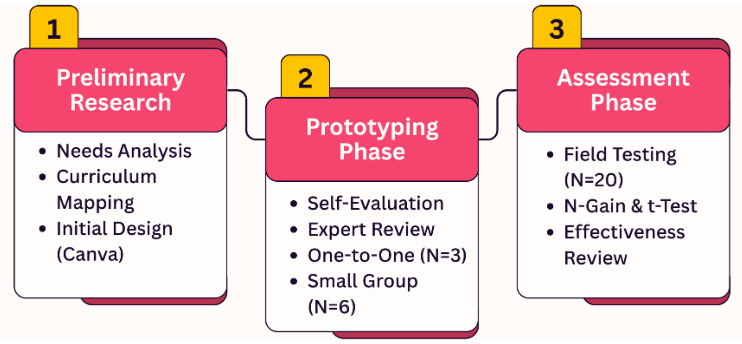

Figure 1. Product development and formative evaluation sequence.

As illustrated in Figure 1, the study comprised three interconnected phases: preliminary research, prototyping phase, and assessment phase. These phases enabled the product to be progressively refined from an initial design into a validated instructional resource through successive cycles of formative evaluation. Throughout the study, both qualitative and quantitative data were collected to evaluate the developed product comprehensively. Qualitative data were obtained from observations, interviews, and expert reviews to support product refinement, whereas quantitative data were derived from validation instruments, practicality questionnaires, and students' learning outcomes to determine the validity, practicality, and effectiveness of the developed digital worksheet.

The research subjects were Year 8 students at SMP IT Indo Global Mandiri Palembang who had completed the SPLDV material. They were selected using a purposive sampling technique based on teacher recommendations in order to represent students with low, medium, and high mathematical ability. The trial was carried out in three stages: Three students participated in the one-to-one stage, six students participated in the small-group stage, and one class of twenty students participated in the field-test stage. In line with common practice for formative evaluation in development research, a small group of three students was used in the one-to-one stage to identify major usability issues. A slightly larger group of six students was used in the small-group stage to test the revised product. Finally, a full class was used in the field test to evaluate the product under realistic classroom conditions. The research was conducted offline during the second semester of the 2025/26 academic year.

The research instruments included observation sheets, semi-structured interview guidelines, validity and practicality questionnaires using a 1–4 Likert scale, and a Computational Thinking ability test consisting of 2 essay items, administered as a pre-test and a post-test. The validity questionnaire assessed content, construction, and language aspects, rated by material, media, and language experts and prepared based on principles of educational instrument validation (Tate et al., 2023), while the practicality questionnaire assessed ease of use, readability, engagement, interactivity, time efficiency, and material suitability. The indicators of mathematical problem-solving ability, mapped to the four CT stages, are presented in Table 1; each of the 2 test items required students to apply all four indicators (understanding the problem, solution planning, and implementation and verification of the solution) to a deforestation-related SPLDV scenario, and student responses were scored using a rubric covering these indicators.

Table 1. Indicators of Problem-Solving and Stages of Computational Thinking

Problem-Solving Indicator	Description	CT Stage
Understanding the problem	Identifying known/asked information in the deforestation context.	Decomposition
Understanding the problem	Finding the relationship/pattern of the given equation.	Pattern Recognition
Solution planning	Simplifying information and modeling the problem into SPLDV form.	Abstraction
Implementation & verification of the solution	Systematically arranging the SPLDV solution steps and checking the correctness of the results.	Algorithm

The AI feature embedded in the digital worksheet used ChatGPT as the underlying platform. Rather than being available on every page, the AI icon/link was placed specifically at the Algorithmic Thinking step of each activity, the point at which students had already worked through decomposition, pattern recognition, and abstraction and were formulating their final solution (see Figure 2), so that AI assistance was concentrated at the CT stage found to be most challenging. After attempting the problem independently, students could consult ChatGPT to check their reasoning: they compared the answer they had already written on the worksheet with the answer generated by ChatGPT and used any discrepancy as a prompt to re-examine their own solution steps. This compare-and-recheck procedure served as the primary control on AI accuracy in this study: ChatGPT's response was never accepted as automatically correct, but was treated as a second opinion to be verified against the student's own step-by-step work and, where discrepancies arose, discussed with the teacher during the session. Regarding data privacy, students interacted with ChatGPT using only the mathematics problem text from the worksheet; no personal or identifying student information was entered into the AI platform.

Table 2. Scoring Rubric for the Computational Thinking Problem-Solving Test

CT Indicator	Score 4	Score 3	Score 2	Score 1	Score 0
Decomposition	Variables written and explained clearly, completely, and accurately.	Nearly complete and accurate	Less clear, only partly accurate	Written but unclear/inaccura te	No answer
Pattern Recognition	Equation written clearly, completely, and correctly.	Nearly complete and correct	Less clear, only partly correct	Written but unclear/incorrect	No answer

CT Indicator	Score 4	Score 3	Score 2	Score 1	Score 0
Abstraction	Equation simplified clearly, completely, and correctly.	Nearly complete and correct	Less clear, only partly correct	Written but unclear/incorrect	No answer
Algorithm	Solution steps written clearly, completely, correctly, and systematically.	Nearly complete, correct, and systematic	Less clear, only partly correct	Written but unclear/incorrect	No answer

Each of the 2 test items was scored using this rubric with a weighted maximum of 5 points for decomposition, 10 points for pattern recognition, 5 points for abstraction, and 30 points for the algorithm indicator, for a maximum of 50 points per item and 100 points for the full test (2 items); this weighting reflects the greater cognitive demand of the algorithmic solution step relative to the other three indicators. A worked answer key specifying the expected equations and solution steps for each item was prepared in advance and used as the basis for scoring.

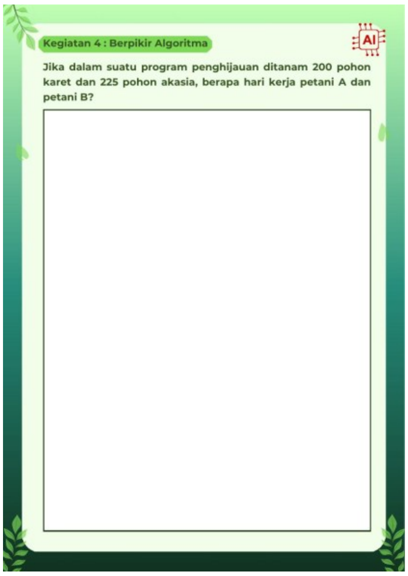

Figure 2. Example worksheet activity page Algorithmic Thinking stage showing the AI icon that links students to ChatGPT

The internal-consistency reliability of the practicality questionnaire, estimated using Cronbach's Alpha on the six aspect scores obtained from the 6 respondents in the small-group trial, was 0.86, indicating good reliability. For the content-validity questionnaire, the two content experts' ratings across the 13 content items showed a Pearson correlation of .64 ($p = .02$) and a corresponding two-rater Cronbach's Alpha of .77, indicating an acceptable to good level of agreement between the two validators.

Observation and interview data were analyzed descriptively and qualitatively to strengthen and enrich the results of the questionnaire (Handika et al., 2025; Sarman et al., 2023). The validity and practicality questionnaire data were analyzed by calculating the percentage of the obtained score against the maximum possible score, then categorized as presented in Table 3.

Table 3. Product Validity and Practicality Categories

Percentage (%)	Validity Category	Practivality Category
81 - 100	Highly Valid	Very Practical
61 – 80	Valid	Practical

Percentage (%)	Validity Category	Practivality Category
41 - 60	Quite Valid	Quite Practical
21 - 40	Less Valid	Less Practical
0 - 20	Invalid	Impractical

(Milenia et al. (2022)

Test data were analyzed through the calculation of the percentage score of problem-solving ability, the Normalized Gain (N-Gain) test to measure the improvement in students' ability before and after using the digital worksheet, and the paired-sample t-test to test the significance of the difference between the pre-test and post-test at a significance level of 0.05. Before the paired-sample t-test, the normality of the pre-test–post-test difference scores was examined using the Shapiro-Wilk test as a prerequisite for the parametric test. In addition to statistical significance, the effect size (Cohen's dz) was calculated to indicate the practical significance of the improvement in problem-solving scores. The digital worksheet was considered effective if the average N-Gain value fell into the medium or high category and/or a significant difference was found between the pre-test and post-test.

RESULTS AND DISCUSSION

This research produced a digital worksheet based on Computational Thinking (CT) and assisted by Artificial Intelligence (AI) on SPLDV material in the context of deforestation, developed on the Canva platform through the preliminary research, prototyping, and assessment phases. The needs analysis in the preliminary research stage showed that SPLDV learning was still dominated by conventional lecture methods and worksheets that had not integrated CT or AI, so that students had difficulty understanding contextual problems and connecting mathematics with real life. These findings confirm the urgency of developing more contextual and interactive teaching materials, consistent with studies reporting similar barriers to understanding SPLDV (Agustina et al., 2022; Nasution, 2021). Based on these findings and the analysis of the Learning Outcomes and Learning Objectives Flow of Phase D, an initial design of the digital worksheet was prepared that combines the deforestation context with the four CT stages (decomposition, pattern recognition, abstraction, and algorithmic thinking) and AI features as a means of feedback.

Validity of the Digital Worksheet

Expert review by material, media, and language experts showed that the developed digital worksheet fell into the very valid category, with an average validity percentage of 95.55%, as shown in Table 4.

Table 4. Average Expert Validation Results.

Aspects	Assessment Criteria	Percentage (%)
Contents	Suitability of the material to learning objectives, CT indicators, deforestation context, and AI integration.	94.23
Media/Construct	Display, navigation, readability, and ease of use of the digital worksheet.	93.75
Language	Clarity, accuracy, and appropriateness of language use.	100
Overall average		95.55 (Very Valid)

The highest percentage was obtained for the language aspect (100%), followed by the content aspect (94.23%) and the media/construct aspect (93.75%). The high validity of the language aspect indicates that the wording of the questions and instructions in the worksheet was communicative and consistent with Indonesian language conventions, while the validity of the content aspect indicates the compatibility between the deforestation problem, the CT stages, and the AI integration with the SPLDV learning objectives. Nevertheless, the validators provided several inputs, including strengthening the illustrations of the deforestation context, adjusting colors and layout, sharpening the instructions at each CT stage, and using the term "mathematical model" more consistently. These inputs were addressed through revision before the digital worksheet was piloted at the one-to-one stage. This high validity is consistent with Husna et al. (2022), who found that digital worksheets with a structured learning approach can produce valid teaching materials that support mathematical problem-solving skills, and with Istiqomah et al. (2021), who emphasized that a clear activity structure in electronic worksheets helps students follow the learning process systematically.

Practicality of the Digital Worksheet

In the one-to-one stage, students responded positively to the attractiveness of the display and the ease of use of the digital worksheet, although some difficulty was found in understanding the instructions for the CT stages and in accessing the AI features; both issues were subsequently improved. The practicality test at the small-group stage showed an average percentage of 89.7%, in the very practical category, as shown in Table 5.

Table 5. Practical Results of Digital Worksheet at the Small Group Stage

Aspects	Percentage (%)	Category
Ease of use	89.6	Very Practical
Time and means suitability	89.6	Very Practical
Implementation in learning	91.7	Very Practical
Use of context	88.9	Very Practical
Support for students	85.4	Very Practical
Affordability	95.8	Very Practical
Average	89.7	Very Practical

The affordability aspect obtained the highest percentage (95.8%), while support for students obtained the lowest percentage, although it remained in the very practical category (85.4%). Students reported that an introductory video on deforestation helped them understand the problem, and that the AI feature helped them when they had difficulty solving problems. These findings reinforce Nabilla et al. (2022), who found that interactive e-worksheets can support mathematics learning through a more active and flexible learning experience.

To illustrate how students carried out the decomposition and pattern-recognition stages, an excerpt from a semi-structured interview with a field-test participant (initials NSS) is presented below. When asked what information she looked for first when reading the problem, NSS explained: "I looked first at what was known in the problem, such as the number of trees to be planted and the target number of trees to be reached." When asked how she determined the variables, she stated: "I set the number of working days for Farmer A as x and for Farmer B as y ... so that it would be easier to write the information from the problem into mathematical form." Regarding the pattern-recognition stage, NSS explained that she related the daily planting rate to the overall target to form the equation, and that she simplified the resulting equation "so it would be easier to calculate using substitution," noting that the value of the equation stayed the same, "only the form was made simpler." This account illustrates that, for this student, decomposition and pattern recognition were carried out as clear, sequential steps, consistent with the comparatively higher percentages obtained for these two indicators in Table 6.

The Effectiveness of the Digital Worksheet on Mathematical Problem-Solving Ability

At the field-test stage, students' Computational Thinking abilities, representing their mathematical problem-solving skills, increased after learning with the digital worksheet. Before the intervention, 35% of students were in the very poor category, 25% were in the poor category, 25% were in the sufficient category, and 15% were in the good category. After the intervention, there were no students in the very poor and poor categories. As many as 60% were in the good category, 25% were in the sufficient category, and 15% were in the very good category. The CT achievement of students by indicator is presented in Table 6.

Table 6. Results of Students' Computational Thinking Indicators

Computational Thinking Indicator	Question 1 (%)	Question 2 (%)
Decomposition	95	87.5
Pattern Recognition	100	100
Abstraction	92.5	87.5
Algorithm	95	87.5

The pattern recognition indicator obtained the highest percentage (100% on both questions), indicating that students were able to relate the contextual information on deforestation to the SPLDV mathematical model. In contrast, the abstraction and algorithmic-thinking indicators obtained relatively lower percentages (87.5%–92.5%), suggesting that some students still needed guidance in simplifying mathematical models and in systematically arranging the solution steps. This pattern suggests that identifying a relationship between given quantities is cognitively less demanding for students than generalizing that relationship into a mathematical structure (abstraction) or sequencing a complete solution procedure (algorithmic thinking), because pattern recognition can often be accomplished through direct comparison of paired data, whereas abstraction and algorithmic thinking require students to generalize a rule and plan multiple sequential steps. This pattern of achievement is consistent with Abidi et al. (2023), who reported that students tend to be strong in decomposition but face more challenges in advanced pattern recognition and algorithmic thinking; in this study, the AI feature acted as scaffolding that provided feedback at both of these more demanding stages, a form of adaptive support that has not been widely provided in previous studies (Nasution et al., 2021).

Descriptively (Table 7), the average student score increased from 42.44 (pre-test) to 76.06 (post-test), while the standard deviation decreased from 21.52 to 11.34, indicating that the improvement occurred fairly evenly across students rather than being concentrated among high-ability students only.

Table 7. Descriptive Statistics

Statistics	Pre-test	Post-test
Number of students	20	20
Minimum score	2.5	55
Maximum value	80	100
Average	42.44	76.06
Standard deviation	21.52	11.34

Table 8. N-Gain, Paired Sample t-Test, Normality, and Effect Size Result

N-Gain	Category	Shapiro-Wilk (W, p)	t-count	Sig. (2-tailed)	Cohen's dz	Remarks
0.60	Medium	0.938, 0.218	11.13	<0.001	2.49 (large)	Significant

These results indicate that the AI-assisted, CT-based digital worksheet is associated with an improvement in students' mathematical problem-solving ability in SPLDV material within the context of deforestation. This improvement appears to be related to the way the four CT stages were operationalized as concrete learning activities rather than as structural labels. At the decomposition stage, the deforestation problems presented contained multiple pieces of information (land area, seed type, carbon absorption, planting cost), requiring students to sort the information before performing calculations; at the pattern recognition stage, paired data presented across sessions trained students to recognize the structure of the relationship before formulating the equation; at the abstraction stage, students practiced distinguishing essential information from narrative information; and at the algorithmic-thinking stage, students were directed to write down the solution steps explicitly before arriving at the final answer. This gradual learning pattern is consistent with the principle of CT as a strategy for breaking complex problems down into simpler solution structures (Cahdriyana & Richardo, 2020; Jamna et al., 2022; Septiana et al., 2024). Because this study used a one-group pre-test–post-test design without a comparison group, the observed improvement cannot be attributed solely to the AI-assisted CT-based digital worksheet; factors such as teacher guidance during implementation, repeated exposure to SPLDV problems, and a possible testing effect between the pre-test and post-test may also have contributed to the change in scores. Future studies using a control-group design are needed to isolate the specific contribution of the AI component.

The deforestation context appears to have made learning more meaningful by connecting SPLDV material with real issues in students' surroundings, consistent with Zulkarnain et al. (2021) and Sari and Anggapuspa (2021), who argued that environmental issues provide an authentic situation that demands analysis and problem-solving while increasing students' environmental awareness. AI integration, meanwhile, appears to have contributed through feedback and adaptive assistance, particularly at the abstraction and algorithmic-thinking stages that were empirically the most challenging for students, consistent with Awang et al. (2025) and Handayani and Rahmat (2023), who highlighted the role of AI in supporting more personalized and interactive mathematics learning without replacing students' own thinking processes (Bakti et al., 2023; Ahmad et al., 2021).

Compared with previous research applying CT to other mathematical materials, such as CT-based e-worksheets in arithmetic sequences and series (Azma et al., 2024), South Sumatran traditional games (Ostian et al., 2023), and students' CT ability in solving SPLDV problems (Husnani et al., 2025), this study extends prior work in three ways: applying all four CT stages completely and continuously within a single deforestation context, integrating AI as adaptive assistance specifically at the stages found to be most challenging, and providing empirical evidence of effectiveness through validity, practicality, and consistent learning-outcome data. This contribution responds to the gap in earlier research, which generally addressed only part of the CT sequence or did not make use of adaptive technology as a form of problem-solving support (Nasution et al., 2021).

Although the results show a significant improvement, several limitations should be noted. First, this study was conducted in a single school with one class of 20 students in the field-test phase, which limits the generalizability of the findings to other contexts, grade levels, or mathematical topics. Second, the one-group pre-test–post-test design without a comparison group means that the observed improvement cannot be attributed solely to the AI-assisted CT-based digital worksheet; teacher guidance, repeated testing, and students' prior exposure to SPLDV material may also have contributed. Third, the trial was implemented over a relatively short duration, so the durability of the improvement in problem-solving skills and its transfer to other topics remain unknown. Fourth, the accuracy of ChatGPT's responses was not independently verified by subject experts; students were guided to compare ChatGPT's answers with their own worked solutions, but this student-level check does not substitute for a formal accuracy audit of the AI's output. Future studies employing a control-group design, a longer intervention period, multiple schools, and an explicit expert audit of AI feedback accuracy are needed to strengthen these findings.

CONCLUSION

Within the scope of this study, the AI-assisted, Computational Thinking-based digital worksheet on SPLDV material in the context of deforestation was found to be valid (95.55%, very valid), practical (89.7%, very practical), and effective in supporting problem-solving skills, as shown by the increase in the average score from 42.44 to 76.06 (N-Gain = 0.60, medium category) and a significant difference between pre-test and post-test scores ($t = 11.13$; $p < 0.001$; Cohen's $dz = 2.49$, large effect). The four CT stages decomposition, pattern recognition, abstraction, and algorithmic thinking were functionally integrated with the deforestation context and supported by AI as a scaffolding feature, helping students move from understanding complex problems toward systematically determined solutions. These findings should be interpreted within the context of a single school, one class of 20 students, and a one-group pre-test–post-test design; they provide initial empirical evidence, rather than a generalizable conclusion, that integrating CT, AI, and an authentic environmental context can support contextual mathematics learning.

RECOMMENDATION

Mathematics teachers may consider using this digital worksheet as an alternative contextual and interactive teaching material for SPLDV, while continuing to guide students to use the AI feature as a support rather than a substitute for their own thinking. Future researchers are recommended to (1) compare AI-assisted CT-based worksheets with non-AI CT-based worksheets or conventional worksheets using a control-group design, to determine the specific contribution of the AI component; (2) extend this approach to other mathematics topics and environmental contexts; (3) broaden the scope of research subjects across multiple schools; and (4) develop AI features capable of providing more individualized feedback based on students' specific difficulties. The limited scope of the school setting and the short duration of the trial in this study should also be taken into account when replicating this approach at other levels or in other contexts.

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AUTHOR CONTRIBUTIONS STATEMENT

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Farah Nabilah Tampubolon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Hapizah	✓	✓		✓	✓					✓		✓		
Meryansumayeka	✓	✓		✓	✓					✓		✓		

CONFLICT OF INTEREST STATEMENT
The Authors state no conflict of interest.

INFORMED CONSENT
Research permission was obtained from SMP IT Indo Global Mandiri Palembang, and student participation in this study was voluntary.

ETHICAL APPROVAL
This research was conducted with permission from SMP IT Indo Global Mandiri Palembang and followed the school's standard procedures for classroom-based learning activities involving students.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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