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Designing PMRI-Based Learning Materials Using the ADDIE Model to Enhance Conceptual Understanding of π (Pi) in Circle Topics

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Abstract

This article is about developing mathematics learning materials related to the Indonesian Realistic Mathematics Education (PMRI) approach for teaching the circle topic, with a focus on enhancing sixth-grade students' conceptual understanding of π (Pi) at MI Ma'arif Pagerwojo. The development followed the ADDIE instructional design model. The research instruments included expert validation sheets, lesson implementation observation sheets, response questionnaires, and achievement tests. Based on expert validation, two validators rated the teaching module at 95.5% and 92.6%, the student worksheet (LKPD) at 91.6% and 94%, and the learning outcome test at 85% and 90% all falling within the "highly valid" category. Observation results of lesson implementation by both teacher and students yielded scores of 90% and 87.5%, respectively, while teacher and student response questionnaires reached 93.7% and 87%. It shows that the developed learning materials are highly practical. The effectiveness also has been proved, as 80% of students met the minimum mastery criterion (KKM), satisfying the criterion for classical completeness. These findings demonstrate that PMRI-based materials effectively facilitate students' meaningful understanding of π through contextual learning activities. Moreover, the context of this study focused on developing instructional materials at the primary school level remains underexplored in educational development research. Thus, this study may serve as a reference for broader international mathematics education, particularly since PMRI aligns closely with the principles of Realistic Mathematics Education (RME).

Keywords: Indonesian Realistic Mathematics Education (PMRI); instructional material development; the concept of Pi (π) value; ADDIE model.

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INTRODUCTION

In primary school mathematics, the topic of circles and the value of π (Pi) serves as a foundational concept for understanding more advanced geometric topics at higher educational levels. However, many students still struggle to grasp the conceptual meaning of π. Mizan (2019) found that among 70 university students surveyed, 18.66% (or 14 students) did not know how to determine the value of π conceptually. Similarly, Narpila et al. (2024) reported that a significant number of seventh-grade students were unaware of the origin of π. Furthermore, Clements & Sarama (2020) emphasized that students' lack of understanding of π as the invariant relationship between the circumference and diameter of a circle stems from the absence of deep instruction on the topic during primary education.

Teacher-centered instruction and the lack of relevant learning materials have also contributed to students' difficulties in developing conceptual understanding in mathematics (Sahara et al., 2023). More than 80% of mathematics learning activities are dominated by teachers, resulting in low student engagement in the learning process (Widjaja et al., 2010). A review of the literature further reveals that instructional materials developed for primary schools have not specifically addressed the concept of π (Pi). This indicates a gap in the availability of learning resources that support students in meaningfully understanding the concept of π in accordance with their cognitive developmental stage (Mizan, 2019). Therefore, it is essential for teachers to implement contextual learning approaches that encourage students to independently construct mathematical concepts (de Freitas & Sinclair, 2014).

Mathematics instruction should primarily focus on the discovery of concepts, rather than merely presenting them as ready-made facts to students (van den Heuvel-Panhuizen, 2000). This perspective aligns with the purpose of 21st-century education, which emphasize the critical thinking development, creativity, collaboration, and communication skills. One instructional approach that resonates with these characteristics is the Indonesian Realistic Mathematics Education (PMRI) approach. This approach offers a promising pathway to enhance students' conceptual understanding, reasoning abilities, and problem-solving skills in mathematics (Fauzan, 2002).

PMRI (Indonesian Realistic Mathematics Education) begins with phenomena that are "real" to students and emphasizes the *process of doing mathematics* (Zulkardi, 2002). This approach is student-centered and promotes *learning by doing*, whereby students develop understanding and skills not merely through theoretical explanations, but through active engagement in meaningful activities (Hadi, 2002). PMRI is adapted from Realistic Mathematics Education abbreviated as RME, that was developed in the Netherlands in the 1970s and later contextualized to align with Indonesia's cultural, geographical, and societal conditions (Sembiring et al., 2008). RME is grounded in the ideas of Freudenthal and his colleagues at the Freudenthal Institute, who viewed mathematics as a human activity (van den Heuvel-Panhuizen, 2000). Accordingly, mathematics should be connected to reality, rooted in students' experiences, and relevant to their lives and communities (Uyen et al., 2021).

The PMRI approach utilizes real-world contexts to help students transform abstract mathematical concepts into more representational and accessible forms (Putri et al., 2015). Furthermore, Yilmaz (2019) noted that one of PMRI's strengths lies in its ability to guide students in rediscovering mathematical concepts through a process of progressive mathematization. PMRI adheres to the same core principles as RME. According to Gravemeijer (1994), there are three fundamental principles in mathematics instruction based on the realistic approach: (1) guided reinvention and progressive mathematizing, (2) didactical phenomenology, and (3) the use of self-developed models.

Guided reinvention and progressive mathematizing refer to students' experiences in independently discovering diverse concepts, principles, or procedures under the guidance of the teacher (Bulut, 2004). Didactical phenomenology is an approach in which students learn concepts, principles, or subject matter through contextual problems that allow for multiple possible solutions (Ali, 2022). Meanwhile, self-developed models involve students constructing their own models in solving their problems, thereby fostering the development of their mathematical thinking processes (Ozturk, 2025).

PMRI also shares the same characteristics as RME. Treffers (1993) identified five key features of realistic mathematics instruction, including: (1) the use of context, where learning begins with contextual problems that are familiar to students' daily lives and are intended to stimulate thinking and support the construction of mathematical understanding (Doorman, 2007); and (2) the use of models for progressive mathematization, which serve as bridges between informal and formal knowledge (Armanto, 2002). In the RME approach, models are utilized to facilitate both horizontal and vertical mathematization (Blum & Niss, 1991). Horizontal mathematization refers to the process of identifying real-world situations and translating them into mathematical language to make them more accessible. In contrast, vertical mathematization involves reorganizing existing mathematical activities into more formal, abstract, and structured forms (De Lange, 1996).

Another key characteristic of RME is the utilization of students' own constructions, where students' thinking serves as the foundation for instructional development (Palinussa et al., 2021). Leveraging students' constructions reinforces the meaning of mathematical concepts, as the understanding emerges from their own experiences and ways of thinking (Gravemeijer, 1994). (4) Interactivity, where the learning process actively engages students in comparing and discussing their solutions in collaborative settings. This goes beyond merely exchanging answers it involves strategic discussions about how solutions are generated and the validity of the reasoning steps used (Yackel & Cobb, 1996). (5) Interconnectedness, which emphasizes that mathematical concepts should not be taught in isolation, but rather as interrelated ideas. This helps students perceive mathematics as a coherent and meaningful whole (Gravemeijer & Doorman, 1999).

To support the implementation of PMRI, it is essential to develop learning materials grounded in the PMRI approach. These instructional materials serve as structured guidelines that facilitate students in discovering mathematical concepts while also enhancing their motivation and engagement in the learning process (Yolanda & Hasanah, 2022). PMRI-based learning materials can foster reflective thinking and promote active student involvement in solving mathematical problems in a meaningful way. Such materials typically include teaching modules, student worksheets (LKPD), and achievement tests (Gravemeijer, 1994).

A teaching module is one of the instructional components designed in accordance with the applicable curriculum, intended to help students achieve the specified learning competencies (Maulida, 2022). Its primary function is to serve as a support tool for teachers in planning and implementing the learning process (Nesri & Kristanto, 2020). Ideally, teachers should develop teaching modules effectively, as poorly planned instruction can result in an unsystematic delivery of content to students. However, in practice, many teachers still lack adequate understanding of how to properly design an effective teaching module (Ceda & Purnomo, 2024).

In addition, another essential instructional component that supports students' active engagement is the student worksheet (LKPD). According to , an LKPD is a learning guide that outlines the activities students need to carry out to achieve specific learning objectives. LKPDs serve to reduce teacher dominance in the classroom while encouraging active student participation throughout the learning process (Septian et al., 2019). Furthermore, Rewatus et al. (2020) describe LKPDs as instructional tools used by teachers to enhance students' learning activity and promote cognitive engagement, thereby assisting them in solving problems during instruction. However, in practice, many of the LKPDs currently used by teachers have not been designed to present contextual problems, and thus fail to fully support students' active involvement in constructing conceptual understanding.

Furthermore, assessment or learning outcome tests should be designed in alignment with PMRI principles to accurately measure students' conceptual understanding, rather than merely assessing procedural recall (Gravemeijer, 1994). In the PMRI approach, assessment is not limited to final answers but also emphasizes students' thought processes in solving mathematical problems. Therefore, assessments should take the form of open-ended, context-based questions that require students to logically and systematically explain their reasoning, strategies, and problem-solving processes (Putri et al., 2015).

Based on the aforementioned explanation, this study offers a novelty in the form of developing PMRI-based instructional materials specifically designed to facilitate students' discovery of the concept of π (Pi) through empirical experiences, the application of real-life contexts, and the systematic implementation of the ADDIE model to produce learning tools that are valid, practical, and effective (Nieveen, 1999). Accordingly, this study aims to develop PMRI-based learning materials on the topic of circles that are valid, practical, and effective in supporting sixth-grade students' conceptual understanding of π (Pi) at the primary school level. This research is expected to enrich the literature on PMRI-oriented instructional design, particularly in embedding mathematical concepts at the elementary level. Moreover, the resulting learning materials may serve as valuable resources for teachers to deliver meaningful instruction on π (Pi) and to reduce misconceptions through realistic, activity-based learning experiences.

METHOD

This study uses a research and development (R&D) approach, which involves a series of steps aimed at improving existing products or developing new ones that are scientifically accountable (Winarni, 2018). The development model adopted in this study is the ADDIE model: Analyze, Design, Development, Implementation, and Evaluation, which provides a systematic yet flexible framework, making it highly suitable for various types of instructional development research (Branch, 2009).

The subjects is included two mathematics lecturers from the Primary School Teacher Education (PGSD) program at Nahdlatul Ulama University, Sidoarjo, who served as validators to assess the validity of the developed instructional materials. Validator 1 holds a bachelor's and master's degree in mathematics education, while Validator 2 holds a bachelor's and master's degree in primary education with a concentration in mathematics. Both have more than five years of teaching experience in geometry and instructional material development courses. Additional research subjects included a sixth-grade mathematics teacher who implemented the instructional materials in the classroom, as well as 30 students from MI Ma'arif Pagerwojo who participated in lessons using the developed materials. According to (Baley, 2011), the minimum sample size for development research is 30 participants; thus, the number of student participants in this study meets the minimum requirement and is considered sufficient to evaluate the practicality and effectiveness of the instructional materials.

The first stage of this study was the analysis phase, during which the researcher conducted interviews with a teacher at MI Ma'arif Pagerwojo to identify both student and teacher needs related to mathematics instruction in sixth grade, particularly concerning students' conceptual understanding of the subject matter. The researcher also analyzed the characteristics of sixth-grade students to ensure that the content of the instructional materials being developed aligned with their needs and cognitive abilities. In addition, a document review of the school's curriculum was carried out to confirm that the developed materials were in accordance with the intended learning outcomes and instructional objectives.

The second stage was the design phase. The researcher gathered references from various sources and conducted a content review to ensure that the instructional materials being developed were aligned with the intended learning outcomes. In this stage, the initial framework of the learning materials was also drafted. The third stage involved developing the designed materials and submitting them for expert validation. The fourth stage was the implementation phase, in which the instructional materials were applied in the classroom. During this phase, the researcher conducted observations to assess teacher and student engagement throughout the learning process, as well as the ease of use of the instructional materials. Attention was also given to the flow of instruction, the alignment of the materials with the allotted time, and the extent to which the materials supported the achievement of learning objectives. In addition, the researcher distributed response questionnaires to both the teacher and students. These observations and questionnaires were used to evaluate the practicality of the instructional materials.

The final stage was the evaluation phase. After the instructional process was completed, students were given a test to assess their understanding of the material. The test was developed based on indicators aligned with the learning objectives. Each student's test score was then compared to the Minimum Mastery Criterion (KKM) to determine the percentage of students who achieved mastery. This evaluation was carried out to assess the effectiveness of the instructional materials in supporting students' comprehension of the subject matter.

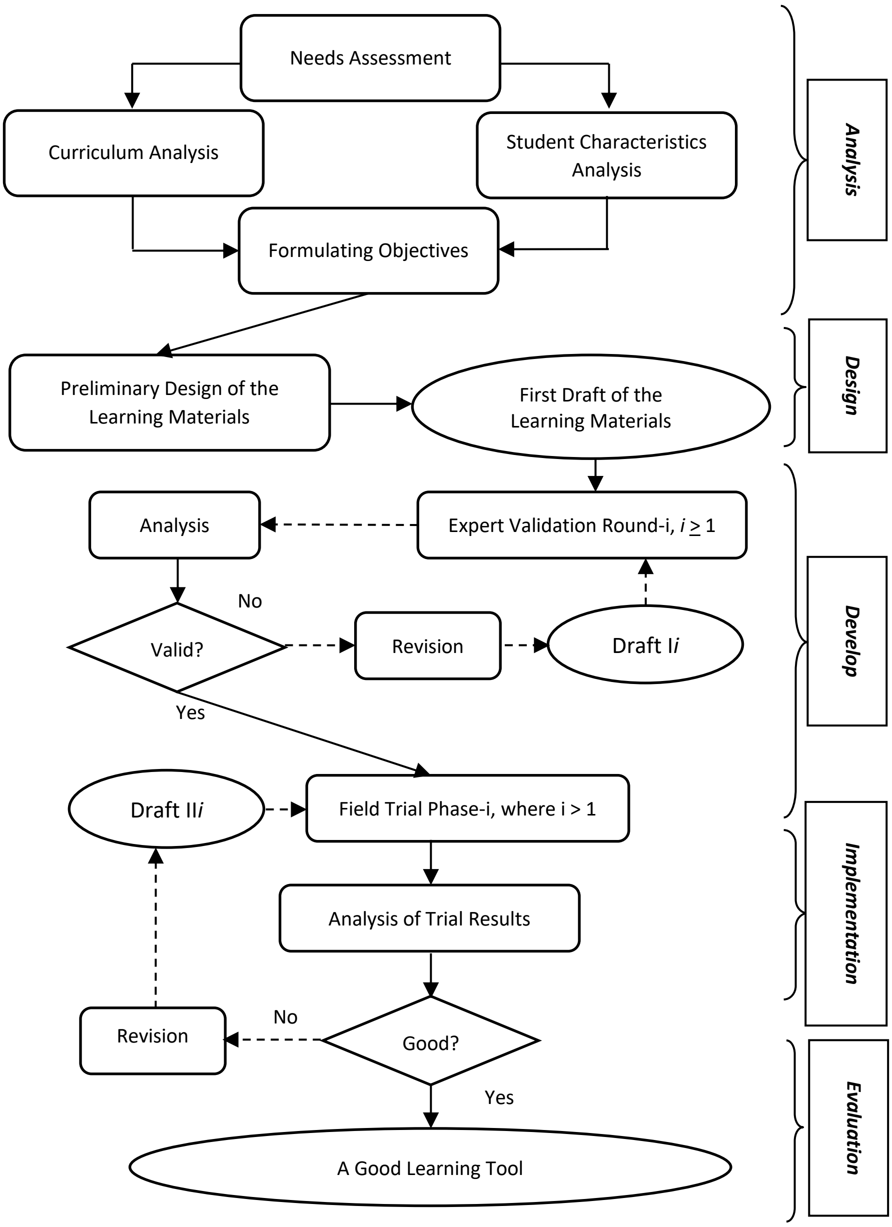


Figure 1. R&D Procedure Using the ADDIE Model

Three data collection techniques were employed in this study: observation, questionnaires, and testing. The research instruments used were classified into three categories: instruments for measuring validity, practicality, and effectiveness. Instruments for assessing the validity of the developed instructional materials included a teaching module validation sheet, an LKPD (student worksheet) validation sheet, and a learning outcome test validation sheet. Each of these instruments took the form of a checklist using a four-point rating scale, in which validators marked the criteria that best represented their evaluation on each validation form. The aspects assessed in each validation sheet are presents in Table 1.

Table 1. Validity Instruments of the Instructional Materials

Instrument	Validity Aspects
Teaching Module Validation Sheet	Completeness of module components; formulation of learning objectives/indicators; learning content; selection of approach and teaching methods; learning activities; learning resources; assessment; appropriateness of time allocation

Instrument	Validity Aspects
LKPD (Student Worksheet) Validation Sheet	Alignment of LKPD with the PMRI approach; quality of LKPD content; alignment of LKPD with didactical requirements; alignment of LKPD with construction requirements; alignment of LKPD with technical requirements
Learning Outcome Test Validation Sheet	Content aspect; language and question-writing aspects

The instruments used to assess the practicality of the developed instructional materials included lesson implementation observation sheets (completed by both teachers and students), as well as teacher and student response questionnaires. The observation sheets used for both teacher and student assessments employed a four-point checklist scale. The teacher response questionnaire also used a four-point checklist, while the student response questionnaire consisted of binary-choice items ("yes" or "no"). The aspects evaluated in each of these instruments are presents in Table 2.

Table 2. Practicality Instruments of the Instructional Materials

Instrument	Practicality Aspects
Observation sheet on the implementation by the teacher	Conducting learning activities using the PMRI approach; teacher-student interaction during learning; efficient time management
Observation sheet on the implementation by the students	Learning steps in the teaching module that reflect the characteristics of the PMRI approach
Teacher and student response questionnaire	Teacher/student responses to mathematics learning using the PMRI approach; perceived benefits of learning mathematics with the PMRI approach

Analysis of Validation Data by Validators

The analysis of instructional media validation data was conducted by calculating the score obtained from the validators using the following formula:

$$\text{Percentage} = \frac{Total\ score\ obtained}{Total\ ideal\ score} \times 100\%$$

The resulting percentage is interpreted based on the following criteria:

Table 3. Validity Criteria

Percentage Interval (%)	Criteria
$80 \leq P < 100$	Very valid
$60 \leq P < 80$	Valid
$40 \leq P < 60$	Fairly valid
$20 \leq P < 40$	Less valid
$0 < P < 20$	Not valid

(Akbar, 2013)

The developed instructional materials must receive a minimum percentage score of $60\% \leq P < 80\%$ from the validators to be categorized as valid.

Analysis of Observation Data from Teachers and Students

The analysis of observation data and response questionnaires from teachers and students aims to assess the practicality of the developed instructional materials. The researcher analyzed the data from observations and teacher and student response questionnaires using the following formula:

$$\text{Percentage} = \frac{Total\ score\ obtained}{Total\ ideal\ score} \times 100\%$$

The resulting percentage is interpreted based on the following criteria:

Table 4. Practicality Criteria

Interval Persentase (%)	Criteria
80 ≤ P < 100	Very Practical
60 ≤ P < 80	Practical
40 ≤ P < 60	Fairly Practical
20 ≤ P < 40	Less Practical
0 < P < 20	Not Practical

(Akbar, 2013)

The developed instructional materials must obtain a percentage score in the range of 60% ≤ P < 80% based on the results of lesson implementation observations and student response questionnaires in order to be categorized as practical.

Analysis of Learning Outcome Test Data

To determine the effectiveness level of the instructional materials, the researcher analyzed the students' learning outcome test results using the following formula:

$$\text{Percentage} = \frac{Number\ of\ students\ scoring \geq \text{KKM}}{Total\ number\ of\ students} \times 100\%$$

The criteria for effectiveness used are as follows:

Table 5. Effectiveness Criteria

Percentage Interval (%)	Criteria
80 ≤ P < 100	Very Effective
60 ≤ P < 80	Effective
40 ≤ P < 60	Fairly Effective
20 ≤ P < 40	Less Effective
0 < P < 20	Not Effective

(Akbar, 2013)

The developed instructional materials are considered effective if the percentage of students achieving at least the minimum mastery criterion (KKM) falls within the effective category (60% ≤ P < 80%) or the highly effective category (P ≥ 80%). This evaluation reflects the extent to which the instructional materials support students in achieving the intended learning outcomes.

RESULTS AND DISCUSSION

The research began with a needs analysis. Based on interviews with the sixth-grade mathematics teacher at MI Ma'arif Pagerwojo, it was found that students had not been taught how to discover the value of π (Pi). Instead, they were simply asked to memorize that π equals 22/7 or 3.14. As a result, students were only able to apply this value in calculating the area or circumference of a circle, which led to a weak conceptual understanding of π (Clements & Sarama, 2020). Therefore, implementing a PMRI-based learning approach at MI Ma'arif Pagerwojo could serve as a solution by providing students with opportunities to independently construct mathematical concepts through real-world experiences (Kamsurya, 2019).

The curriculum implemented at the school follows the *Merdeka* Curriculum. The learning objectives for Phase C of the mathematics subject in Grade 6 of primary school (SD/MI) require students to be able to calculate the areas of various two-dimensional shapes (triangles, quadrilaterals, polygons, and circles) and their combinations, as well as the surface area and volume of cubes, rectangular prisms, and their combinations. Students are also expected to explain the comparison between two different quantities related to speed and flow rate, along with their respective units. Based on these competencies, the researcher formulated three instructional objectives: (1) through learning activities using the PMRI approach, students are expected to accurately understand the concept of π (Pi); (2) through learning activities using the PMRI approach, students are expected to accurately derive the formulas for the circumference and area of a circle; and (3) through learning activities using the PMRI approach, students are expected to accurately solve problems related to the circumference and area of a circle.

The sixth-grade students at MI Ma'arif Pagerwojo are between 11 and 12 years old and are at the actual operational stage of Piaget's cognitive development theory. This stage is characterized by a tendency to explore, experiment, and investigate. In addition, the students exhibit diverse academic abilities and personality traits. The analysis phase is used to identify students' learning needs (Aldoobie, 2015) and to determine the specifications for product development objectives (Hernawati, 2016).

The second stage is the design phase, in which the researcher developed the instructional materials and research instruments based on the results of the needs analysis. In addition, the selected formats were designed with careful consideration of the characteristics of the PMRI approach (Hernawati, 2016). As explained by Nindiawati et al. (2021), the design phase involves constructing the initial draft of the learning materials, which includes outlining the framework, organizing the content, and developing the assessment instruments to be used.

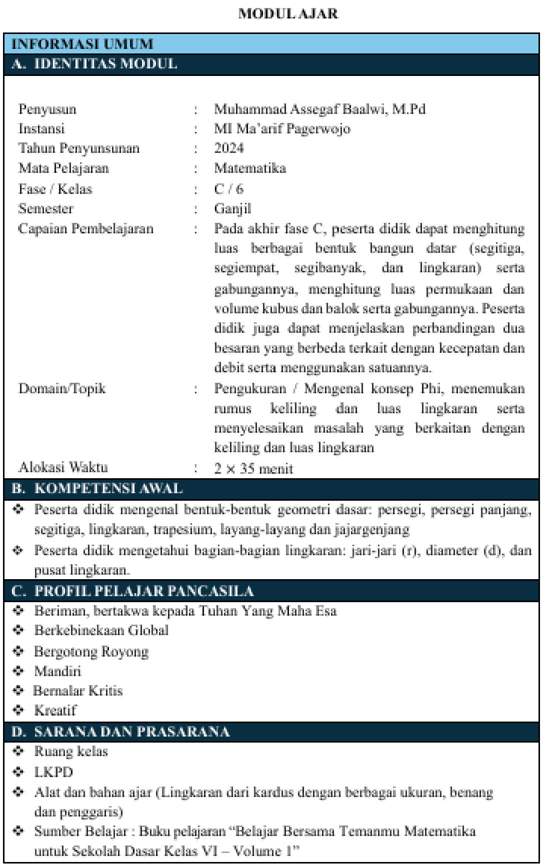
The next stage involved developing the product based on the results of the analysis and initial design, followed by expert validation to ensure the appropriateness of the content (Alodwan, 2018). Based on validation by two subject-matter experts, the teaching module received scores of 95.5% and 92.6%, indicating that it falls within the "highly valid" category. Similarly, the LKPD (student worksheet) was validated by two experts who assigned scores of 91.6% and 94%, respectively—also classified as "highly valid." The validation results for the learning outcome test were 85% and 90%, confirming that the test is likewise in the "highly valid" category. These results indicate that the developed instructional materials meet the required standards of content quality, alignment with the instructional approach, and technical soundness. Furthermore, the score differences between validators were minimal, with the largest gap being only 5%, suggesting that the evaluations were consistent and free from significant bias. Therefore, the instructional materials that have passed expert validation and meet the validity standards may be considered appropriate for classroom implementation (Setiyadi, 2017).

The expert validators provided several suggestions regarding the instructional materials. These served as the basis for the researcher to refine the content development, enhance the quality of instruction, and ensure alignment with the intended instructional objectives (Woo, 2018).

Table 6. Suggestions for Improvement from Expert Validators

Instructional Material	Validator 1	Validator 2
Teaching Module	The prompting question should begin by asking students to mention circular-shaped objects around them.	The allocation of instructional time should be adjusted to align with the characteristics of PMRI.
	The PMRI characteristic of "intertwinement" can be linked to the activity of discovering the area of a circle.	At the end of the lesson, it is recommended to include a teacher-led activity that provides

Instructional Material	Validator 1	Validator 2
		information about the material to be studied in the next meeting.
LKPD	The sentence that guides students to draw conclusions in the "construction" stage needs to be improved.	It might be helpful to add images that support the context in the student worksheet (LKPD).
	For the PMRI characteristic of "intertwinement," it is necessary to provide context or guidance such as: "Divide the circle into several sectors (e.g., slices of pizza), then rearrange them to resemble the shape of a rectangle. Students are guided to discover the formula for the area of a circle."	It is recommended to include a table for recording the measurements of each circle.
Learning outcome test	There are several words with typing errors.	There are several misspelled words.
	The language used in the test instructions needs to be improved.	


MODUL AJAR

INFORMASI UMUM

A. IDENTITAS MODUL

Penyusun	:	Muhammad Assegaf Baalwi, M.Pd
Instansi	:	MI Ma'arif Pagerwojo
Tahun Penyunsunan	:	2024
Mata Pelajaran	:	Matematika
Fase / Kelas	:	C / 6
Semester	:	Ganjil
Capaian Pembelajaran	:	Pada akhir fase C, peserta didik dapat menghitung luas berbagai bentuk bangun datar (segitiga, segiempat, segibanyak, dan lingkaran) serta gabungannya, menghitung luas permukaan dan volume kubus dan balok serta gabungannya. Peserta didik juga dapat menjelaskan perbandingan dua besaran yang berbeda terkait dengan kecepatan dan debit serta menggunakan satuannya.
Domain/Topik	:	Pengukuran / Mengenal konsep Phi, menemukan rumus keliling dan luas lingkaran serta menyelesaikan masalah yang berkaitan dengan keliling dan luas lingkaran
Alokasi Waktu	:	2 × 35 menit

B. KOMPETENSI AWAL

- Peserta didik mengenal bentuk-bentuk geometri dasar: persegi, persegi panjang, segitiga, lingkaran, trapesium, layang-layang dan jajargenjang
- Peserta didik mengetahui bagian-bagian lingkaran: jari-jari (r), diameter (d), dan pusat lingkaran.

C. PROFIL PELAJAR PANCASILA

- Beriman, bertakwa kepada Tuhan Yang Maha Esa
- Berkebinekaan Global
- Bergotong Royong
- Mandiri
- Bernalar Kritis
- Kreatif

D. SARANA DAN PRASARANA

- Ruang kelas
- LKPD
- Alat dan bahan ajar (Lingkaran dari kardus dengan berbagai ukuran, benang dan penggaris)
- Sumber Belajar : Buku pelajaran "Belajar Bersama Temanmu Matematika untuk Sekolah Dasar Kelas VI – Volume 1"

Figure 2. Teaching Module

Figure 3. Student Worksheet (LKPD)

The suggestions provided by the expert validators were addressed in a systematic and targeted manner to enhance the quality of the developed instructional materials. In the teaching module, recommendations to begin the lesson with contextual questions were accommodated by incorporating guiding prompts that ask students to identify circular objects in their surroundings, thereby reinforcing real-world context. Adjustments were also made to the time allocation to ensure alignment with key PMRI phases, such as guided reinvention and progressive mathematization. Furthermore, the PMRI characteristic of *interconnectedness* was implemented through exploratory activities that involved representing circle segments as approximate rectangles to help students understand the concept of area visually and conceptually. In the LKPD, revisions were made to the wording of instructional prompts in the construction phase to more explicitly guide students in drawing conclusions, along with the addition of relevant supporting images to strengthen contextual understanding. For the learning outcome test, improvements focused on technical aspects, including correcting typographical errors and simplifying the language of the questions to better match the literacy level of primary school students. The revised components of the instructional materials, as suggested by the validators, are illustrated in Figures 2 and 3 below.

The next stage involved implementing the instructional materials in a sixth-grade classroom at MI Ma'arif Pagerwojo, accompanied by classroom observations and the distribution of response questionnaires to both the teacher and students regarding the implementation of the learning process (Aldoobie, 2015). This was carried out to assess the practicality of the developed product (Hernawati, 2016). The results of the lesson implementation observations showed a percentage score of 90% from the teacher and 87.5% from the students. Meanwhile, the teacher and student response questionnaires regarding the PMRI-based learning each yielded scores of 93.7% and 87%, respectively.

Based on these percentages, the average practicality score was 91.85% from the teacher and 87.25% from the students. These averages were calculated by combining two indicators lesson implementation observations and response questionnaires for each group. Both scores fall within the 80% to 100% range, which is categorized as "highly practical." This indicates that both the teacher and students perceived the instructional materials as easy to use, relevant to learning activities, and supportive of a smooth instructional process. Moreover, the difference between the teacher and student average scores was only around 4.6%, suggesting minimal variation in perceptions between the primary users of the materials. This consistency reflects a high level of stability in how the practicality of the materials was perceived both from the teacher as the facilitator and the students as the learners. Such perceptual stability reinforces the conclusion that the instructional materials are not only theoretically sound but also practically applicable across diverse classroom contexts. Instructional materials are considered practical if they are easy to use and implement in mathematics instruction (Hernawati, 2016).

The final stage involved administering a test to students to determine the effectiveness of the PMRI-based instructional materials. Based on the test results from 30 sixth-grade students, the lowest score was 52, the highest was 90, with a mean score of 78.5. A total of 80% of the students met the minimum mastery criterion (KKM), with 24 students scoring above the threshold and 6 students falling below. These results indicate that the PMRI-based instructional materials can be considered effective for use in the learning process. In addition, to strengthen the effectiveness analysis from a statistical perspective, the effect size was calculated using Cohen's *d* formula.

$$d = \frac{78.5 - 70}{10.06} = \frac{8.5}{10.06} = 0.845$$

The results showed that the Cohen's *d* value was 0.845, which falls within the *large effect* category according to (Cohen, 2013) interpretation. This indicates that the PMRI-based instructional materials are not only effective in terms of mastery proportion, but also have a significant impact on students' cognitive learning outcomes. These findings support those of Arsaythamby & Zubainur (2014), who demonstrated that the implementation of realistic mathematics education significantly improves students' engagement, participation, and understanding in elementary mathematics learning. Similarly, (Laurens et al., 2017) found that this approach enhances students' critical thinking, problem-solving abilities, and conceptual understanding. Thus, the developed instructional materials have been proven to generate meaningful positive impacts on the mathematics learning process at the elementary level. Realistic mathematics education helps students construct mathematical concepts through its characteristic use of models, progressing from concrete representations to abstract thinking (Zaini & Marsigit, 2014). Moreover, (van den Ham & Heinze, 2018) emphasized that the development of instructional materials aligned with learning objectives plays a significant role in improving student achievement. Given that the PMRI-based materials in this study meet the criteria for validity, practicality, and effectiveness, it can be concluded that these materials are of high quality, as described by Nieveen (1999).

In addition, the integration of technology in education represents a strategic component for enhancing the effectiveness and scalability of instructional material implementation. The PMRI-based learning materials developed in this study hold strong potential for transformation into digital formats, such as e-modules, interactive worksheets, or application-based assessments. The integration of digital media such as instructional videos, artificial intelligence, and Learning Management System (LMS) platforms can further reinforce the core characteristics of PMRI, particularly in the visualization of concrete models and progressive mathematization. (Herlawan et al., 2023) also demonstrated that the integration of PMRI with digital technology significantly enhances students' critical thinking skills. Therefore, extending these instructional materials toward digital formats not only strengthens the overall effectiveness of the learning process but also aligns with national policy priorities to advance numeracy literacy and the digital transformation of primary education.

CONCLUSION

The development of PMRI-based mathematics instructional materials on the topic of circles, aimed at fostering students' conceptual understanding of the value of π (Pi), was carried out using the ADDIE model, encompassing the stages of analysis, design, development, implementation, and evaluation. Validation results indicated that the teaching module, student worksheet (LKPD), and achievement test developed in this study were all categorized as highly valid. The materials also demonstrated high levels of practicality and effectiveness in supporting students' understanding of the meaning of π (Pi) through contextual approaches and discovery-based activities. These findings underscore the importance of designing context-based instructional materials to bridge the gap between students' conceptual understanding and procedural fluency when dealing with abstract topics such as π (Pi). The broader implication of these results highlights the need to integrate PMRI principles into the national elementary mathematics curriculum, shifting the instructional focus from rote memorization toward more meaningful comprehension. Furthermore, the findings emphasize the urgency of providing continuous, needs-based professional development for teachers, enabling them to design contextual learning experiences that promote students' mathematical thinking. Strategically, this study has the potential to inform educational policy, positioning realistic approaches as a central framework for reforming mathematics instruction at the primary level. It also opens new avenues for the development of teaching approaches that are more contextual and responsive to 21st-century learning needs.

RECOMMENDATION

Due to the limited scope and sample size, this development research was conducted at a single primary school and focused solely on one mathematics topic circles with an emphasis on understanding the value of π (Pi). Future studies are encouraged to expand the implementation of PMRI-based instructional materials across various educational levels and more diverse student populations to examine the consistency and generalizability of the findings. Although this study examined the validity, practicality, and effectiveness of the materials, further research is needed to explore in greater depth how these materials support comprehensive and sustained conceptual understanding of mathematics within broader instructional contexts. This research is expected to contribute to the design of mathematics learning materials aligned with the principles of Realistic Mathematics Education (RME), particularly in fostering conceptual understanding through contextual activities. The integration of digital technology into PMRI-based materials is also recommended to enhance student engagement and respond to the pedagogical demands of 21st-century mathematics education. Such development is expected to strengthen the global relevance and adaptability of PMRI as a meaningful, student-centered model for mathematics instruction.

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