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Development of digital mathematics teaching materials based on problem-based learning to improve student learning outcomes

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Abstract: This study aims to develop the digital teaching materials based on problem-based learning (PBL) to improve students' mathematics learning outcomes. The development of teaching materials was carried out by integrating PBL stages into the material of systems of linear equations in two variables (SLETV) and spatial figures through the presentation of contextual problems, learning videos, group activities, digital worksheets, and interactive evaluations. 36 ninth grade students were involved in this research. The quality of the teaching materials was assessed based on the aspects of validity, practicality, and effectiveness. Validity was obtained through assessments by material experts and media experts, while practicality was measured based on teacher and student responses. The effectiveness of the teaching materials was analyzed through improvements in student learning outcomes based on pretest, posttest, and N-gain scores. The results showed that the PBL-based digital teaching materials met the valid criteria based on the assessments of material experts (92%) and media experts (95%). The results of teacher (96%) and student (98.56%) responses also showed that the teaching materials were in the practical category. In addition, the improvement in learning outcomes indicated that the PBL-based digital teaching materials were effective for use in mathematics learning (N-gain 0,76). Thus, the developed teaching materials are suitable for use as an alternative learning method that supports students' understanding of mathematical concepts and problem-solving abilities.

Keywords: Digital-based learning resources, interactive media, mathematics learning

Abstrak: Penelitian ini bertujuan untuk mengembangkan bahan ajar digital berbasis *problem-based learning* (PBL) untuk meningkatkan hasil belajar matematika siswa. Pengembangan bahan ajar dilakukan dengan mengintegrasikan tahapan PBL ke dalam materi sistem persamaan linear dua variabel (SPLDV) dan bangun ruang melalui penyajian masalah kontekstual, video pembelajaran, aktivitas kelompok, lembar kerja digital, dan evaluasi interaktif. 36 siswa kelas IX terlibat dalam penelitian ini. Kualitas bahan ajar dinilai berdasarkan aspek validitas, kepraktisan, dan efektivitas. Validitas diperoleh melalui penilaian ahli materi dan ahli media, sedangkan kepraktisan diukur berdasarkan tanggapan guru dan siswa. Efektivitas bahan ajar dianalisis melalui peningkatan hasil belajar siswa berdasarkan skor *pretest*, *posttest*, dan N-gain. Hasil penelitian menunjukkan bahwa bahan ajar digital berbasis PBL memenuhi kriteria valid berdasarkan penilaian ahli materi (92%) dan ahli media (95%). Hasil tanggapan guru (96%) dan siswa (98.56%) juga menunjukkan bahwa bahan ajar berada pada kategori praktis. Selain itu, peningkatan hasil belajar menunjukkan bahwa bahan ajar digital berbasis PBL efektif digunakan dalam pembelajaran matematika (N-gain 0,76). Dengan demikian, bahan ajar yang dikembangkan layak digunakan sebagai alternatif pembelajaran yang mendukung pemahaman konsep dan kemampuan pemecahan masalah matematika siswa.

Kata kunci: Sumber belajar berbasis digital, media interaktif, pembelajaran matematika

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INTRODUCTION

Mathematics learning is expected to train students in analytical and structured thinking, essential skills for facing various academic and non-academic challenges in the future. The reality on the ground shows that conventional learning methods still dominate and are often ineffective. The one-way, teacher-centered learning process leads to low

student participation and reduced motivation (Arif et al., 2026; Damopolii et al., 2026; Murti et al., 2024). The limited use of learning media in textbooks makes students bored and disengaged from the learning (Nasrul et al., 2024; Nurhikmah et al., 2025). The limited use of school facilities and learning approaches that are not oriented towards direct experience hinder students' understanding and mastery of skills (Kasman et al., 2026; Nwankwo et al., 2024). These issues emphasize the need for a transformation towards a more interactive, contextual, and student-centered learning approach.

Mathematics is essential, yet many students struggle to grasp abstract concepts, such as systems of linear equations in two variables (SLETV) (Puspita & Syamsuri, 2022), geometric (Parindang et al., 2024), and statistics (Djamilah et al., 2023). This is often due to differences in students' understanding levels, a lack of connection between the material and real-life situations, and monotonous learning models. Students' inability to visualize these abstract concepts can reduce learning motivation and trigger anxiety about the subject. Digital technology offers significant opportunities to enhance the learning process through the use of multimedia, interactive applications, and online platforms that can enrich students' learning experiences (Meryansumayeka et al., 2025). Therefore, innovative learning models and digital-based media are needed to bridge the gap between abstract concepts and their application in everyday life.

Research shows that the use of digital media and problem-based learning (PBL) can engage students and improve their learning success (Damopolii & Kurniadi, 2019; Hassan et al., 2025; Yomaki et al., 2023). The application of PBL with the help of ICT media in the material of the SLETV successfully improved students' conceptual understanding and numeracy skills significantly (Meryansumayeka et al., 2025). Sopanda et al. (2022)) also proved that the integration of digital media and PBL resulted in an increase in conceptual understanding with a higher N-Gain value in the experimental class compared to the control class. Meanwhile, Belva and Jailani (2023) showed that the use of digital media such as GeoGebra in PBL learning can improve SLETV understanding and also trigger learning interest and problem-solving skills significantly.

Support for the effectiveness of PBL-based digital teaching materials is also evident in research by Irmawati and Hadi (2024), who reported that the PBL-based e-module they developed had a high level of validity and practicality, and achieved a classical completion rate of 81%. Furthermore, Nazaretha et al. (2022) demonstrated that the development of interactive video-based digital teaching materials for SLETV successfully encouraged the majority of students to achieve minimum standard scores and received positive feedback from students. These facts reinforce the relevance of developing PBL-based digital teaching materials for junior high school mathematics instruction, not only due to the potential for adequate infrastructure but also to address the need for active and contextual learning that can improve student learning outcomes.

Initial observations were conducted at public junior high schools (SMPN) in Makassar City as a preliminary step to identify the actual conditions of mathematics learning and the need for digital teaching materials development. Based on data from the Ministry of Primary and Secondary Education (Kemendikdasmen), Makassar City has 57 public junior high schools spread across various sub-districts, each with varying student characteristics, learning environments, and the availability of facilities and infrastructure. Of these junior high schools, three (School A, B, and C) were selected as observation locations based on (1)

regional representation, (2) the implementation of a curriculum that demands student-centered learning, (3) the availability of basic Information and Communication Technology (ICT) facilities, and (4) ongoing problems in the mathematics learning process and outcomes.

Observations indicate that mathematics learning at SMPN A is still dominated by lectures and routine practice exercises. Teachers serve as the primary source of information, while students tend to be passive and follow one-way learning. The instructional materials used are still limited to printed textbooks and simple worksheets, so learning does not fully encourage students to develop conceptual understanding independently and contextually. At SMPN B, mathematics learning also relies on a conventional approach. Students experience difficulty understanding abstract concepts, particularly in materials that require problem-solving skills such as SLETV and Geometric Shapes. Although schools have relatively adequate digital learning support facilities, their utilization is not optimal and they are not yet integrated with learning models that encourage active student engagement. SMPN C exhibits a relatively similar situation. Learning support facilities such as LCD projectors and internet access are available, but their use is still limited to visual presentations without the support of interactive digital teaching materials. Mathematics learning does not consistently link material to contextual problems close to students' lives, resulting in students' conceptual understanding and learning motivation not developing optimally.

These learning conditions result in low student engagement, limited critical thinking and problem-solving skills, and suboptimal mathematics learning outcomes, particularly in materials such as two-variable linear equation systems and geometric shapes. Therefore, PBL was chosen because it is able to address learning problems encountered in the field and is relevant because it places contextual problems as the starting point of learning, encourages active student involvement in the investigation process, and is in line with constructivist learning principles, while supporting connectivist principles by utilizing technology as a means of accessing, linking, and developing knowledge. The selection of mathematics subjects is based on the characteristics of abstract and hierarchical concepts, thus requiring a learning approach that is able to visualize concepts and link them to real situations. Observation results show that mathematics is one of the subjects that experiences the most obstacles in understanding concepts and student learning outcomes. Consequently, it is evident from the comprehensive observation results that digital teaching materials that are both systematically designed and integrated with the problem-based learning model are required. In order to enhance student engagement, fortify conceptual comprehension, and positively influence mathematics learning outcomes in junior high schools, digital teaching materials are anticipated to be capable of presenting mathematics material in an interactive, contextual, and visual manner. This research aims to develop digital teaching materials for PBL-based mathematics subjects to improve learning outcomes in junior high schools.

METHOD

Research and Development is employed. This study was conducted at three junior high schools in Makassar: SMPN A, SMPN B, and SMPN C. The research sample involved 36 ninth-grade students and one mathematics teacher. All three schools were involved in the

needs analysis, but the product trial only involved students and teachers at SMPN B. The validators involved in this research were two people, a material validator and a media validator. The validity criteria were adapted from the research Arif et al. (2026).



Fig. 1. Stages of digital teaching material development

In this investigation, a response questionnaire, a learning outcome test, a media and material validation instrument, and a needs identification questionnaire were implemented. A pretest and a posttest were administered. The pretest was designed to evaluate students' abilities prior to the use of digital teaching materials, whereas the posttest was designed to evaluate their abilities after use. In the odd semester, the examinations consisted of multiple-choice questions regarding the ninth-grade mathematics course. The digital teaching materials' efficacy was evaluated using the test results.

Qualitative data analysis was implemented to evaluate the necessity of digital instructional materials in this investigation. Through interviews, observations, and document analysis, this methodology endeavours to gain a comprehensive understanding of the digital teaching materials requirements of both students and teachers. The data were subjected to a systematic analysis, which included data reduction, data presentation, and the drawing of conclusions or verification. This method identified patterns, themes, and trends in the demand for digital teaching materials, enabling the development of the resulting materials to be more in line with the characteristics and requirements of users.

From teacher and student response questionnaires, as well as from observations of their activities, the practicality analysis of digital teaching materials was conducted. Observations of student and teacher activities commenced with a brief trial and persisted until the conclusion of the lesson. At the conclusion of the meeting, questionnaires were distributed to both students and educators. The practicality of digital teaching materials for learning was demonstrated through the analysis of data from the questionnaires. The practicality criteria were derived from the research conducted by Arif et al. (2026).

The interpretation of student learning test results was used to ascertain the effectiveness of digital teaching materials. The N-Gain (Normalised Gain) test was implemented to evaluate the effectiveness of the learning process by determining the relative increase in student comprehension before and after the learning process. This method enables educators to acquire a more comprehensive understanding of the efficacy of a curriculum or learning method. The quantitative assessment of student mastery of the material is possible through the results of the N-Gain analysis. The N-gain categories were derived from Hake (1998).

RESULTS AND DISCUSSION

Based on the analysis of student needs at junior high schools A, B, and C in Makassar, differences were found in learning characteristics, mathematical understanding needs,

technology access, and preferences for PBL-based digital teaching materials. These differences serve as the basis for determining priorities for developing digital teaching materials appropriate to the conditions of each school.

Table 1. Mapping of needs analysis results

Analysis Aspects	SMPN A	SMPN B	SMPN C
Learning Characteristics	Prefers direct explanations and practice	Enjoys direct explanations, visual media, and interactive activities	Requires direct explanations and simple activities
Mathematical Difficulties	Requires extensive guidance in understanding SLETV, spatial figures, and story problems	Still has difficulty with math despite being more prepared to use digital media	Requires conceptual reinforcement and problem-solving support
Digital Literacy	Uneven distribution	Relatively good	Quite diverse and requires support
Technology Access	School facilities are limited and internet access varies	Internet access and device use are relatively good	Limited school technology facilities
Media Preferences	Less interest in interactive videos and quizzes	Very interested in videos, quizzes, and simulations	Less interest in visual media and complex interactivity
PBL Readiness	Requires mentoring and reinforcement of contextual learning	Relatively more prepared for contextual and collaborative learning	Requires gradual introduction of contextual problems
Development Priorities	Simple teaching materials, step-by-step guides, and short orientation videos	Interactive teaching materials, contextual videos, quizzes, and group activities	Light learning materials, explicit instruction, and structured support

Overall, the needs analysis results for the three schools indicated that the development of PBL-based digital mathematics teaching materials was necessary to support students' conceptual understanding and problem-solving skills. Junior high school A Makassar required more support and learning guidance, junior high school B Makassar was more prepared for the use of interactive teaching materials, while junior high school C Makassar required simple and accessible teaching materials. Therefore, the developed product needed to integrate problem-oriented videos, contextual problem presentations, collaborative activities, and step-by-step problem-solving guidance, taking into account the

characteristics of each school. Subsequent product development used junior high school B for product trials. This was adjusted to suit the available internet facilities and the digital teaching materials developed.

The needs analysis results indicated that junior high school students still had difficulty understanding abstract mathematical concepts, such as relations, functions, and problem modeling, thus requiring teaching materials supplemented with visualizations and contextual examples. This finding aligns with Kurniati et al. (2021), who reported that most students struggle to understand abstract concepts without the aid of digital visualization. Furthermore, differences in digital literacy skills and student learning needs demonstrate the importance of presenting material through text, video, animation, and interactive quizzes. This is supported by Winarni et al. (2021) and Yarmi et al. (2024) who stated that the digital media and PBL developed must align with the characteristics and needs of students in mathematics learning. Ayari et al. (2025) in their systematic review showed that integrating PBL with technology is a fundamental need to address students' low abilities.

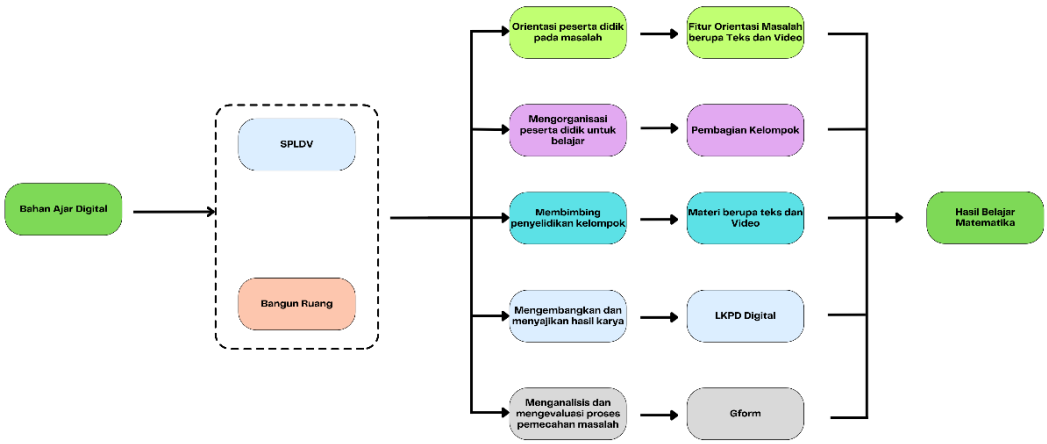


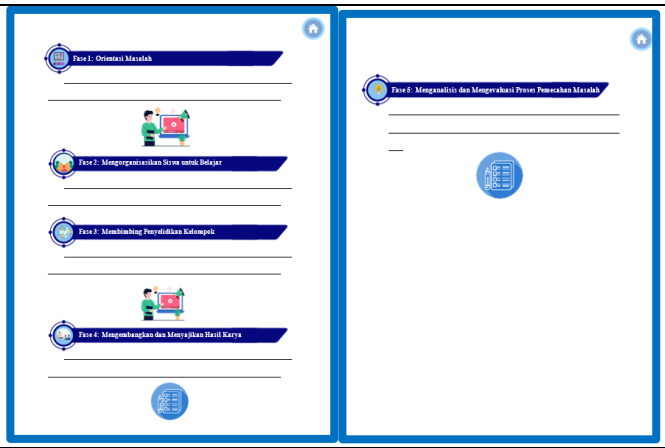
Fig. 1. Digital teaching material prototype

The digital teaching prototype was designed to ensure integration between content structure, visual design, and the integration of PBL syntax into each learning component, and is outlined as follows:

a. The digital teaching materials represent the main product being developed, namely digital mathematics teaching materials. The teaching materials function as an integrated learning tool containing technology-based materials, activities, media, and evaluations to support active, student-centered learning.
b. Scope of the material. The center section, bordered by a dotted line, indicates the scope of the main material in the digital teaching materials, namely SLETV and geometric shapes. These two materials are designed as a context for implementing the PBL model, so mathematical concepts are not presented directly but are constructed through problem-solving.
c. Orienting students to problems. At this stage, the teaching materials provide problem-oriented features in the form of text and video. These features aim to introduce contextual problems relevant to everyday life, thereby fostering curiosity, motivating students, and directing the learning focus to the problem to be solved.

d. Organizing students for learning. This stage is supported by dividing them into study groups. Students are guided to work collaboratively in groups, assign roles, and formulate initial steps for problem-solving. This feature emphasizes the development of social skills and cooperation in problem-based learning.
e. Guiding group investigations. During the investigation phase, teaching materials provide text and instructional videos. These media serve as scaffolding, helping students explore concepts, gather information, and develop problem-solving strategies without diminishing their active role in discovering concepts.
f. Developing and presenting work. This stage is facilitated through digital student worksheets. Student worksheets contain problem-solving tasks that require students to systematically formulate solutions, including calculations, conceptual explanations, and presentations of group discussion results. This feature supports students' mathematical communication skills.
g. Analyzing and evaluating the problem-solving process. The final stage of PBL is supported by Google Forms as a digital evaluation tool. This evaluation is used to measure conceptual understanding, assess students' thinking processes, and encourage reflection on the problem-solving strategies and results.

Table 1. Storyboard of digital teaching materials



Text, Images and Videos	**Description**	**Action**
Text, Images and Videos	PBL Learning Activities Implementing PBL steps, consisting of problem orientation, group investigation, product development, and reflection.	1. Image: case study example and contextual questions. 2. Video: link to learning video. 3. Action: hyperlink to Google Form for group assignment submission.

The storyboard for the digital teaching materials for mathematics subjects using PBL in junior high schools was developed systematically by incorporating the needs analysis,

characteristics of learning outcome and learning objectives as well as the problem-based learning principles into the structure and design of an interactive e-book. Digital learning scenarios were designed to provide authentic problem solving opportunities. Teaching materials were developed to incorporate the PBL elements. Visuals and interactivity were designed. All materials, including materials presentation, group activities, learning videos, contextual illustrations and digital assessment links were chosen and designed to support critical thinking, independent inquiry and knowledge building. The use of technologies such as flipbooks, hyperlinks, icons and interactive digital media made the teaching materials more communicative, easy to access and relevant to the needs of 21 st century learners. This means that the digital teaching materials not only incorporate the PBL principles but also support active, meaningful and student-centred learning.

The design of digital teaching materials in PBL-based mathematics learning integrates problem-based learning structures, student developmental needs, and modern instructional design principles that emphasize visualization, interactivity, and independent learning. Digital teaching materials designed with this approach are able to provide contextual, challenging, and meaningful learning experiences, thus aligning with the curriculum demands and 21st-century competency requirements in junior high school mathematics learning. This aligns with the assertion that educational technology encompasses the systematic design, development, and utilization of learning media to support effective learning processes (Arif et al., 2026). This design framework aligns with findings that the integration of multimedia such as video, animation, and simulations can help convey abstract material visually, making it easier to understand and stimulating student learning interest (Akpan & Udoh, 2026; Ranti Ayu Kartika et al., 2025). In addition, the integration of learning technology is a requirement in the context of modern learning to expand access, effectiveness, and efficiency of the learning process (Nurkamilah et al., 2020).

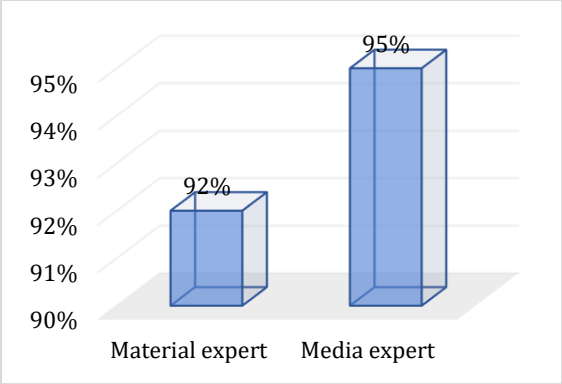
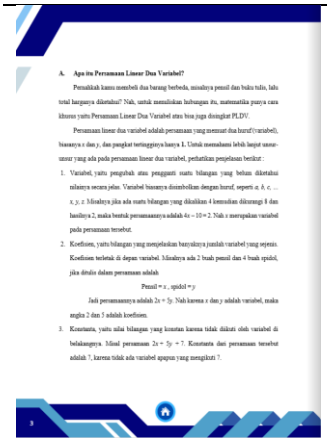
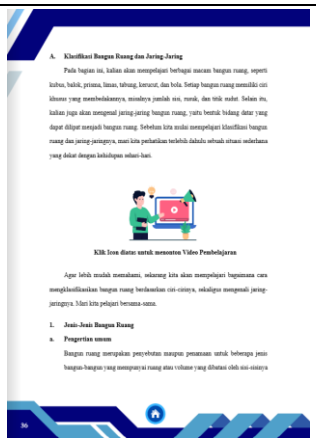
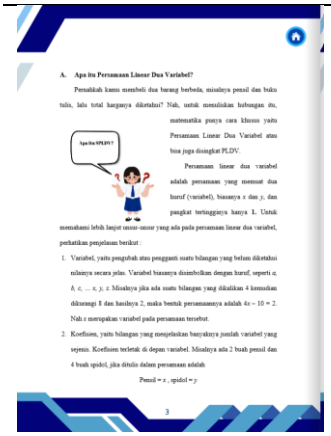


Fig. 2. Validation findings from media and material experts

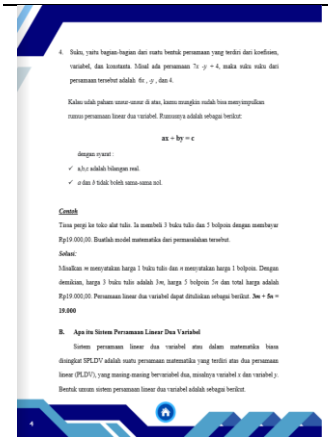
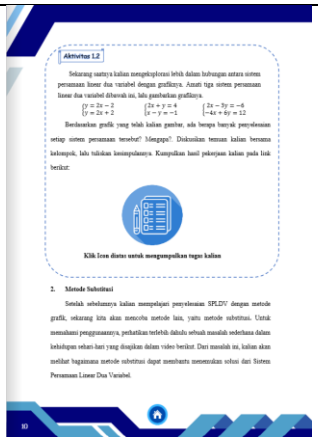
The validation results of the material and content of digital teaching materials (Figure 2) for PBL-based mathematics in junior high schools indicate that the developed product is highly valid, with a user validity level (V-user) of 92%. Meanwhile, the validation results from media experts were 95%. This value reflects that almost all aspects of the media and design have met the quality standards required for effective digital teaching materials.

Table 2. Results of revisions to digital teaching materials by content/material experts

Suggestion
Reinforcement of the fundamentals of SLETV and Spatial Building
Pre-Revision View
 
View after revision
 

Based on input from content/material experts, the focus was on the need to strengthen basic concepts related to SLETV and spatial structure in digital teaching materials. Follow-up to this input was seen through material improvements that included more comprehensive conceptual explanations, the presentation of relevant examples, and the addition of illustrations to support the understanding process. The information delivery structure was revised to be more systematic, thus facilitating logical sequencing between sections of the material. Improvements to the layout and visual elements also contributed to increased readability and effectiveness of content presentation. Overall, the revision results showed an increase in the quality of the substance and coherence of the material in accordance with the demands of developing teaching materials based on scientific studies. Overall, these results confirm that the digital teaching materials have met the eligibility standards as learning resources that support the implementation of PBL-based mathematics learning in junior high schools.

Table 3. Results of revisions to digital teaching materials by media and design experts

Suggestion
Appropriate color selection
Pre-revision view
 
View after revision
 

The validity of digital teaching materials for PBL mathematics is a fundamental aspect that determines the quality and feasibility of a product before it is implemented in the learning process. The content validity of digital teaching materials is assessed through the material's suitability to learning objectives, student characteristics, mathematical principles, and applicable curriculum requirements. Expert validation results indicate that the media aspect achieved a very high level of validity. Components that received the highest scores included the suitability of the visual appearance to the characteristics of junior high school students, font readability, navigation effectiveness, color proportions, and clarity of illustrations and learning videos. Good visual quality plays a crucial role in digital learning because it facilitates students' understanding of abstract mathematical concepts, which are often a barrier in traditional learning. Empirically, educational technology has been proven to provide significant support in improving students' motivation, attention, and conceptual understanding (Akpan & Udoh, 2026; Ardono et al., 2026).

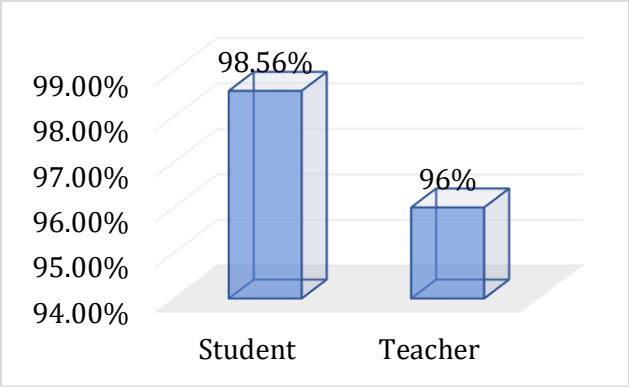


Fig. 3. Student and teacher responses during the trial

Student responses in these findings reflect that the presentation of material in the form of problems and problem-based activities can support comprehensive student understanding. Student assessments of the ease of understanding of the instructions, the teaching materials' ability to facilitate critical thinking, and their support for independent learning showed a strong positive trend. Furthermore, indicators related to learning motivation, such as enthusiasm, resistance to boredom, and flexibility to learn at any time, also consistently scored high. Technology use is positively correlated with increased student motivation and learning engagement, so easy-to-use and engaging digital teaching materials directly increase their practicality (Amir et al., 2025; Dita et al., 2023; Runniarsiti et al., 2025). Thus, the integration of technology not only fosters students' motivation to engage in self-directed learning but also supports their comprehension of complex concepts.

Teachers assessed these teaching materials as meeting the pedagogical, aesthetic, and functional principles required for mathematics learning. The cover design, font legibility, color contrast, and layout structure were deemed adequate to support comfortable and effective use. Furthermore, ease of navigation further reinforces the student-friendly nature of these teaching materials. In terms of substance, teachers assessed that the material aligned with the objectives of junior high school mathematics learning and was presented in the form of problems relevant to the PBL approach. Learning activities that stimulate exploration, problem-solving, and the association of concepts with real-life situations also received high scores. The presence of various media such as text, images, videos, and animations was deemed well-integrated and able to strengthen student understanding. Teachers also observed that these teaching materials supported independent learning, increased learning motivation, and accelerated the process of understanding mathematical concepts. PBL-based digital materials were practical and increased student engagement, thus enabling students to succeed in learning (Aristaningsih et al., 2025; Damopolii & Kurniadi, 2019).

Student learning outcomes after using PBL-based digital learning materials showed improvement. Pretest and posttest data showed that the average student initial score was 6.86, then increased to 16.92 after learning (Figure 4), with an average N-gain value of 0.76, which is in the high category (Figure 5). These results show that digital materials for education have the potential to improve students' mathematical performance.

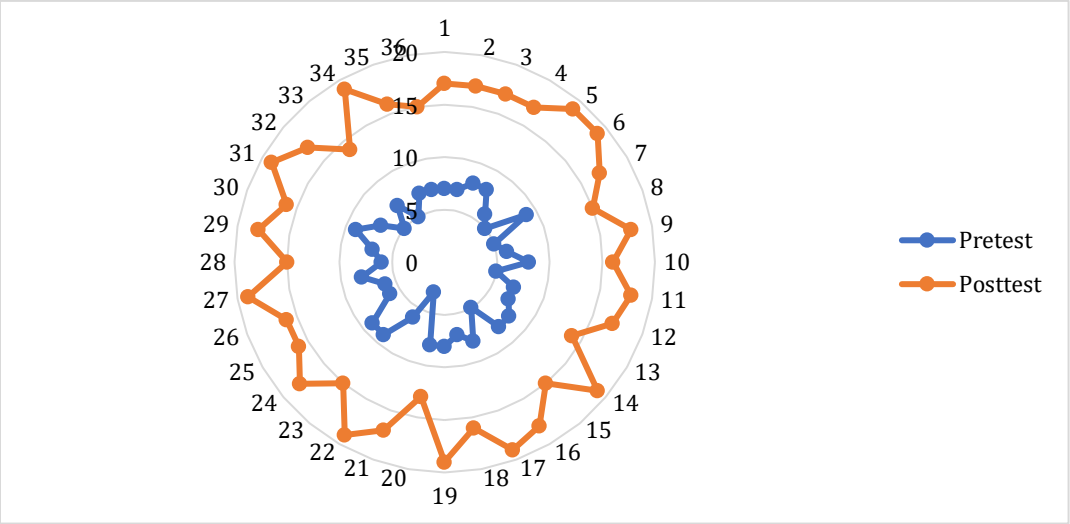


Fig. 4. Average of students' pretest and posttest

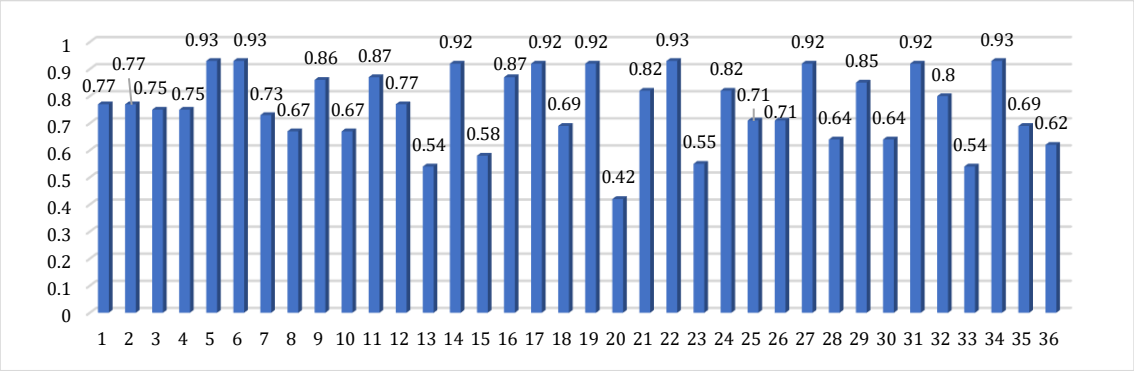


Fig. 5. Student N-gain

The improvement in students' post-test scores showed that the use of digital learning materials based on PBL can help students improve their conceptual knowledge and problem-solving skills. This was supported by Ayari et al. (2025), who found that the use of PBL can contribute positively to students' mathematics learning due to the students being actively involved in problem solving situations. The use of technology in PBL was also found to have a positive impact on students' mathematics learning outcomes (Aransado, 2026). The students who obtained moderate N-gain scores showed that students' learning outcomes depend on their ability. Therefore, this shows the importance of providing students with incremental learning support. Haruehansawasin and Kiattikomol (2018), found that providing learning support in PBL can improve the learning outcomes for students with low ability. This was supported by Zuo et al. (2023), who found that the use of incremental learning support (scaffolding) can have a positive impact on learning outcomes in digital environments. Overall, this shows that combining PBL with digital technology and incremental learning support can help students with varying abilities.

The implementation of digital teaching materials based on PBL can improve mathematics learning outcomes through learning stages that encourage students to actively build conceptual understanding. In the problem orientation stage, the presentation of contextual text and videos helps students connect SLETV material and spatial geometry to

everyday life situations. Next, group formation provides opportunities for students to exchange ideas and determine problem-solving strategies. In the inquiry stage, digital materials in the form of text and videos serve as learning guides, helping students understand concepts and gradually find solutions. This process aligns with research by Tamami et al. (2025), which showed that PBL has a positive influence on student engagement. Meanwhile, Yang et al. (2025), and Yomaki et al. (2023) found that PBL is more effective than conventional learning in supporting student understanding.

In the development and presentation stages, digital worksheets help students systematically organize problem solutions, explain the rationale for using formulas, and communicate the results of discussions. This activity strengthens understanding because students not only obtain answers but also understand the solution process. Furthermore, evaluation via Google Forms can help students identify errors and improve their understanding when accompanied by clear feedback. Van Der Kleij et al. (2015) found that digital feedback accompanied by explanations was more effective in improving learning outcomes than feedback that simply indicated correct or incorrect responses. Furthermore, a meta-analysis by Sung et al. (2016) showed that technology integration in learning positively impacts student learning outcomes. Thus, the integration of problem-solving activities, presentation of results, and digital evaluation can help students understand mathematical concepts more deeply and improve their learning outcomes.

CONCLUSION

The results of the study indicate that the developed problem-based learning (PBL)-based digital teaching materials meet the criteria of validity, practicality, and effectiveness for use in mathematics learning. Product validity was demonstrated through assessments by material experts and media experts, which demonstrated a valid category. From a practical perspective, teacher and student responses indicated that the digital teaching materials were simple to use and supported learning. Meanwhile, the effectiveness test results indicated that the use of PBL-based digital teaching materials improved students' mathematics learning outcomes. Therefore, PBL-based digital teaching materials are deemed suitable for use as alternative teaching materials that support active, structured, and problem-solving-oriented mathematics learning.

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