Development of Mathematics Learning Tools Based on STEM-PJBL: Validity and Practicality

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Abstract: ***Project-based learning tools need to be developed to improve mathematical problem-solving skills. This research aims to (1) produce project-based learning tools with a STEM approach that are valid and practice the data handling materials, and (2) determine the effectiveness of STEM-PjBL tools in improving students' mathematical problem-solving abilities. The research method used was development research which consists of Preliminary Research, Prototyping, and Assessment phases with the research subjects of SMPN 6 Denpasar students. Data was collected by tests, observations, and documentation. The validation results of the learning tools show that the Student Book meets the valid criteria with an average validity score of 3.47. The teacher's manual meets the very valid criteria with an average validity score of 3.82, and the lesson plan meets the very valid criteria with an average validity score of 3.61. The results of the field test showed that the teacher's book met the practical criteria with an average score of 3.11 in field test II. The student's book met the practical criteria with an average score of 3.01 in field test II. The lesson plan met the practical criteria with an average score of 3.25 in field test II. The implementation of STEM-PjBL tools improves the student's mathematical problem-solving skill by 68,35 in the field test I and by 71,13 in the field test II. The conclusions of this study are the learning tools developed in this study are categorized as valid and practical and are able to improve students' mathematical problem-solving abilities.***

Keywords: STEM-PjBL Toolkits, Mathematical Problem Solving Ability, Data Handling, Research and Development, SMPN 6 Denpasar students.

1. Introduction

Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 21 of 2016 states that the objectives of students learning mathematics include: understanding mathematical concepts, using reasoning in observing a pattern or trait, solving problems, communicating an idea using representations, and appreciating the benefits of mathematics [14]. Based on these regulations, one of the important abilities that is required in the 21st century is problem solving ability. In addition, Erdoğan (2019) states that if students want to compete in a globalized world, they must master four abilities called the 4Cs, namely 1) Communication, 2) Creativity, 3) Critical Thinking and Problem Solving, and 4) Collaboration [6].

The results of PISA (Program of International Student Assessment) assess mathematical literacy skills, which include students' ability to analyze, reason, and communicate ideas effectively when students propose, formulate, solve, and interpret solutions to mathematical problems in various situations. The 2018 PISA results show that the mathematics scores of Indonesian students have decreased from 386 to 371. It can be seen that there are problems with students' mathematical problem solving ability.

STEM (Science, Technology, Engineering, and Mathematics) is a design of learning activities where students directly apply their knowledge to solve real-world problems with an interdisciplinary approach. The word STEM was first stated by the National Science Foundation (NSF) of the United States as an educational reform in the fields of science, technology, engineering, and mathematics that aims to increase competitiveness and students' understanding of STEM [8]. Through STEM education, students learn to think critically, analytically, creatively, collaboratively, and innovatively in solving real problems [1].

R.M. Capraro stated project-based learning provides contextual, authentic, useful experiences to acquire the concepts of science, technology, engineering, and mathematics and is supported by arts, social sciences and language arts [15]. The design principles of project-based learning emphasize the importance of projects as the main means of teaching and students as active participants in constructing knowledge [3]. Through the project-based learning model, students are given more opportunities to explore abilities in cognitive, affective, and psychomotor aspects and students will have their own products that will foster a sense of pride in themselves [2]. PjBL learning strongly supports the development of students' creativity [7][17].

Several studies have also been conducted related to STEM-PjBL, such as experimental research by Ani Ismayani in 2016 which showed that students' mathematical creativity increased after the implementation of STEM-PjBL in the classroom [10]. Design research by Susanti and Kurniawan in 2020 has succeeded in producing student HLT on number pattern material based on Project-based Learning with a STEM approach where HLT is able to make students more active, creative, and collaborative [18]. Researchers who have applied STEM-PjBL also suggest several things to other researchers, such as in a study by Nanang Priatna in 2020 suggesting that subsequent researchers apply STEM-PjBL as an effort to improve other mathematical abilities [13]. In addition, research by Anna Nur Hikmawati in 2018 suggested for further researchers to apply STEM-PjBL to measure students' problem-solving abilities [9]. This study developed a STEM-PjBL device with the subject of Data Presentation which includes Teacher's Books, Student Books, and RPPs (Lesson Plans) aimed at improving the mathematical problem solving abilities of students and students of SMPN 6 Denpasar.

2. Literature Survey

2.1 Project-based learning models

The project is an effort by mobilizing various available resources, and organized to achieve certain goals within an agreed time period [5]. Project organization is needed so that project objectives can be achieved. The organization includes considering efficiency, timeliness, and conformity with the expected quality.

The project that will be carried out in this research adapts to the material to be taught, provided that the project must involve four disciplines, namely science, technology, engineering, and mathematics. Projects do not have to and most will not be completed in one meeting, but several meetings to complete a single project. Projects are well-defined outcomes and ill-structured tasks, meaning that the product of the project has been clearly defined but the process is not, but depends on students' creativity and the scope of the problems. Projects can be physical objects, digital, or programs. An example of a goal that can be achieved in project work is to overcome the problem of pollution in a village. In this example, the project objectives are clear (well-defined outcomes) and students can certainly use various ways to solve the problem depending on the cause of the environmental pollution problem (ill-structured tasks).

2.2 STEM Approach

The word STEM was coined by the National Science Foundation (NSF) of the United States as an educational reform in the fields of science, technology, engineering, and mathematics with the aim of increasing competitiveness and students' understanding of STEM [7]. Through STEM education, students learn to think critically, analytically, creatively, collaboratively, and innovatively in solving real problems [1]. This is in accordance with the industrial era 4.0 which requires the ability to solve problems, be creative, think critically, and collaboratively.

Based on these various descriptions, it can be concluded that an approach that integrates the disciplines of science, technology, engineering, and mathematics with its application focuses the learning process on solving real problems in everyday life is the meaning of the STEM approach.

Mathematics learning in this study uses an interdisciplinary level of integration, meaning the link between concepts and skills learned from two or more disciplines with the aim of deepening knowledge and skills [] (English, 2016). Interdisciplinary learning emphasizes that learning is carried out not only in one discipline, for example a problem is indeed relevant to be discussed in the corridor of mathematics but if the problem does not make sense according to other sciences, then the problem cannot be raised in learning. This happens a lot in learning that is said to be contextual but does not consider other sciences, such as raising the problem of someone buying dozens of watermelons without being given a sufficient reason, just to make the problem look contextual. Mathematics lessons taught will be more effective because the fields of science, technology, and engineering will strengthen and complement student learning materials in understanding and applying mathematics lessons. A subject does allow the need for interdisciplinary knowledge, for example in answering problems regarding the volume of water, students need to understand that the nature of water fills an empty space, so it is the same as the volume of a container. Learning mathematics using the STEM approach in learning is designed to provide opportunities for students to apply the knowledge they have acquired academically into the real world.

3. Method

The Plomp development model is a reference in conducting this research. According to Plomp & Nieveen, the phases of development research consist of three stages, namely: 1) Preliminary Research, 2) Prototyping, and 3) Assessment [12]. The product produced in this study is a STEM-PjBL learning tool in the form of a teacher's book and a student's book to be able to improve students' problem solving abilities. Three aspects that are reviewed in assessing the quality of learning tools are validity, practicality, and effectiveness. The procedure in this study is divided into three stages which are illustrated in the chart below:

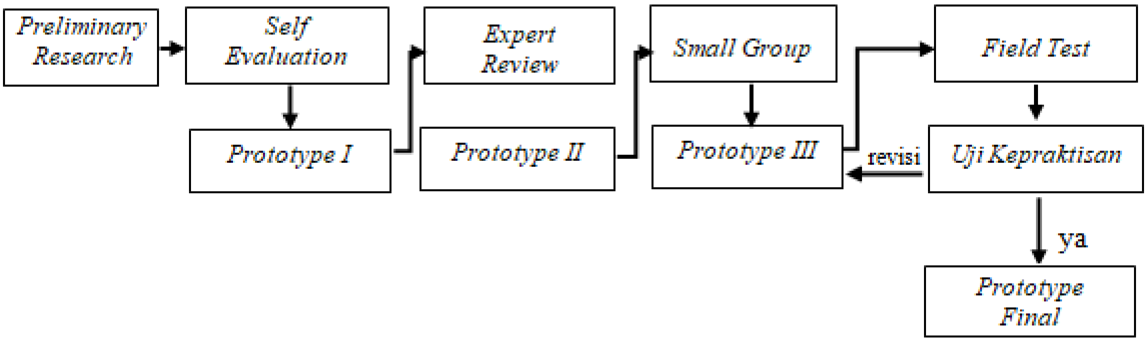

Figure 1: Research procedure

This study collects data for review and draws conclusions. Student learning outcomes are known through tests after going through the learning process with the STEM-PjBL Toolkit. This test was carried out at the end of field tests I and II. During the learning process, researchers used observation sheets to assess the practicality of using the developed device. Two observers are tasked with carrying out this assessment. Learning tools that have undergone improvements in each phase are archived as research documentation. In addition, the results of the validity, practicality, and effectiveness assessments are also documented.

The validity of the learning tools was assessed by three experts and calculated using the formula:

$$Sr = \frac{total\ score}{the\ number\ of\ the\ items}$$

Description:
Sr = average score based on validation results

The following are the criteria for the scores obtained:

Table 1: Criteria for Validity of Learning

Score	Criteria
$3,5 \leq Sr \leq 4,0$	Very Valid
$2,5 \leq Sr \leq 3,5$	Valid
$1,5 \leq Sr \leq 2,5$	Invalid
$1,0 \leq Sr \leq 1,5$	Very Invalid

[16]

Questionnaires filled out by teachers and students in the limited trial, field test I, and field test II became the benchmark for practicality assessment. The practicality calculation formula is:

$$Sr = \frac{total\ score}{the\ number\ of\ the\ items}$$

Description:
Sr = average score based on validation results

The following are the criteria for the scores obtained:

Table 2: Practical Criteria for Learning Devices

Score	Criteria
$3,5 \leq Sr \leq 4,0$	Very practical
$2,5 \leq Sr < 3,5$	Practical
$1,5 \leq Sr < 2,5$	Impractical
$1,0 \leq Sr < 1,5$	Very Impractical

[16]

Learning tools are said to be effective if in each field test the average posttest score is higher than the average pretest score.

$$X0 < X1$$

Description:
X0: the average class uses conventional learning tools
X1: class average using the STEM-PjBL perangkat device

4. Results

The activities in this study have succeeded in developing mathematics learning tools according to the characteristics of STEM-PjBL that meet the valid criteria. There are two basic competencies that are expected to be achieved using this learning tool, namely: 1) Analyzing the data by the way it is presented (tables, line charts, bar charts, and pie charts), 2) Collecting, processing, interpreting, and presenting observational data. in the form of tables, diagrams, and graphs.

Based on the initial analysis, it was found that the main things that need to be considered and handled in learning include: (1) conventional learning where students tend to be just listeners, (2) in learning students tend to memorize the material so they are less able to understand the concepts being studied. , (3) teachers rarely develop learning tools independently that should be adapted to the conditions of students, (4) students are less active during learning activities, 5) learning tools used as a whole do not provide real learning for students. The prototyping phase is followed by an assessment phase in the process, where each test phase is followed by an assessment.

Then, the data collection stage, where the researcher begins by collecting the data needed to develop learning tools. Data collection includes analysis of the material through various references and collection of images related to the data presentation material. Researchers compiled books based on KD 3.16. Analyzing the data by the way it is presented (tables, line charts, bar charts, and pie charts) and 4.16. Collect, process, interpret, and present observational data in the form of tables, diagrams, and graphs.

Then, the product design phase where learning tools are designed based on the problems found in the initial research phase and adapted to project-based learning with a STEM approach. The products produced are in the form of teacher books, student books, and RPP (Learning Implementation Plans) which are attached with LKPD. The important parts of the student book are the introductory section which aims to introduce students that they will not only learn mathematics but also apply it in an environmental context, the section “Let's Observe!” introduce the material to students contextually and its nature is still very basic so that students will explore the material more in the next activity (project work), the "Let's Ask!" make students feel that their questions, participation, and activeness are important in learning, section “Let's Reason!” make students think more critically, the section “Let's Do a Project!” which is the main characteristic of the book, which aims to make students able to apply their knowledge and knowledge directly and dig deeper into their knowledge through working on the project, the last part is the section "Let's Practice!" aims to make students more familiar with problem solving type questions and they also practice to solve them.

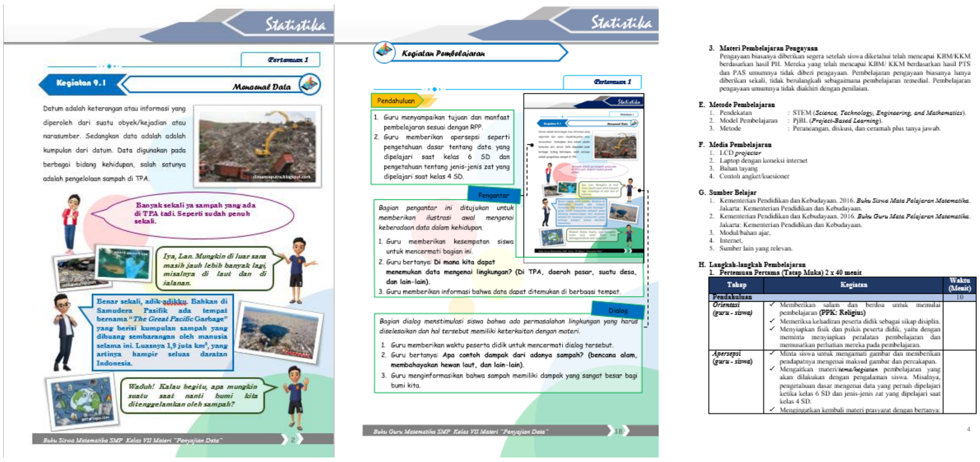

Figure 2: Prototype I learning device

The validity of the learning tools was assessed, including content validity and construct validity. Content validity assesses the suitability of the device with the development theory that is used as a guide, in this study is the development theory by Plomp and is in accordance with the demands of the applied learning characteristics. Then construct validity assesses the suitability of the learning devices developed with the characteristics of the applied learning. To assess construct validity, the researcher asked the opinion of three experts who acted as validators. Validators read, analyze, comment on, and assess learning tools on the validation sheet. Following are the results of the validation by three validators.

Table 3: Construct Validity Results

No.	Learning Media	Validator score average 1	Validator score average 2	Average validator score 3	The average score of the three validators	Category
1	Student book	3,23	3,32	3,91	3,47	Valid
2	Teacher's manual	3,92	3,85	3,69	3,82	Very Valid
3	Lesson Plan	3,50	3,59	3,73	3,61	Very Valid

The student book is declared valid because it is in the range $3,0 \leq Sr < 3,5$. Then the teacher's manual and lesson plans have been declared very valid with a range of $3,5 \leq Sr \leq 4,0$. In addition, the validator has also reviewed the feasibility of student response questionnaires, teacher response questionnaires to teacher books, student books, and the implementation of learning. The validator has stated that the questionnaires are suitable for use.

After validation, the device was declared valid to be applied but with several revisions. The following are some of the revisions made to the prototype I student book.

- Match time with activities
- Clarify project work
- Fixed an example of a frequency distribution table
- Adding a place setting to the story to make it more illustrative and interesting
- Checking EYD (Indonesian Enhanced Spelling) usage

Revisions also occur in the teacher's manual, including:

- Clarify the transition between preliminary activities and core activities
- Improve writing by paying attention to EYD (Indonesian Enhanced Spelling)

The lesson plans also received revisions, including:

- Fixed some of the sources presented in the form of links
- Re-allocation of time due to online learning
- Check writing with attention to EYD (Indonesian Enhanced Spelling)

The prototype II is ready for use in the field. The test conducted on prototype II was a limited field test consisting of 12 students taken from class VII 9 SMPN 6 Denpasar. The assessment carried out is in the form of teacher assessment of the practicality of the book and the implementation of learning, in addition to student assessment of student books. The following are the results of the assessment in this limited test.

Table 4: Prototype II Assessment Results

No.	Rating result	Average score	Criteria
1	Observer 1 on learning devices	2,70	Practical
2	Observer 2 on learning devices	2,60	Practical
3	Teachers on the implementation of learning tools	2,89	Practical
4	Student responses to student books	2,86	Practical

Based on the results of student assessments, teacher observations, and observer observations, there are things that need to be improved or added to the learning device, so revisions are needed. The following are the details of the revisions made to the prototype II student book.

- Changed the editor of “Let's Get to the Project!” to “Let's Get On With The Project!”
- Adding reading sources through QR codes as an effort to improve students' reading literacy and technological literacy

Improvements to the teacher's book only adjust to the additions made to the student book. Then, the lesson plans need to clarify the activities in the discussion process and project work so that it is more supportive of online learning. The results of the revision carried out by researchers on prototype II resulted in prototype III which will be used in field testing I.

Prototype III was then tested again in the field test stage I with 23 students of class VII 8 SMPN 6 Denpasar and a math teacher in 7 meetings. The following are the results of the assessment obtained in the field test I.

Table 5: Results of Prototype III Assessment

No.	Rating result	Average score	Criteria
1	Observer 1 on learning devices	2,90	Practical
2	Observer 2 on learning devices	3,00	Practical
3	Teachers on the implementation of learning tools	3,00	Practical
4	Student responses to student books	2,90	Practical

In this first field test, students were also given a problem-solving ability test at the end of the meeting. The test results show that the class average has increased between before and after using the STEM-PjBL device, where before the study the average value of the class was 56.29 then after the study, the class average increased to 68.35.

After the first field test, the observations of teachers and researchers found several things that still needed to be revised, especially in student books, including:

- The author's way of delivering the book is made to be more interesting, concise, and fresh.
- Characters are made to be more flexible.
- Writing the introduction of the book is made more interesting and concise

Improvements to the teacher's book still only adjust to changes and additions to the student book, while the lesson plans are not revised. The results of the revision carried out by researchers on prototype III resulted in prototype IV which will be used in field tests II.

Prototype IV was then tested in the second field test stage with 7th grade students of SMPN 6 Denpasar and mathematics teaching teachers in 7 meetings. The following is a summary of the assessments obtained from the field test II.

Table 6: Prototype IV. Assessment Results

No.	Rating result	Average score	Criteria
1	Observer 1 on learning devices	3,20	Practical
2	Observer 2 on learning devices	3,30	Practical
3	Teachers on the implementation of learning tools	3,11	Practical
4	Student responses to student books	3,01	Practical

In this second field test, students were also given a problem-solving ability test at the end of the meeting. The test results show that the average class has increased between before and after using the STEM-PjBL device, where before the study the average value of the class was 60.59 then after the study, the class average increased to 71.13. In addition, this average value is also more than the class average value when the field test I indicated that the revision process was quite influential.

Based on this assessment, prototype IV has also been assessed as practical. However, there are still some small things that researchers need to improve in the device so as to produce a final product. The things that need to be revised in the prototype IV student book, include:

- Expand reading resources through QR codes to add project ideas that students will make.
- Added how to use the book.

Improvements to the teacher's book still only adjust to changes and additions to the student book, while the lesson plans are not revised. The result of this revision is the final product.

The following is a display of the learning tools along with one of the sites developed as an example for students to create their projects:

Figure 3: The final product of the learning device

This final product has been in the form of student books, teacher manuals, and lesson plans that have STEM-PjBL characteristics. This has also been shown from the learning activities carried out during the limited trial, field test I, and field test II. This STEM-PjBL device is designed with a focus on improving students' problem solving abilities. By working on complex projects, where the science involved also pays attention to other sciences, students will be better trained to solve problems directly, not only in writing.

5. Conclusion

This research has succeeded in developing valid, practical, and effective STEM-PjBL tools and has characteristics that distinguish it from other learning tools. The characteristics of the student books developed in this study are (1) the student books contain learning activities according to the STEM-PjBL stages, (2) students directly experience problems and apply mathematics in their lives, and (3) student books contain problems that are close to life. students related to the material being studied, (4) Students get a lot of ideas in making projects through reading sources that are connected to books. The characteristics of the teacher manual developed in this study were (1) the teacher manual facilitates and guides the teacher in the learning process in the classroom with the STEM-PjBL model, (2) the teacher manual contains project ideas that allow students to make, and (3) Contains lesson plans and Students' Worksheet that support the STEM-PjBL learning process.

6. Suggestion

Some suggestions that the researcher hopes for are, 1) The next teachers, or writers, can develop similar learning tools with a wider scope of material, 2) teachers need to adapt the technology used to school conditions, and 3) readers who intend to apply this learning tool should pay attention to the background conditions of students.

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