DEVELOPMENT OF PROBLEM-BASED LEARNING MATHEMATICS TOOLS FOR LINEAR PROGRAMMING TO FACILITATE STUDENTS' MATHEMATICAL COMMUNICATION SKILLS

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ABSTRACT This research is driven by the challenges teachers face in designing learning tools aligned with the 2013 curriculum. The purpose of this study is to develop mathematics learning tools based on the Problem-Based Learning (PBL) model to enhance students' mathematical communication skills, ensuring these tools are both valid and practical. The developed learning tools include a syllabus, Lesson Plan, and Student Worksheets. The development process follows the 4-D model, which consists of the stages: Define, Design, Develop, and Disseminate. The subjects of this study were 35 students from class XI at SMAN 5 Tapung. Research instruments included validation sheets to assess the feasibility and validity of the learning tools and student response questionnaires to evaluate the practicality of the student worksheets. The analysis of validation data revealed that the mathematics learning tools are highly valid, with an average rating of 94% for the syllabus, 95% for the lesson plan, and 92% for the student worksheets. The practicality data analysis showed that the student response ratings categorized the tools as very practical, with an average rating of 88.37%.

Keywords: problem-based learning (PBL), mathematical communication skills, instructional tools development, linear programming

ABSTRAK Penelitian ini didorong oleh tantangan yang dihadapi guru dalam merancang perangkat pembelajaran yang selaras dengan kurikulum 2013. Tujuan dari penelitian ini adalah mengembangkan perangkat pembelajaran matematika berbasis model Problem-Based Learning (PBL) untuk meningkatkan kemampuan komunikasi matematis siswa, dengan memastikan bahwa perangkat tersebut valid dan praktis. Perangkat pembelajaran yang dikembangkan meliputi silabus, Rencana Pelaksanaan Pembelajaran (RPP), dan Lembar Kerja Peserta Didik (LKPD). Proses pengembangan mengikuti model 4-D, yang terdiri dari tahap Define, Design, Develop, dan Disseminate. Subjek penelitian ini adalah 35 siswa kelas XI di SMAN 5 Tapung. Instrumen penelitian mencakup lembar validasi untuk menilai kelayakan dan validitas perangkat pembelajaran serta kuesioner tanggapan siswa untuk mengevaluasi kepraktisan LKPD. Analisis data validasi menunjukkan bahwa perangkat pembelajaran matematika sangat valid, dengan rata-rata penilaian 94% untuk silabus, 95% untuk RPP, dan 92% untuk LKPD. Analisis data kepraktisan menunjukkan bahwa penilaian tanggapan siswa mengkategorikan perangkat tersebut sebagai sangat praktis, dengan rata-rata penilaian 88,37%.

Keywords: problem-based learning (PBL), kemampuan komunikasi matematis, pengembangan media pembelajaran, program linear

INTRODUCTION

Mathematical communication skills refer to students' ability to express and interpret mathematical ideas orally, in writing, or through demonstrations in mathematics learning (Mardhiyanti et al, 2013). According to the Decision of the Head of BSKAP Number 033/H/KR/2022, one of the objectives of mathematics learning is to communicate ideas using symbols, tables, diagrams, or other media to clarify the state of a problem and to present a situation using mathematical symbols or models.

Mathematical communication skills are related to the development of understanding of mathematical learning materials by communicating mathematical thoughts using accurate mathematical language (Ansori et al, 2015). These skills are not only about conveying ideas or thoughts in solving mathematical problems effectively, but they also need to be optimized to achieve the desired learning objectives. Mathematical communication skills encompass the ability to write, listen, analyze, interpret, evaluate ideas, symbols, terms, and information related to mathematical learning materials (Ermida et al, 2024).

The primary reasons for the importance of students' mathematical communication skills in mathematics learning are explained by Hikmah et al (2019) as follows: (1) Mathematics serves as a tool for communicating mathematical ideas clearly, precisely, and concisely; (2) The process of mathematics involves social activities that include interactions between students and between students and teachers. Mathematical communication skills are essential for students because they need to communicate in various ways, both written and oral, and create effective communication in different forms and content, whether orally, in writing, or through multimedia (Awaliyah et al, 2019).

In fact, research conducted by Oktavianingsih and Warmi (2021) indicates that the mathematical communication skills of 12th-grade students on linear programming material are relatively low, with a 50% success rate on the indicator of mathematical expression, which involves expressing daily events using mathematical symbols. Relevant research by Nuraeni and Imami (2021) also shows that the mathematical communication skills of 12th-grade students on linear programming material are below 33% on the written text indicator, indicating that students struggle to use mathematical symbols in written problem-solving. This is consistent with findings from Nugroho et al (2017), who stated that most students find it challenging to interpret real-life problems into mathematical models.

Wulanningsih et al (2021) stated that PBL with a scientific approach is very suitable for studying linear programming material because it is related to everyday life and can facilitate students' mathematical communication skills. Sofyan (2012) mentioned that PBL can actively engage students in expressing mathematical ideas into new understandings, thereby making it more likely to facilitate mathematical communication skills. John Dewey, as cited by Sufi (2016), noted that there is a connection between PBL and mathematical communication skills, as demonstrated by the learning process where students can learn from real problems presented in groups. The learning tools to be designed in this research will use PBL based on the 2013 curriculum.

The importance of learning tools, according to Tanjung & Nababan (2018), is that they serve as one of the guidelines for teachers in conducting classroom learning. Learning tools should also support preparing students to acquire new knowledge (Atika et al., 2020). The Regulation of the Minister of Education and Culture No. 20 of 2016 on Standards of Primary and Secondary Education Processes states that learning planning consists of syllabi, lesson plans, media, learning resources, learning assessments, and learning scenarios. Some essential tools include syllabi, lesson plans, student worksheets, books, and evaluation instruments.

However, in reality, many teachers still struggle to maximize learning planning. This is clarified by interviews with several high school mathematics teachers in Kampar, as follows: (1) teachers find it challenging to prepare learning tools based on the 2013 curriculum; (2) there is a lack of teacher understanding of the 2013 curriculum; (3) although teachers have attended training on the 2013 curriculum, they still face difficulties in preparing the recommended tools; (4) other teachers' tools still rely on devices obtained from MGMP forums, which are adapted to the conditions of each school's students and the process standards contained in the Regulation of the Minister of Education and Culture No. 22 of 2016, meaning that some teachers have yet to prepare tools according to the 2013 curriculum.

Based on the issues outlined regarding the low mathematical communication skills of students, this research aims to develop a PBL-based mathematics learning tool that aligns with the learning objectives set in the 2013 curriculum. To facilitate students' mathematical communication skills, it is necessary to develop learning tools that are both valid and practical. The developed learning tools aim to provide structured learning for students and facilitate mathematical communication skills. Therefore, the researcher will develop a PBL-based mathematics learning tool on linear programming material that meets both validity and practicality standards.

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METHODS

This research aims to develop a learning tool that incorporates elements of mathematical communication skills aligned with the learning objectives for linear programming material. The development model used is the 4-D model designed by Thiagarajan, et al (1974). This model consists of four stages: define, design, develop, and disseminate.

In the define stage, activities include: (1) Preliminary Analysis, aimed at obtaining an overview of the situations and conditions in the field, identifying the problems faced, and determining these problems; (2) Student Analysis, aimed at examining the characteristics of students at SMAN 5 Tapung during the learning process; (3) Material Analysis, needed to identify and systematically arrange relevant materials based on the preliminary analysis; (4) Task Analysis, aimed at determining the Basic Competence and indicators of competency achievement in the linear programming material based on the K13 curriculum; and (5) Specification of Learning Objectives, aimed at formulating learning objectives to identify the necessary studies in preparing syllabi, lesson plans, and student worksheets in the linear programming material.

In the design stage, activities include: (1) Format Selection, useful for choosing a design that can help and facilitate students in understanding the concept of linear programming material; and (2) Initial Design of Learning Tools, including syllabi, lesson plans, and student worksheets according to the previously chosen format.

In the develop stage, activities include: (1) Expert Evaluation, where the developed learning tools are validated by validators; and (2) Development Trials, where, after the learning tools are validated, the researcher conducts small group trials to assess the readability of the student worksheets.

In the disseminate stage, activities that can be carried out in this research include seminars to present the results and the preparation of articles for publication in journals.

The data collection techniques used in this research include: (1) Interviews conducted with six mathematics teachers in Kampar to discuss the curriculum applied in their respective schools and the obstacles faced in creating learning tools to understand the students' mathematical communication skills; and (2) Questionnaires aimed at obtaining evaluations provided by validators. The validators assess the learning tools based on categories such as very good, good, fair, and poor.

The final data collection technique is (3) Practicality Data, which involves questionnaires to gather students' responses to the student worksheets. The readability of the student worksheets is assessed based on the students' responses, using a simple measurement scale where positive and negative responses are recorded.

The analysis techniques used include qualitative data analysis in the form of suggestions and feedback from validators, which are used for revisions, and quantitative data analysis in the form of validity analysis of the learning tools and readability analysis of the learning tools. The validity data is analyzed using a formula to calculate the percentage of validity, which is then categorized to determine if the tools are highly valid, valid, less valid, or not valid.

Based on the validity analysis, the learning tools are considered valid if the average validation score falls within the acceptable range, allowing them to be tested. Practicality data from the student responses are also analyzed using a percentage-based formula to determine the level of practicality, categorized as highly practical, practical, less practical, or not practical.

According to Arikunto (2012), teaching modules are considered usable if the readability percentage exceeds 70%. A developed product is deemed to meet the practicality aspect well if the minimum achieved practicality level is categorized as Practical.

FINDING AND DISCUSSION

The results of this study include a learning tool based on the Project-Based Learning (PBL) model, designed to facilitate mathematical communication skills in linear programming material for 11th-grade students at SMAN 5 Tapung. The developed learning tool comprises a syllabus, lesson plans, and student worksheets prepared for four meetings on linear programming material. The research model employed is the 4-D model, consisting of four stages: define, design, develop, and disseminate.

During the define stage, five key activities were undertaken: (1) initial-final analysis, (2) student needs analysis, (3) material analysis, (4) task analysis, and (5) formulation of learning objectives. The initial-final analysis aimed to identify the fundamental problems essential for the development of the learning tools. Interviews were conducted with six mathematics teachers from several high schools in Kampar, including SMAN 5 Tapung, SMAN 3 Tapung, SMAN 2 Tambang, SMAN 1 Tapung Hilir, SMAN 2 Siak Hulu, and SMAN 1 Tapung Hulu. These interviews revealed that the 2013 curriculum is currently used in these schools, but the tools employed by the teachers—such as syllabi, lesson plans, and student worksheets—are not fully aligned with the curriculum's standards. The lesson plans created by the teachers lacked critical components, including learning objectives, learning models, and adherence to the process standards of the 2013 curriculum.

Specifically, when designing lesson plans, teachers failed to incorporate Core Competencies (KI), Basic Competencies (KD), indicators, the instructional model, clear steps, assessment forms, criteria, instruments, alternative answers, and scoring guidelines. The lesson plans generally covered only the content of the material. This indicates a lack of understanding among teachers in formulating learning objectives that consider key aspects such as audience, behavior, conditions, and degrees.

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Additionally, the components of learning materials were not detailed according to facts, concepts, principles, and procedures.

Further document analysis revealed that the student worksheets used during the learning process in linear programming were inadequate. These worksheets included material summaries and practice exercises but lacked structured steps to guide students in mastering specific concepts. The presentation of material was insufficient to support students in constructing and understanding mathematical concepts.

Although the textbooks available in schools are based on the 2013 curriculum and include various learning activities, their usage in classrooms is not effectively directed by teachers, resulting in suboptimal outcomes.

Student analysis was conducted through interviews and surveys with 11th-grade students at SMAN 5 Tapung. The findings indicate that students prefer discussing with peers rather than asking teachers for help. They favor collaborative learning activities, making the PBL model, which emphasizes group activities and peer discussions, particularly suitable. The PBL model introduces problems at the start of the learning process, prompting students to work together to solve them.

In the material analysis stage, the researcher identified core concepts and organized them into mathematical concepts. The Basic Competencies (KD) relevant to linear programming material include KD 3.2, which involves explaining linear programs with two variables and their solution methods using contextual problems, and KD 4.2, which involves solving contextual problems related to linear programs with two variables. Linear programming problems are frequently applied in various fields such as industry and commerce, including production optimization in factories or companies. Learning mathematics with linear programming material requires students to creatively translate general problems into mathematical expressions, leading to mathematical solutions.

In the task analysis stage, the researcher analyzed the tasks in the form of competencies that students need to achieve through learning activities. This included reviewing Core Competencies (KI) and Basic Competencies (KD) related to the material and elaborating them into measurable indicators to meet the Minimum Completeness Criteria (KKM). The essential tasks that students must master to achieve these criteria were also analyzed.

The formulation of learning objectives aimed to define the studies needed to develop the syllabus, lesson plans, and student worksheets for linear programming material. Based on this analysis, the learning objectives were identified with scientific justification, particularly for the student worksheets, which were designed using the PBL model to enhance students' mathematical communication skills.

In the design stage, the format for the mathematics learning tools was selected, and an initial design was prepared based on the problem-based learning steps. The designed syllabus included components such as Basic Competencies (KD), learning material, and learning activities across four meetings on linear programming. The lesson plans covered essential elements like identity, Core Competencies (KI), Basic Competencies (KD) and indicators, learning objectives, learning materials, justifications, models, methods, media, tools, learning resources, steps, and assessments. The student worksheets were designed to facilitate student investigations, featuring a cover page, content, activities, and conclusion sections.

In the development stage, the designed learning tools are refined and organized according to the chosen format. The learning activities follow the stages of the problem-based learning (PBL) model, which are grounded in scientific justification. These stages include problem orientation (understanding), organizing student learning (thinking), providing opportunities for individual and group investigations (collecting information and analyzing), presenting and discussing work results (communicating), and analyzing and evaluating the problem-solving process.

The learning activities are divided into three stages: the preliminary stage, core stage, and closing stage, as outlined in the initial design. During the preliminary stage, the teacher greets the students upon entering the classroom, and the class leader leads a prayer to start the lesson. The teacher ensures that students are psychologically and physically prepared for the learning process by emphasizing discipline, punctuality, and attendance. The teacher then introduces the main topic of the lesson, states the learning objectives, provides motivation, explains the assessment criteria, and outlines the learning activities using the PBL model. Following this, the teacher organizes the students into pre-assigned groups of five and distributes the student worksheets to each student.

In the core stage, the learning activities are carefully structured based on the steps of the PBL model, supported by scientific justification. The student worksheets are developed in alignment with these steps and include indicators for enhancing mathematical communication skills in the linear programming material for 11th-grade students. The problems presented at the beginning of the student worksheets are contextual, related to the material being studied. The activities within the worksheets are systematically organized to facilitate students' understanding of the concepts. These worksheets are equipped with relevant images and are designed with attractive colors to engage students actively in the learning process. The design of the worksheets includes sections for the cover page, content, and practice exercises.

The developed learning tools were validated by experts and underwent a trial test. Feedback from the validators was incorporated into revisions to ensure that the tools met the required validity criteria. Following these revisions, the learning tools were considered valid. The validated tools were then tested with students. In this study, the trial was conducted with a small group of 35 students from the 11th grade at SMAN 5 Tapung to evaluate the practicality of the developed learning tools. The

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average evaluations provided by three validators for the syllabus, lesson plans, student worksheets, and exercises are presented in Tables 5 through 7 below.

Table 1. Results of Syllabus Validation

Assessment Aspects	Assessment Indicators	Validator			Average percetage per Indicator	Average percentage per Aspect
		1	2	3		
Content	Completeness of the syllabus identity	4	4	4	100%	96%
		4	4	4		
		4	4	4		
		4	4	4		
		4	4	4		
		4	4	4		
	Clarity of Core Competencies and Basic Competencies	4	4	4	100%	
		4	4	4		
	Clarity of lesson plan formulation	4	4	4	96%	
		4	4	4		
		3	4	4		
		3	4	4		
	Relevance of teaching materials	4	4	4	97%	
		4	4	4		
		3	4	4		
	Relevance of assessment to learning outcomes	4	4	3	96%	
		4	4	4		
	Alignment of learning resources with objectives, PBL, and student characteristics	4	4	4	89%	
		3	4	3		
		3	4	3		
Construction	Alignment of learning resources with objectives, PBL, and student characteristics	3	4	4	92%	92%
		3	4	4		
		4	4	3		

Based on Table 1, the evaluation results from the validators are as follows: the content aspect received a score of 96%, indicating it is highly valid, while the construction aspect received a score of 92%, also indicating high validity. The overall average evaluation score from the validators is 94%, classifying the syllabus as "highly valid." Consequently, according to the validation results from the three validators, it can be concluded that the revised syllabus is ready for testing without the need for further revisions.

Table 2. Results of Lesson Plan Validation

Indicator	Lesson Plan 1 (%)	Lesson Plan 2 (%)	Lesson Plan 3 (%)	Lesson Plan 4 (%)	Average (%)
Completeness of the RPP (Lesson Plan) identity	100	100	100	100	100
Clarity of Core Competencies (KI) and Basic Competencies (KD)	100	100	100	100	100
Clarity of the formulation of achievement indicators	94	94	94	94	94
Alignment of learning objectives with achievement indicators	96	96	96	96	96
Suitability of learning materials	94	94	94	94	94
Alignment of tools, media, and learning resources with objectives, teaching model, and student characteristics	89	89	89	89	89
Suitability of learning outcomes assessment	96	96	96	96	96
Alignment of teaching activities with process standards	98	98	98	98	98
Alignment of teaching activities with the PBL (Problem-Based Learning) model	90	90	90	90	90
Alignment of teaching activities with KKM (Minimum Completeness Criteria)	94	94	94	94	94
Average (%)	**95**	**95**	**95**	**95**	**95**

Based on Table 2, the evaluation results from the validators for Lesson Plan 1 through Lesson Plan 4 show a score of 95%, indicating that they are highly valid. Therefore, the overall average evaluation score from the validators for the revised Lesson Plan is 95%, meaning the RPP is categorized as "highly valid."

Table 3. Results of Student Worksheet Validation

Assessment Aspects	Indicators	Student Worksheet (%)				Average (%)
		1	2	3	4	
Completeness	Completeness of worksheet components	100	100	100	100	100
Materials	Suitability of learning materials	97	97	97	97	97

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Assessment Aspects	Indicators	Student Worksheet (%)				Average (%)
		1	2	3	4	
	Presentation of learning materials	93	93	93	93	93
Implementation	Alignment of worksheet with problem-based learning steps	96	96	96	96	96
	Alignment of worksheet with Minimum Completeness Criteria	97	97	97	97	97
Didactic Criteria	Alignment of worksheet with students' skill levels	89	89	89	89	89
Constructive Criteria	Accuracy of word choice and language used	86	86	86	86	86
Technical Criteria	Font used in worksheet	88	88	88	88	88
	Images presented in worksheet	92	92	92	92	92
	Presentation of worksheet	83	83	83	83	83
Average (%)		**92**	**92**	**92**	**92**	**92**

Based on Table 3, the evaluation results from the validators for various aspects are as follows: the content aspect scored 96%, indicating it is highly valid, and the construction aspect scored 92%, also indicating high validity. Thus, the overall average evaluation score from the validators is 94%, meaning the student worksheet is categorized as "highly valid."

After conducting the trial and obtaining response scores filled out by the students, the researcher calculated and analyzed the response scores regarding the practicality of the revised worksheet. The results of the student responses concerning the practicality of the worksheet can be seen in Table 4 below:

Table 4. Results of Student Responses on Worksheet Practicality

No	Aspect	Student Worksheet (%)				Average (%)
		1	2	3	4	
1	Appearance and Language	92.14	91.61	89.64	90.18	90.89
2	Learning Activities	85.36	85.14	85.29	83.86	84.91
3	Presentation of Materials	88.21	89.64	87.86	88.57	88.57
4	Benefits	90.36	87.86	89.64	88.57	89.11
Average		**89.02**	**88.56**	**88.11**	**87.80**	**88.37**

Based on Table 4, the evaluation results from the students regarding various aspects are as follows: the aspect of presentation and language received a score of 90.89%, categorizing it as "very practical"; the aspect of material presentation received a score of 88.57%, also categorized as "very practical"; and the aspect of benefits received a score of 89.11%, similarly categorized as "very practical." Thus, the overall average score for the practicality of the worksheet is 88.37%, indicating that the revised worksheet is considered "very practical" for use by students.

CONCLUSIONS AND RECOMMENDATIONS

Based on the validation and practicality results, the developed learning tools, including the syllabus, lesson plans (RPP), and student worksheets (LKPD), have been rigorously evaluated and refined through a systematic process. The evaluation by expert validators revealed high validity across all components, with average validation scores of 94% for the syllabus, 95% for the lesson plans, and 92% for the student worksheets. Additionally, the practicality assessment conducted with students indicated that the learning tools are "very practical" for classroom use, with an overall average score of 88.37% for the LKPD.

These findings demonstrate that the Project-Based Learning (PBL) model integrated into the learning tools effectively facilitates the development of students' mathematical communication skills, particularly in the context of linear programming material. The high validity and practicality scores suggest that these tools are well-constructed and highly suitable for implementation in the educational setting, meeting the requirements of the 2013 curriculum. Therefore, it can be concluded that the developed learning tools are ready for broader application in teaching and learning, offering a robust framework for enhancing students' engagement and comprehension in mathematics.

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