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Integrating mathematical literacy and self-regulated learning through PBL-based linear programming worksheets for culinary vocational students

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ABSTRACT

Background: Culinary vocational education requires students to make various decisions related to menu planning, ingredient allocation, production scheduling, cost efficiency, and profit optimization. These decision-making processes involve quantitative reasoning and problem-solving skills that are closely associated with mathematical concepts, particularly linear programming. However, many vocational students struggle to connect abstract mathematical concepts with authentic culinary contexts. In addition, mathematical literacy and self-regulated learning remain significant challenges, as mathematics instruction is often dominated by teacher-centered approaches and lacks contextual relevance. Consequently, students tend to demonstrate limited engagement, inadequate problem-solving skills, and low levels of learning autonomy. Therefore, innovative learning media that integrate authentic culinary contexts with active learning approaches are needed to foster these essential 21st-century competencies.

Purpose: This study aims to develop problem-based learning (PBL) worksheets on linear programming that are valid, practical, and effective in enhancing mathematical literacy and self-regulated learning among culinary vocational high school students.

Method: This study employed a Research and Development (R&D) approach based on the ADDIE model, comprising five stages: Analysis, Design, Development, Implementation, and Evaluation. The participants were tenth-grade students enrolled in the culinary vocational program at SMK Negeri 6 Yogyakarta. Data were collected through observations, questionnaires, mathematical literacy tests, and self-regulated learning scales. The data were analyzed using descriptive statistics, paired-samples t-tests, and N-gain analysis to assess the effectiveness of the developed worksheets.

Findings: The findings revealed that the developed PBL-based worksheets met the validity and practicality criteria, as demonstrated by expert validation and positive student responses. Furthermore, the implementation of the worksheets significantly improved students' mathematical literacy and self-regulated learning, as evidenced by the paired-samples t-test results ($p < 0.05$) and moderate N-gain scores. These findings suggest that contextualized, problem-based worksheets can promote more meaningful and self-directed mathematics learning among culinary vocational students.

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INTRODUCTION

In the 21st century, mathematical literacy has become one of the essential competencies that students need in order to solve problems, make decisions, and apply mathematical concepts in real-life situations (Sujatha & Vinayakan, 2022). Mathematical literacy refers to an individual's ability to formulate, employ, and interpret mathematics in various contexts using mathematical reasoning, concepts, procedures, and facts (OECD, 2018). This competence is closely related to students' ability to think critically, communicate ideas, and solve contextual problems effectively. Alongside cognitive competence, self-regulated learning also plays an important role in supporting students' academic achievement (Arigiyati et al., 2023; Zimmerman, 1990). Self-regulated learning enables students to manage their learning process independently, including planning, monitoring, and evaluating their own learning activities (Zumbrunn et al., 2011). Therefore, both mathematical literacy and self-regulated learning are considered important competencies that should be developed in mathematics education.

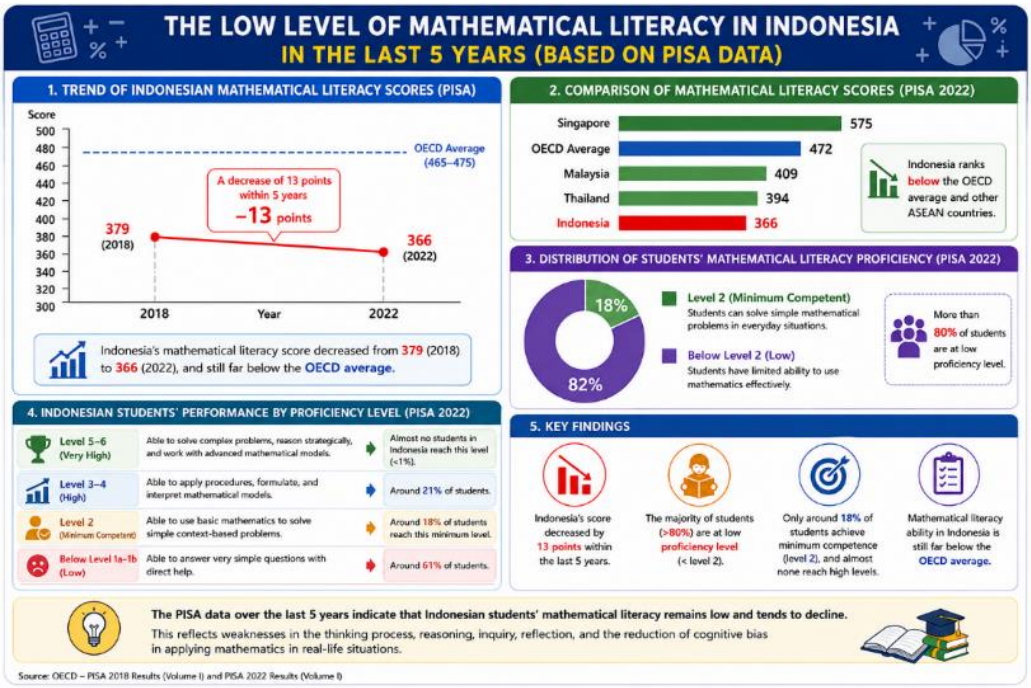
However, the reality in schools indicates that these competencies remain relatively low. Indonesia's achievement in the Programme for International Student Assessment (PISA) still shows unsatisfactory results in mathematical literacy, where Indonesian students consistently perform below the OECD average. Figure 1 shows that Indonesia's mathematical literacy score declined from 379 in 2018 to 366 in 2022, remaining far below the OECD average (472) and behind several ASEAN countries such as Singapore (575), Malaysia (409), and Thailand (394). Furthermore, more than 80% of Indonesian students performed below PISA Level 2, indicating that most students still struggle to apply mathematical knowledge in real-life situations and highlighting the urgent need for learning approaches that promote reasoning, problem-solving, and mathematical literacy development (OECD, 2024).

This national condition becomes more pronounced in vocational high schools, where mathematics is often perceived as abstract, difficult, and disconnected from students' vocational specializations (Brantlinger, 2022; Ozdemir & Onder-Ozdemir, 2017; Wulandari et al., 2025). Based on the research findings of Supianti et al. (2022), it can be concluded that the mathematical literacy skills of vocational high school students were still limited at Levels 5 and 6, which require advanced reasoning to solve complex problems as well as the ability to generalize and communicate findings. A common weakness identified was the students' inability to provide complete and well-justified conclusions in their written responses. Selvia

et al. (2025) found that vocational high school students demonstrated low initial mathematical literacy, as reflected by the pretest mean score of 55.4, with the greatest difficulty observed in the interpretation aspect of mathematical literacy. These findings indicate that low mathematical literacy is a national-scale problem that also manifests at the school level, including in vocational education contexts.

Figure 1.

Mathematics Literacy of Indonesian Student's achievement in the PISA



The core problem addressed in this study is the limited availability of contextual, field-relevant learning materials that can simultaneously develop mathematical literacy and self-regulated learning of vocational high school students, particularly those in the Culinary Arts program. Preliminary observations and interviews conducted at SMK Negeri 6 Yogyakarta during the 2023/2024 academic year, involving one mathematics teacher and X-grade students of the Culinary Arts program, revealed that students still experienced substantial difficulties in learning linear programming. Students struggled to translate real-world situations from the culinary field (such as planning food production with limited raw material budgets and recipe yields) into mathematical models in the form of inequalities and were unable to accurately interpret solutions obtained through graphical representations for decision-making purposes.

The needs analysis further confirmed the urgency of this problem from the instructional-material side. Observations and interviews showed that classroom learning was still dominated by teacher-centred instruction, in which students tended to rely on memorization and worked examples provided by the teacher rather than engaging in reasoning and conceptual understanding. The teaching materials used were limited to

government-issued textbooks, which were considered insufficiently comprehensive (containing limited problems and not covering all required topics) and to teacher-developed worksheets that functioned mainly as discussion aids to reinforce previously explained concepts. The teacher confirmed that no worksheets had yet been developed specifically to foster students' mathematical literacy and self-regulated learning.

Qualitative data from observations and interviews also revealed several interconnected challenges underlying these difficulties. These included students' tendency to depend on teacher guidance and predetermined examples rather than exploring solutions independently, low learning initiative and self-confidence when facing advanced-level problems different from the examples provided, the absence of contextual worksheets specifically integrating linear programming with culinary-field problems, the limited use of mathematical literacy contexts (personal, social, occupational, and scientific) in available teaching materials, and the lack of instructional designs that simultaneously develop mathematical literacy and self-regulated learning. SMK Negeri 6 Yogyakarta was selected as the research site because it offers the Culinary Arts program that becomes the focus of this study, has adequate infrastructure to support the implementation of the developed learning model, and is considered representative of vocational students based on its geographical location and the socio-economic background of its students. While these findings are context-specific to this school and program, similar patterns reported in other vocational settings suggest that they reflect broader challenges in vocational mathematics education in Indonesia.

To address these issues, innovative learning media and instructional approaches are needed to create more meaningful and contextual learning experiences. One alternative that can be implemented is the use of student worksheets integrated with the Problem-Based Learning (PBL) model. PBL emphasizes authentic and contextual problems as the basis for learning activities, allowing students to actively construct knowledge, collaborate with peers, and develop problem-solving skills (Arends, 2015). Through PBL, students are encouraged not only to understand mathematical concepts procedurally but also to apply them in solving real-world problems relevant to their vocational field (Xueting & Ismail, 2024). In culinary vocational education, contextual problems related to production planning, cost optimization, and resource allocation can support students in understanding linear programming concepts more meaningfully (Chen et al., 2021).

Several previous studies have investigated the development of mathematics learning media and the implementation of PBL in mathematics education. Rahmadi (2015) developed problem-based learning tools for vocational students focusing on reasoning and communication skills. Isnaniah & Imamuddin (2022) designed mathematical literacy tasks integrated with cultural contexts to improve students' literacy skills. Azizah et al. (2024) also

developed mathematical literacy-oriented learning media for vocational students using contextual approaches. Other studies have shown that PBL can improve students' problem-solving abilities, mathematical literacy, and learning motivation (Syafitri et al., 2021; Rani et al., 2024). However, previous studies have not specifically integrated mathematical literacy and self-regulated learning within PBL-based worksheets designed for culinary vocational students on linear programming material. In addition, the integration of multiple mathematical literacy contexts, including personal, social, occupational, and scientific contexts, remains limited.

Based on these conditions, this study aims to develop PBL-based student worksheets for linear programming that are valid, practical, and effective in enhancing students' mathematical literacy and self-regulated learning. The developed worksheets are expected to provide contextual learning experiences aligned with students' vocational backgrounds, encourage active participation in learning, and support the development of essential 21st-century competencies. The novelty of this study lies in the integration of problem-based learning, mathematical literacy contexts, and self-regulated learning within worksheets specifically designed for culinary vocational high school students. Therefore, this research is expected to contribute to the development of innovative mathematics learning media in vocational education.

METHODS

This study employed a field research design using a quantitative approach within the framework of Research and Development (R&D). The Research and Development (R&D) framework was selected in this study because it enables researchers to systematically develop, validate, and evaluate educational products (Huda et al., 2025; Syahrul et al., 2025). The research aimed to develop and evaluate problem-based learning (PBL) student worksheets for linear programming to enhance students' mathematical literacy and self-regulated learning. The development process followed the ADDIE model, consisting of five stages: Analyze, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it offers a clear, sequential, and iterative development process that emphasizes continuous evaluation and revision at each stage, making it more flexible and systematic for developing instructional materials (Abuhassna et al., 2024; Hera et al., 2025). The study was conducted empirically to examine the effectiveness of the developed learning media in actual classroom settings.

The research was carried out at SMK Negeri 6 Yogyakarta during the odd semester of the academic year. The participants were tenth-grade culinary vocational students selected through random sampling techniques. The culinary department was chosen because the contextual problems integrated into the worksheets were closely related to culinary

vocational activities, such as production planning, optimization, and resource allocation. This contextualization was intended to support students in understanding linear programming concepts more meaningfully and practically.

The data sources in this study consisted of primary data obtained directly from students, teachers, and expert validators. Data collection techniques included classroom observations, interviews with mathematics teachers, expert validation questionnaires, student response questionnaires, mathematical literacy tests, and self-regulated learning questionnaires. Observations and interviews were conducted during the preliminary stage to identify problems and learning needs in mathematics instruction (Kaskens et al., 2022). Expert validation questionnaires were used to evaluate the validity and feasibility of the developed worksheets, while student response questionnaires measured the practicality of the product (Rahmi, 2023).

Mathematical literacy tests and self-regulated learning questionnaires were administered before and after the implementation of the worksheets to examine students' improvement. The collected data were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics were used to summarize and describe the characteristics of the collected data (Fulk, 2023), while inferential statistics were employed to test hypotheses and draw conclusions about the effectiveness of the developed worksheets based on sample data. Validation and practicality data were analyzed descriptively by calculating the average scores obtained from expert validators and students' responses. Meanwhile, the effectiveness of the developed worksheets was analyzed using paired sample t-tests and N-gain analysis with the assistance of RStudio software. The paired sample t-test was used to determine significant differences between pretest and post-test scores (Assuah et al., 2022), while the N-gain analysis was used to measure the level of improvement in students' mathematical literacy and self-regulated learning after the implementation of the PBL-based worksheets (Triyono et al., 2024).

RESULT AND DISCUSSION

Results

The following section presents the results of the implementation of the developed worksheets and discusses students' mathematical literacy and self-regulated learning based on their learning activities and written work.

The development of the problem-based learning (PBL) worksheets for linear programming was carried out using the ADDIE model, consisting of Analyze, Design, Development, Implementation, and Evaluation stages. The findings from each stage of the ADDIE model are presented as follows.

Analyze

The analysis stage was conducted through classroom observations, semi-structured interviews, and document analysis at SMK Negeri 6 Yogyakarta. The participants involved in this stage consisted of one mathematics teacher and 72 Grade XI vocational students. Observation sheets were used to examine classroom learning activities and student engagement during mathematics lessons. Semi-structured interviews were conducted to explore teachers' and students' perceptions regarding learning difficulties, mathematical literacy, self-regulated learning, and the need for more contextual learning materials. Meanwhile, document analysis was carried out to review existing teaching materials, student worksheets, lesson plans, and students' learning outcomes in order to identify gaps between current instructional practices and the competencies expected in mathematics learning. A summary of the needs analysis findings is presented in Table 1.

Table 1.

Summary of Needs Analysis Findings

Aspect	Findings
Learning approach	Learning was predominantly teacher-centered, with limited student interaction and discussion.
Mathematical literacy	Students experienced difficulties interpreting contextual problems and constructing mathematical models.
Self-regulated learning	Students tended to depend on teacher guidance and showed limited initiative in learning independently.
Learning materials	Existing worksheets focused mainly on procedural exercises and did not explicitly facilitate mathematical literacy or self-regulated learning.
Development needs	A contextual and student-centered worksheet is needed to support problem-solving, mathematical literacy, and self-regulated learning.

These findings demonstrate the necessity of developing Problem-Based Learning (PBL) worksheets that provide authentic contextual problems, encourage active student participation, and foster the development of mathematical literacy and self-regulated learning among vocational students.

Design

Based on the results of the needs analysis, the worksheet was designed according to the characteristics and syntax of the Problem-Based Learning (PBL) model to enhance vocational students' mathematical literacy and self-regulated learning. The design process began with the formulation of learning objectives aligned with the linear programming curriculum and the mathematical literacy processes proposed by the OECD, namely formulate, employ, and interpret/evaluate. Self-regulated learning indicators, including

learning responsibility, self-monitoring, reflection, and independent problem-solving, were also incorporated into the worksheet design.

The product blueprint (Table 2) was developed to ensure alignment among learning objectives, PBL activities, mathematical literacy indicators, and self-regulated learning indicators. The worksheet structure consisted of five main sections corresponding to the PBL syntax: (1) Problem Orientation, (2) Organizing Students for Learning, (3) Guiding Investigation, (4) Developing and Presenting Solutions, and (5) Evaluation and Reflection. The alignment between PBL stages, learning activities, and the corresponding indicators is summarized in Table 2.

Table 2.

Blueprint of the Developed PBL Worksheet

PBL Stage	Learning Activities	Mathematical Literacy Indicators	Self-Regulated Learning Indicators
Problem Orientation	Analyzing contextual vocational problems	Formulate	Learning responsibility
Organizing Students	Identifying known and unknown information	Formulate	Planning learning activities
Guiding Investigation	Constructing mathematical models and solving problems	Employ	Self-monitoring
Developing and Presenting Solutions	Presenting and discussing solutions	Employ, Interpret	Independent problem-solving
Evaluation and Reflection	Evaluating solutions and reflecting on learning processes	Interpret/Evaluate	Reflection and self-evaluation

Table 2 illustrates the alignment between the PBL stages, learning activities, mathematical literacy indicators, and self-regulated learning indicators incorporated into the developed worksheet. Through this alignment, students were guided to engage in meaningful problem-solving processes while simultaneously strengthening their self-regulation skills. To enhance the relevance of learning, the contextual problems embedded in the worksheet were derived from culinary vocational situations, including production planning, menu optimization, nutritional analysis, and cost calculation. These contexts were selected to facilitate students' connections between mathematical concepts and authentic workplace situations.

To operationalize the integration of mathematical literacy and self-regulated learning, the developed worksheet incorporated contextual vocational tasks across all stages of Problem-Based Learning. The implementation of each stage is outlined as follows: At the problem orientation stage, students were presented with authentic and contextual problems closely related to culinary vocational activities, such as production planning, menu

optimization, nutritional analysis, and cost calculation. These contextual situations were intended to stimulate students' curiosity and encourage them to connect mathematical concepts with real-life vocational practices.

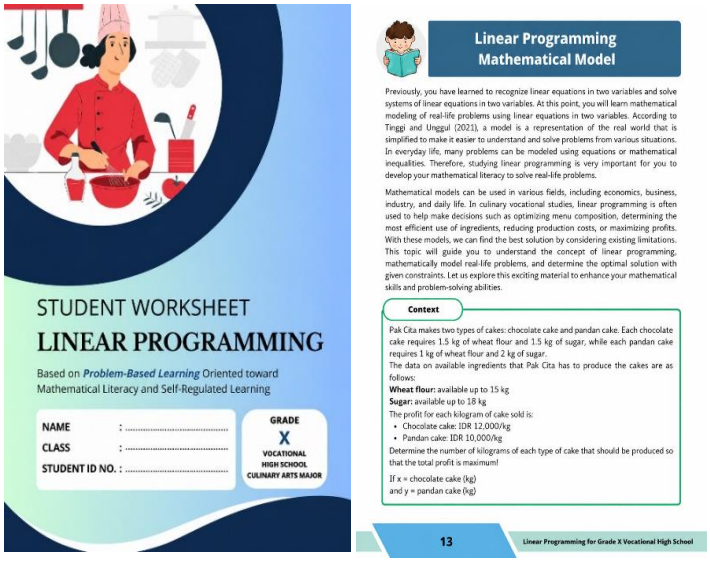
In the organizing and investigation stages, the worksheets provided guiding questions and scaffolding activities to help students identify relevant information, determine variables, formulate objective and constraint functions, and construct mathematical models systematically. Collaborative discussion activities were also designed to encourage students to exchange ideas, communicate mathematical reasoning, and develop problem-solving strategies together. These activities were intended to support the development of students' mathematical literacy through active exploration and reasoning processes.

Furthermore, reflection and evaluation sections were included to support students' self-regulated learning. Through these sections, students were encouraged to monitor their understanding, evaluate the effectiveness of their solution strategies, identify difficulties encountered during learning activities, and reflect on their own learning progress. The worksheets also contained evaluation questions designed to measure students' ability to apply linear programming concepts in various contextual situations.

Visually, the worksheets were designed using Canva software to create attractive, organized, and student-friendly learning materials. The layout, typography, illustrations, and colour combinations were adjusted to vocational students' characteristics in order to increase readability, learning motivation, and engagement during classroom activities. The design stage focused on creating contextual, interactive, and problem-oriented worksheets that could facilitate meaningful mathematics learning experiences for vocational students. Figure 2 shows an example of the worksheet prototype developed during the design stage, including the cover page, and worksheet content.

Figure 2.

Cover and Worksheet Content



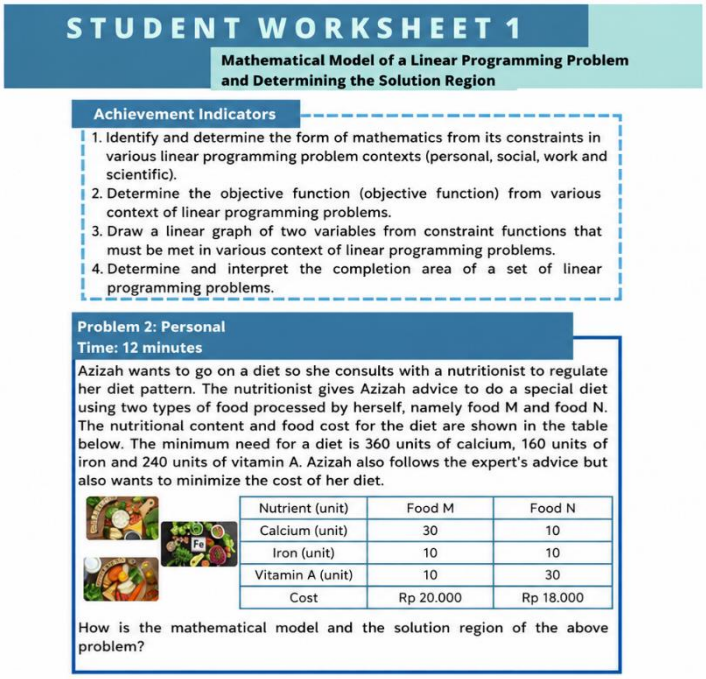
Development

At the development stage, the designed worksheets were refined and adjusted based on the characteristics of mathematical literacy and self-regulated learning indicators. The mathematical literacy indicators integrated into the worksheets included students' ability to formulate contextual problems into mathematical representations, employ mathematical concepts and procedures appropriately, and interpret as well as evaluate solutions within real-life situations. Meanwhile, the self-regulated learning indicators emphasized students' ability to manage learning activities independently, monitor their own understanding, demonstrate responsibility during problem-solving activities, and evaluate their learning outcomes reflectively.

The worksheets integrated contextual problems related to culinary vocational activities, such as production planning and optimization problems. Furthermore, the worksheets incorporated four mathematical literacy contexts, namely personal, social, occupational, and scientific contexts, to support students' understanding of mathematics in real-life situations. In the personal context, students were asked to determine the optimal combination of two healthy food menus that fulfilled nutritional requirements while minimizing daily food expenses. Figure 3 presents an authentic vocational problem in the context of nutrition and cost optimization.

Figure 3.

Personal Context Problem: Determining the Optimal Healthy Food Combination



STUDENT WORKSHEET 1

Mathematical Model of a Linear Programming Problem and Determining the Solution Region

Achievement Indicators

1. Identify and determine the form of mathematics from its constraints in various linear programming problem contexts (personal, social, work and scientific).
2. Determine the objective function (objective function) from various context of linear programming problems.
3. Draw a linear graph of two variables from constraint functions that must be met in various context of linear programming problems.
4. Determine and interpret the completion area of a set of linear programming problems.

Problem 2: Personal
Time: 12 minutes

Azizah wants to go on a diet so she consults with a nutritionist to regulate her diet pattern. The nutritionist gives Azizah advice to do a special diet using two types of food processed by herself, namely food M and food N. The nutritional content and food cost for the diet are shown in the table below. The minimum need for a diet is 360 units of calcium, 160 units of iron and 240 units of vitamin A. Azizah also follows the expert's advice but also wants to minimize the cost of her diet.

Nutrient (unit)	Food M	Food N
Calcium (unit)	30	10
Iron (unit)	10	10
Vitamin A (unit)	10	30
Cost	Rp 20.000	Rp 18.000

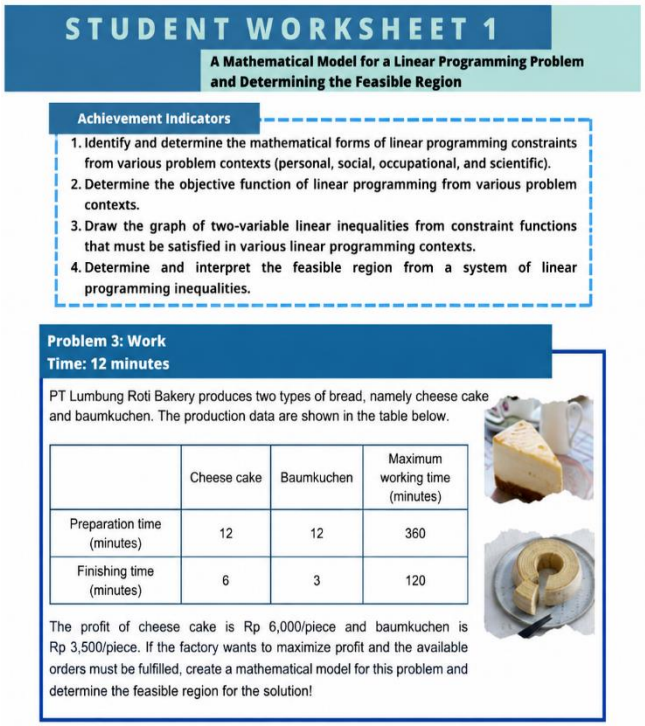
How is the mathematical model and the solution region of the above problem?

In the occupational context, students were presented with a bakery production planning problem that required them to determine the optimal quantities of cheese cakes and baumkuchen to maximize profit while satisfying production time constraints. Through this activity, students applied linear programming concepts to formulate mathematical

models, analyze feasible regions, and interpret optimal solutions in a realistic workplace setting. Figure 4 presents an authentic workplace-related problem in a bakery production setting.

Figure 4.

Occupational Context Problem: Determining Optimal Cake and Bread Production



STUDENT WORKSHEET 1

A Mathematical Model for a Linear Programming Problem and Determining the Feasible Region

Achievement Indicators

1. Identify and determine the mathematical forms of linear programming constraints from various problem contexts (personal, social, occupational, and scientific).
2. Determine the objective function of linear programming from various problem contexts.
3. Draw the graph of two-variable linear inequalities from constraint functions that must be satisfied in various linear programming contexts.
4. Determine and interpret the feasible region from a system of linear programming inequalities.

Problem 3: Work
Time: 12 minutes

PT Lumbung Roti Bakery produces two types of bread, namely cheese cake and baumkuchen. The production data are shown in the table below.

	Cheese cake	Baumkuchen	Maximum working time (minutes)
Preparation time (minutes)	12	12	360
Finishing time (minutes)	6	3	120

The profit of cheese cake is Rp 6,000/piece and baumkuchen is Rp 3,500/piece. If the factory wants to maximize profit and the available orders must be fulfilled, create a mathematical model for this problem and determine the feasible region for the solution!

In the social context, students were presented with a coffee shop production problem that required them to determine the optimal number of Frappe and Espresso drinks to maximize sales revenue under limited resource constraints. Through this activity, students applied the corner point method to formulate mathematical models, analyze feasible solutions, and interpret optimal decisions within an authentic business setting. Figure 5 presents an authentic social-context problem based on a coffee shop business scenario.

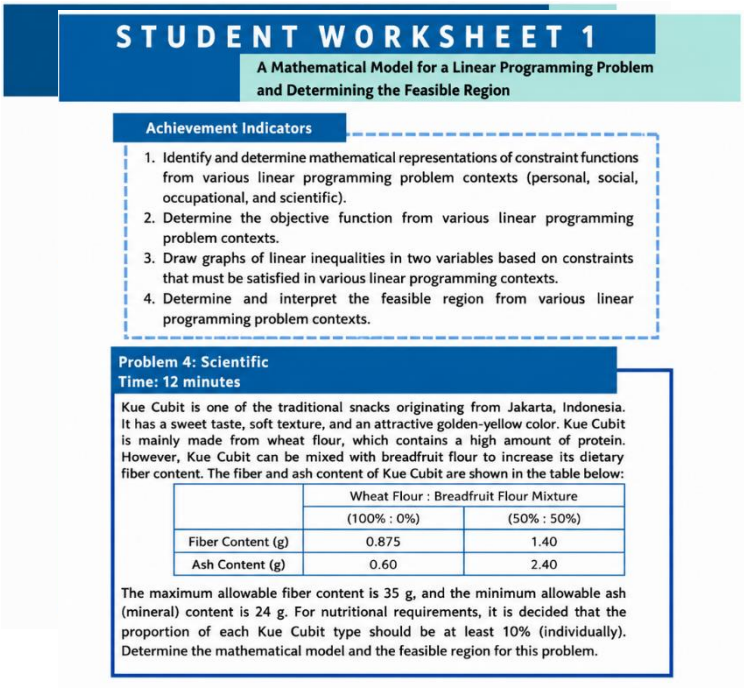
Meanwhile, in the scientific context, students were presented with a problem involving the nutritional composition of *Kue Cubit*, requiring them to analyze fiber and mineral content constraints and determine the feasible region of a linear programming model. Through this activity, students applied mathematical concepts to interpret scientific data and make evidence-based decisions within a food science context. Figure 6 presents a scientific-context problem involving the nutritional composition of *Kue Cubit.*

These contextual problems enabled students to connect linear programming concepts with authentic situations closely related to culinary vocational practices. By engaging with personal, social, occupational, and scientific contexts, students were encouraged to formulate mathematical models, analyze constraints, and interpret solutions in meaningful real-world settings. Furthermore, the integration of vocationally relevant problems

enhanced students' understanding of the practical applications of mathematics while fostering their mathematical literacy and decision-making skills.

Figure 5.

Social Context Problem: Determining Optimal Meal Package Distribution



STUDENT WORKSHEET 1

A Mathematical Model for a Linear Programming Problem and Determining the Feasible Region

Achievement Indicators

1. Identify and determine mathematical representations of constraint functions from various linear programming problem contexts (personal, social, occupational, and scientific).
2. Determine the objective function from various linear programming problem contexts.
3. Draw graphs of linear inequalities in two variables based on constraints that must be satisfied in various linear programming contexts.
4. Determine and interpret the feasible region from various linear programming problem contexts.

Problem 4: Scientific
Time: 12 minutes

Kue Cubit is one of the traditional snacks originating from Jakarta, Indonesia. It has a sweet taste, soft texture, and an attractive golden-yellow color. Kue Cubit is mainly made from wheat flour, which contains a high amount of protein. However, Kue Cubit can be mixed with breadfruit flour to increase its dietary fiber content. The fiber and ash content of Kue Cubit are shown in the table below:

	Wheat Flour : Breadfruit Flour Mixture	
	(100% : 0%)	(50% : 50%)
Fiber Content (g)	0.875	1.40
Ash Content (g)	0.60	2.40

The maximum allowable fiber content is 35 g, and the minimum allowable ash (mineral) content is 24 g. For nutritional requirements, it is decided that the proportion of each Kue Cubit type should be at least 10% (individually). Determine the mathematical model and the feasible region for this problem.

Figure 6.

Scientific Context Problem: Determining Nutritional Balance and Minimum Cost

Then, the developed worksheets were subsequently evaluated by two expert validators consisting of a mathematics education expert and a learning media expert. The validation instrument comprised five assessment aspects: competency, content quality, language, presentation, and graphic design. Each item was assessed using a five-point Likert scale ranging from 1 (very poor) to 5 (excellent). The total validation score was then converted into qualitative categories using the ideal score conversion criteria proposed by (Widoyoko, 2009). Based on the instrument used, the minimum possible score was 63 and the maximum possible score was 147. The validity categories are presented in Table 3.

Table 3.

Worksheet Validity Criteria

Feasibility Criteria Interval	Category
$X > 147$	Very Good
$119 < X \leq 147$	Good
$91 < X \leq 119$	Fairly Good
$63 < X \leq 91$	Poor
$X \leq 63$	Very Poor

The validation results indicated that both validators assigned a total score of 141 (Table 4), placing the developed worksheets in the "Good" category and indicating that the product was valid and feasible for implementation with minor revisions. Although both validators produced the same total score, differences were observed in several assessment aspects. Validator 1 assigned higher scores to competency, language, and graphic design, whereas Validator 2 provided higher scores for content quality and presentation. These variations suggest that the validators had different emphases during the evaluation process, despite arriving at the same overall judgment regarding the quality of the product.

Table 4.

Validation Results of PBL-Based Worksheets

Assessment Aspect	Validator 1	Validator 2	Mean Score	Percentage (%)
Competency	17	15	16	80
Content Quality	59	62	60.5	86.4
Language	25	22	23.5	78.3
Presentation	16	19	17.5	87.5
Graphic Design	24	23	23.5	94.0
Total Score	141	141	141.0	85.5
Category	Good	Good	Good	

Analysis of each aspect revealed that graphic design received the highest percentage score (94.0%), indicating that the layout, typography, illustrations, and visual appearance of the worksheets were highly appropriate and attractive for vocational students. The presentation aspect also obtained a high score (87.5%), suggesting that the learning activities were systematically organized according to the Problem-Based Learning syntax. Content quality achieved a score of 86.4%, demonstrating that the materials, contextual problems, and mathematical literacy activities were relevant to the learning objectives. Meanwhile, the competency aspect received 80.0%, indicating adequate alignment between learning objectives, activities, and assessment components. The language aspect obtained the lowest percentage score (78.3%), although it still fell within the valid category, suggesting that several revisions were needed to improve clarity, consistency, and readability of instructions.

In addition to the quantitative evaluation, the expert validators provided several qualitative suggestions to improve the developed worksheets. These suggestions focused on enhancing instructional clarity, strengthening the contextual relevance of the problems, improving visual presentation, and increasing the effectiveness of scaffolding activities. All recommendations were carefully reviewed and incorporated into the revision process before the worksheets were implemented in classroom learning. A summary of the validators' suggestions and the corresponding revisions is presented in Table 5.

Table 5.

Revision of the Worksheets Based on Expert Validators' Suggestions

Validators' Suggestions	Revisions Implemented
Several instructions were unclear and potentially difficult for students to follow independently	Instructions were rewritten using simpler and more explicit language, and step-by-step guidance was added to several activities.
Some contextual problems were insufficiently related to students' vocational experiences.	The contexts were revised using culinary-based situations such as menu planning, ingredient management, and production optimization.
The consistency of layout, typography, and illustrations needed improvement.	Font styles, spacing, page layouts, and visual elements were standardized throughout the worksheets
Additional scaffolding was needed to support students in constructing mathematical models and interpreting solutions.	Guiding questions, prompts, and reflection activities were added to assist students in formulating, employing, and interpreting mathematical models.

Implementation

During the implementation process, students showed active participation and engagement in discussing the contextual problems presented in the worksheets. Based on classroom observations conducted using a student activity observation sheet, students collaboratively identified relevant information, discussed alternative solution strategies, and communicated their ideas within their groups. Several students initially experienced difficulties in translating contextual situations into mathematical models; however, the guiding questions and scaffolding prompts embedded in the worksheets assisted them in constructing mathematical representations more systematically.

Observations further indicated that students were able to engage in activities related to the mathematical literacy processes of formulate, employ, and interpret/evaluate. During group discussions, students identified relevant information from contextual problems, formulated variables and constraints, applied graphical and algebraic procedures to solve problems, and interpreted solutions within vocational contexts. In addition, reflection activities included in the worksheets encouraged students to evaluate their learning processes and discuss the effectiveness of their solution strategies.

To evaluate the practicality of the developed worksheets, a student response questionnaire was administered to 72 tenth-grade culinary vocational students after the implementation stage. Responses were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The average scores were subsequently converted into qualitative categories based on the following criteria: 1.00–1.80 (Very Poor), 1.81–2.60 (Poor), 2.61–3.40 (Fair), 3.41–4.20 (Good), and 4.21–5.00 (Very Good). The results are presented in Table 6.

Table 6.
Student Response Results on the Practicality of the Worksheets

No.	Practicality Aspect	Average Score	Percentage (%)	Category
1	Attractiveness of worksheet design and layout	4.35	87.0	Very Good
2	Clarity of instructions and explanations	4.21	84.2	Good
3	Contextual relevance of the problems	4.40	88.0	Very Good
4	Ease of use during learning activities	4.18	83.6	Good
5	Support for mathematical problem-solving	4.27	85.4	Very Good
6	Support for collaborative discussion activities	4.24	84.8	Very Good
7	Motivation and learning engagement	4.33	86.6	Very Good
8	Overall practicality of the worksheets	4.28	85.6	Very Good

As shown in Table 6, the developed worksheets obtained an overall average score of 4.28 out of 5.00, equivalent to 85.6%, indicating a "Very Good" level of practicality. The highest-rated aspect was the contextual relevance of the problems (88.0%), suggesting that students perceived the culinary-based contexts as meaningful and closely related to their vocational experiences. High ratings were also obtained for worksheet attractiveness (87.0%) and learning motivation and engagement (86.6%), indicating that the visual design and learning activities successfully captured students' interest. Although the ease-of-use aspect received the lowest score (83.6%), it still fell within the "Good" category, suggesting that students generally experienced few difficulties when using the worksheets. These findings indicate that the developed worksheets were highly practical, well accepted by students, and suitable for supporting contextual mathematics learning in vocational education settings.

Evaluation

The evaluation stage was conducted to determine the effectiveness of the developed PBL-based worksheets in enhancing students' mathematical literacy and self-regulated learning. The evaluation process included analyzing students' mathematical literacy test scores, self-regulated learning questionnaire results, and students' responses toward the implementation of the worksheets.

Prior to hypothesis testing, the pretest and post-test data were examined for normality. The results indicated that all datasets were normally distributed ($p > 0.05$), satisfying the assumptions required for parametric analysis. Therefore, paired-sample t-tests

were conducted to examine differences between students' pretest and post-test scores. The result is presented in Table 7.

Table 7.

Paired Sample T-Test Results

Variable	n	Mean Pretest	Mean Posttest	t	df	p-value	Interpretation
Mathematical Literacy	72	34,166	79,53	21.15	71	< 0.05	Significant Improvement
Self-Regulated Learning	72	68,361	90,236	14.619	71	< 0.05	Significant Improvement

The paired-sample t-test results revealed statistically significant differences between students' pretest and post-test scores in both mathematical literacy and self-regulated learning. The substantial increase in mean scores indicates that students demonstrated better performance after participating in learning activities using the developed worksheets.

To determine the magnitude of improvement, normalized gain (N-gain) analysis was conducted. The interpretation of N-gain scores, where $g < 0.30$ is categorized as low, $0.30 \leq g < 0.70$ as medium, and $g \geq 0.70$ as high. The results of the N-gain analysis are presented in Table 8.

The N-gain analysis showed that mathematical literacy achieved a medium improvement ($g = 0.64$), approaching the upper boundary of the medium category. This result suggests that the developed worksheets effectively facilitated students' ability to formulate, employ, and interpret mathematical concepts within contextual situations. Through the Problem-Based Learning approach, students were repeatedly exposed to authentic culinary problems requiring them to identify relevant information, construct mathematical models, apply solution procedures, and evaluate the reasonableness of their solutions. Such learning experiences align closely with the mathematical literacy processes proposed by OECD and may explain the relatively substantial improvement observed in this study.

Table 8.

N-Gain Results

Variable	N-Gain Score	Category
Mathematical Literacy	0.64	Medium
Self-Regulated Learning	0.33	Medium

In contrast, self-regulated learning obtained an N-gain score of 0.33, which is positioned near the lower boundary of the medium category. Although this result indicates a positive improvement, the magnitude of the gain remains relatively modest and should therefore be interpreted cautiously. The finding suggests that the developed worksheets contributed to the initial development of students' self-regulated learning; however, the improvement was not as substantial as that observed in mathematical literacy. This result is

understandable because self-regulated learning encompasses complex dispositions such as goal setting, self-monitoring, self-evaluation, responsibility, and learning persistence, which generally require continuous and long-term practice to develop. Consequently, a relatively short implementation period may not have been sufficient to produce substantial changes in students' self-regulatory behaviors.

In addition to the quantitative findings, student responses indicated that the worksheets were interesting, contextual, visually attractive, and helpful in understanding linear programming concepts. Students reported that the culinary-based contexts made mathematics learning more meaningful and relevant to their vocational field. Collaborative discussion activities and reflection sections were also perceived as beneficial in encouraging active participation, responsibility, and independent learning.

The evaluation results indicate that the developed worksheets satisfied the criteria of effectiveness by producing statistically significant improvements in students' mathematical literacy and self-regulated learning. Nevertheless, the relatively modest N-gain score for self-regulated learning suggests that longer implementation periods, repeated reflection activities, and sustained opportunities for independent learning may be necessary to achieve stronger improvements in students' self-regulatory skills.

Discussion

The findings indicate that the developed worksheets effectively supported the development of students' mathematical literacy through contextual and authentic problem-solving activities. The formulate, employ, and interpret processes demonstrated by students reflect the core components of mathematical literacy. Students were not only able to perform mathematical calculations but also capable of understanding contextual situations, representing them mathematically, and interpreting solutions meaningfully.

The formulate activities played an important role in helping students connect real-life culinary situations with mathematical concepts (Baki et al., 2009). Students identified variables, constraints, and objectives from contextual problems related to production planning and optimization. These findings indicate that contextual learning environments can facilitate students' understanding of abstract mathematical concepts more concretely. This result is consistent with previous studies stating that contextual mathematical tasks improve students' ability to connect mathematics with everyday experiences (Clarke & Roche, 2018; Hidayana & Lianingsih, 2025).

The employ process revealed that students developed diverse mathematical strategies when solving optimization problems. Some students preferred graphical methods, while others relied on algebraic calculations. This diversity of approaches

indicates that mathematical literacy involves flexible reasoning and strategic thinking rather than merely procedural competence. The contextual worksheets provided opportunities for students to explore different methods according to their own understanding and experiences.

The interpret and evaluate process became one of the most important findings in this study because students demonstrated the ability to connect mathematical solutions with practical vocational situations. Students were able to explain the meaning of optimal solutions within culinary production contexts and evaluate whether the obtained results were realistic and applicable. This finding shows that mathematical literacy in vocational education should emphasize meaningful interpretation and practical decision-making rather than only symbolic manipulation.

In addition to improving mathematical literacy, the developed worksheets also contributed to students' self-regulated learning. During learning activities, students became more active in discussing ideas, monitoring their understanding, and evaluating their own work. The worksheets encouraged students to take responsibility for their learning process through collaborative discussions and reflective activities. These findings support previous research emphasizing that student-centered learning approaches can enhance learning independence and self-management skills (Moradoff et al., 2021).

These findings are consistent with the theoretical foundations of Problem-Based Learning. According to Kuncoro et al., (2021) & Rizal et al., (2023), PBL encourages students to actively construct knowledge through authentic problem situations, collaborative inquiry, and reflective learning activities. Such characteristics are particularly relevant to the development of mathematical literacy because they engage students in meaningful problem-solving processes rather than routine procedural tasks. Previous studies have similarly reported that PBL can effectively improve students' mathematical literacy by promoting reasoning, modelling, and contextual problem-solving abilities (Tamamal et al., 2025; Yani et al., 2025). Furthermore, research has shown that PBL supports the development of self-regulated learning by providing opportunities for students to plan, monitor, and evaluate their learning processes through collaborative investigation and reflection activities (Khoiriyah & Roberts, 2025; Yuni et al., 2021). However, several studies have also reported that improvements in self-regulated learning tend to occur more gradually than improvements in cognitive outcomes, which is consistent with the findings of the present study (Efklides & Schwartz, 2024; Van Der Graaf et al., 2022).

Another important contribution of this study lies in the integration of four mathematical literacy contexts: personal, social, occupational, and scientific contexts. Most previous studies focused only on one or two contextual dimensions, whereas this

study integrated multiple contexts within vocational mathematics learning (Bolstad, 2023; Niss & Jablonka, 2020). The use of culinary vocational contexts made mathematics learning more relevant to students' future professional experiences, increasing engagement and participation during classroom activities.

Compared with previous studies, this research provides a stronger emphasis on the exploration of students' mathematical literacy processes rather than solely focusing on the implementation of the PBL model itself. The diversity of students formulate, employ, and interpret strategies became a significant finding showing that vocational students possess varied mathematical thinking patterns when provided with meaningful contextual learning experiences.

CONCLUSION

The developed Problem-Based Learning (PBL) worksheets for linear programming were found to be valid, practical, and effective for vocational mathematics learning. The worksheets successfully enhanced students' mathematical literacy, as indicated by a medium N-gain score of 0.64, and improved students' self-regulated learning, with an N-gain score of 0.33. These findings suggest that contextual culinary-based problems integrated within the PBL framework effectively supported students in formulating mathematical situations, applying solution strategies, and interpreting solutions in meaningful real-life contexts, while also encouraging greater responsibility and independence in learning.

This study demonstrates that integrating personal, social, occupational, and scientific contexts into PBL-based worksheets can create meaningful learning experiences that bridge mathematics and vocational practices. The findings contribute to the development of vocational mathematics learning media that foster not only procedural competence but also mathematical literacy and self-regulated learning as essential 21st-century skills. For mathematics teachers, the developed worksheets may serve as an alternative instructional resource for implementing contextual and student-centered learning in vocational education. Future researchers are encouraged to investigate the long-term impact of PBL-based worksheets on students' mathematical literacy and self-regulated learning, as well as to adapt and evaluate similar worksheets across different vocational programs, mathematical topics, and educational settings to strengthen their effectiveness and generalizability.

DECLARATIONS

Author Contribution

Dewi, C.K., & Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Visualization, and Project Administration.; **R. Rosnawati**, Writing – Review & Editing, Methodology, and Formal Analysis.; **Nadzeri, M.B.,** Supervision and Validation.

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Conflict of Interest

The authors declare no conflict of interest.

Declaration of AI Use

ChatGPT was used to improve language clarity, grammar, and academic writing quality under the supervision and full responsibility of the authors. All research design, data collection, analysis, interpretation of results, and final manuscript decisions were conducted by the authors independently.

Additional Information

Not applicable.

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