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Multimedia-Supported Problem-Based Learning in School Mathematics: A Systematic Review of Trends, Integration, and Pedagogical Roles

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Abstract. Multimedia is increasingly used in problem-based learning (PBL) in mathematics, yet how it is integrated across PBL phases and the pedagogical roles it serves have not been clearly synthesized. This systematic review examined research trends, multimedia use across PBL phases, pedagogical roles, reported impacts, challenges, and research gaps in multimedia-supported PBL in school mathematics. Following PRISMA guidelines, studies were identified through Scopus and ERIC. Eleven empirical studies published between 2018 and 2026 met the inclusion criteria, and their methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT). The studies were concentrated mainly in Indonesia and Türkiye, with GeoGebra being the most frequently used tool. Multimedia was used across several PBL phases but was most prominent during investigation activities. Across the studies, four main pedagogical roles were identified: visualization and representation, exploration and investigation, construction of understanding, and solution verification. Positive cognitive and affective outcomes were reported in several studies, although the results were not consistent across studies or measures. The studies also reported technical

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and student-related challenges. Overall, multimedia was used primarily to support students' investigation during PBL, while its use in other phases was less evident. Research across educational levels remains limited, particularly at the primary school level.

Keywords: problem-based learning; multimedia; school mathematics; pedagogical roles; systematic review

1. Introduction

Mathematics education needs to move beyond merely emphasizing procedural fluency and conceptual accuracy. Instead, mathematics learning should engage students in challenging situations that extend beyond purely mathematical contexts, involving real-world scenarios that require students to use mathematics to answer questions, solve problems, understand phenomena and relationships, and make informed decisions (Niss & Højgaard, 2019). PBL provides one way to create such learning experiences. It begins with authentic and ill-structured problems that encourage students to investigate, identify what they need to learn, and develop possible solutions (Hmelo-Silver, 2004).

Rather than receiving information primarily from the teacher, students in PBL take a more active role in analyzing problems, working with others, and directing aspects of their own learning. The teacher supports this process by facilitating and guiding students as they work toward solutions (Hmelo-Silver, 2004; Savery, 2006). These characteristics make PBL relevant to the development of problem-solving, self-directed learning, collaboration, and flexible knowledge (Hmelo-Silver, 2004). Previous studies also reported benefits for conceptual understanding and academic achievement (Merritt et al., 2017).

Nevertheless, the characteristics of PBL also impose considerable cognitive demands on students. They are required to understand complex problems, identify learning needs, integrate information from multiple sources, and develop and evaluate solutions based on knowledge acquired through self-directed and collaborative learning (Hmelo-Silver, 2004; Laxman, 2012). This can be particularly challenging in mathematics, where abstract concepts are often expressed through different forms of representation. Coordinating these representations is important for developing conceptual understanding and solving mathematical problems (Duval, 2006). Complex problem-solving tasks may also increase cognitive load, particularly for students with limited prior knowledge, making appropriate instructional support and scaffolding important (Kirschner et al., 2006).

Advances in digital technology have opened up new ways to support mathematics learning through multimedia. Text, images, diagrams, graphs, animations, simulations, and mathematical software can provide different ways for students to represent and explore mathematical ideas (Schoenherr et al., 2024). The potential of multimedia to support learning can be explained by the Cognitive Theory of Multimedia Learning (CTML) proposed by Mayer (2009). This theory suggests that learning occurs through two information-processing channels with

limited capacity and requires learners to actively select, organize, and integrate information. Consequently, multimedia has the potential to promote deeper understanding by facilitating the integration of complementary verbal and visual representations.

Within PBL, where students engage in inquiry and problem solving, multimedia can serve not only as a means of presenting information but also as a tool to support these activities. Digital representations and interactive tools can help students understand problem situations, visualize abstract mathematical concepts, explore mathematical relationships, and test possible solutions. Simulations, for example, allow students to manipulate problem components, conduct experiments, and receive feedback on the consequences of their actions, thereby supporting investigation and problem-solving processes (Jonassen, 2011).

With the rapid advancement of digital technologies, a wide range of tools, including instructional videos, learning management systems (LMS), computer simulations, GeoGebra, augmented reality (AR), virtual manipulatives, web-based applications, and dynamic mathematics software, have increasingly been incorporated into mathematics education to support visualization, exploration, and the development of students' conceptual understanding (St Omer et al., 2025). However, the use of multimedia in PBL remains highly diverse in terms of the technologies employed, the PBL phases in which they are integrated, and the pedagogical functions they serve.

As studies on multimedia-supported PBL continue to grow, a synthesis is needed to understand how multimedia has been used and what roles it plays in mathematics PBL. Several reviews have examined PBL and technology in mathematics education, but their focus differs from that of the present review. Merritt et al. (2017) reviewed PBL in K-8 mathematics and science education, although all nine studies that met the final inclusion criteria were conducted in science contexts. Kirabo et al. (2024) examined technology-supported PBL in mathematics teacher education, encompassing a broad range of technological tools and applications, with a focus on implementation procedures, benefits, and implementation challenges.

Ssali et al. (2025) reviewed PBL in secondary school mathematics, with an emphasis on implementation principles, conditions that support its effectiveness, and implementation challenges. However, these reviews did not systematically map how specific types of multimedia are used across PBL phases or the pedagogical roles they serve in school mathematics. Examining these dimensions together can provide a more detailed understanding of how multimedia is integrated into the PBL process and the purposes it serves in supporting mathematics learning.

To develop a more comprehensive understanding of how multimedia is integrated into PBL implementation in school mathematics, this study addressed the following research questions:

1. What are the research trends and methodological characteristics of studies on multimedia-supported PBL in school mathematics? (RQ1)
2. What types of multimedia are used, and how are they integrated across PBL phases? (RQ2)
3. What pedagogical roles does multimedia play? (RQ3)
4. What impacts and implementation challenges are reported? (RQ4)
5. What research gaps and future directions are identified in the existing literature? (RQ5)

2. Methodology

This study employed a systematic literature review (SLR), a systematic method for identifying, evaluating, and interpreting existing research within a particular field to identify knowledge gaps and directions for future research (García-Peñalvo, 2022). The review examined studies published over a 20-year period that investigated the use of multimedia in PBL within school mathematics. The article selection and reporting process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

2.1 Identification

During the identification stage, a systematic search was conducted across two databases, Scopus and ERIC, which are widely used and reliable sources for identifying relevant educational research literature (Kholid et al., 2023). Scopus was selected because of its broad coverage of scholarly publications from various regions worldwide (Baas et al., 2020). It also applies a rigorous content selection process conducted by the independent Content Selection and Advisory Board (Baas et al., 2020). Its multidisciplinary coverage, including the social sciences, further makes Scopus relevant to mathematics education research (Mongeon & Paul-Hus, 2016). ERIC was selected because it is a major database of educational literature and has served educational researchers since 1966 (Strayer, 2008). However, its coverage is more strongly oriented toward the United States (Fitzgerald et al., 2025). Therefore, Scopus and ERIC were used together to provide broader coverage, particularly of international literature relevant to mathematics education.

The search strategy was developed using the PICOC framework (Population, Intervention, Comparison, Outcome, and Context) to identify the key concepts relevant to the objectives of this study, as presented in Table 1. Petticrew and Roberts (2006) explicitly argued that, for systematic reviews in the social sciences, four components (PICO) may be insufficient and can be extended to five components (PICOC). Based on this framework, keywords and synonyms related to PBL, multimedia, and school mathematics were combined using Boolean operators (AND and OR). For this review, multimedia included digital tools, instructional materials incorporating multimedia, and student-produced multimedia used within PBL activities.

A 20-year publication window (2007–2026) was used to provide broad temporal coverage and reduce the risk of overlooking earlier studies at the intersection of multimedia, PBL, and school mathematics. Given the absence of prior systematic reviews explicitly addressing this intersection, this wide time range was selected to minimise the risk of overlooking relevant early studies. The initial database search was conducted in April 2026 and updated on June 10, 2026, to identify newly published studies before the review was finalized. In addition, the search was restricted to documents classified as “Article” in Scopus. For the ERIC database, only documents categorized as “Journal Articles” and marked as “Peer reviewed only” were included. Review articles were excluded because they do not present findings from empirically conducted research (Ishartono, Razak, et al., 2023).

Table 1: PICOC framework

PICOC framework	Categories	Keywords
Population	School	-
Intervention	PBL	(“problem-based learning” OR “problem based learning” OR “PBL”)
	multimedia	(“multimedia” OR “visual representation” OR “graphical representation” OR “computer animation” OR “interactive simulation” OR “dynamic visualization” OR “educational video” OR “screencast” OR “instructional video” OR “GeoGebra” OR “Desmos” OR “applet” OR “dynamic software” OR “dynamic geometry” OR “Cabri” OR “PhET” OR “Geometer’s Sketchpad” OR “virtual manipulative” OR “interactive media” OR “augmented reality” OR “interactive whiteboard” OR “digital material”)
Comparison	-	-
Outcome	-	-
Context	mathematics	mathematics

No keywords were assigned to the School category because studies do not consistently use terms such as “school” or related descriptors in their titles or abstracts. Instead, this criterion was considered during the subsequent screening process. Accordingly, the search queries used in the Scopus and ERIC databases are presented in Figure 1.

("problem-based learning" OR "problem based learning" OR "PBL") AND
 ("mathematics") AND ("multimedia" OR "visual representation" OR
 "graphical representation" OR "computer animation" OR "interactive
 simulation" OR "dynamic visualization" OR "educational video" OR
 "screencast" OR "instructional video" OR "GeoGebra" OR "Desmos" OR
 "applet" OR "dynamic software" OR "dynamic geometry" OR "Cabri" OR
 "PhET" OR "Geometer's Sketchpad" OR "virtual manipulative" OR
 "interactive media" OR "augmented reality" OR "interactive whiteboard" OR
 "digital material")

Figure 1: Search query used in Scopus and ERIC databases

In Scopus, the search was restricted to the Article Title, Abstract, and Keywords fields. In ERIC, the same query was applied using the platform's default search interface. The search yielded 23 articles from Scopus and 28 articles from ERIC, resulting in a total of 51 potentially relevant articles for further review. These articles were exported and compiled into a single database for the subsequent selection process. Duplicate records identified across the two databases were removed before the titles and abstracts were screened.

2.2 Study Selection and Eligibility Criteria

During the screening stage, articles were evaluated according to the predefined inclusion and exclusion criteria (Table 2). Clearly defined inclusion and exclusion criteria are among the key factors determining the quality and methodological rigor of a systematic literature review (Ishartono, Halili, et al., 2023). The inclusion criteria comprised peer-reviewed journal articles that focused on school mathematics, implemented PBL, and incorporated multimedia into the learning process. Although the database searches were restricted to peer-reviewed journal articles, review articles were still retrieved and excluded during screening because the present review focused on empirical studies. Records that appeared potentially eligible after title and abstract screening were sought for full-text retrieval.

Table 2: Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Document type	Journal articles	Conference paper, book chapter, review, book, conference review
Population	School students	University students
PBL	Studies implementing PBL	Studies not implementing PBL
Multimedia	Multimedia incorporated into the learning process	No multimedia use
Context	School mathematics	Context outside school mathematics

Of the 51 articles identified in the initial search, four duplicate records ($n=4$) were found across the two databases and subsequently removed. After duplicate removal, 47 records were screened based on their titles and abstracts. Of these, 30 were excluded, and 17 reports were sought for full-text retrieval.

Articles that passed the screening stage subsequently underwent full-text review to confirm their alignment with the study objectives and research questions. One report ($n = 1$) could not be retrieved in full text because it was no longer accessible through the journal website or the authors' institutional profiles. Although the available abstract suggested that the study was limited to the design phase of the ADDIE model, the report was recorded as not retrieved because its eligibility could not be formally assessed without access to the full text.

A more in-depth evaluation was then conducted regarding the implementation of PBL, the use of multimedia, and the context of school mathematics. Articles that did not meet the eligibility criteria after full-text assessment were excluded. Five reports were excluded after full-text assessment: one because it focused on higher education, one because it was a non-empirical study, and three because they provided insufficient information on multimedia use within PBL implementation. Following full-text assessment, 11 studies met the eligibility criteria and were included in the final synthesis. The study selection process is summarized in the PRISMA 2020 flow diagram in Figure 2.

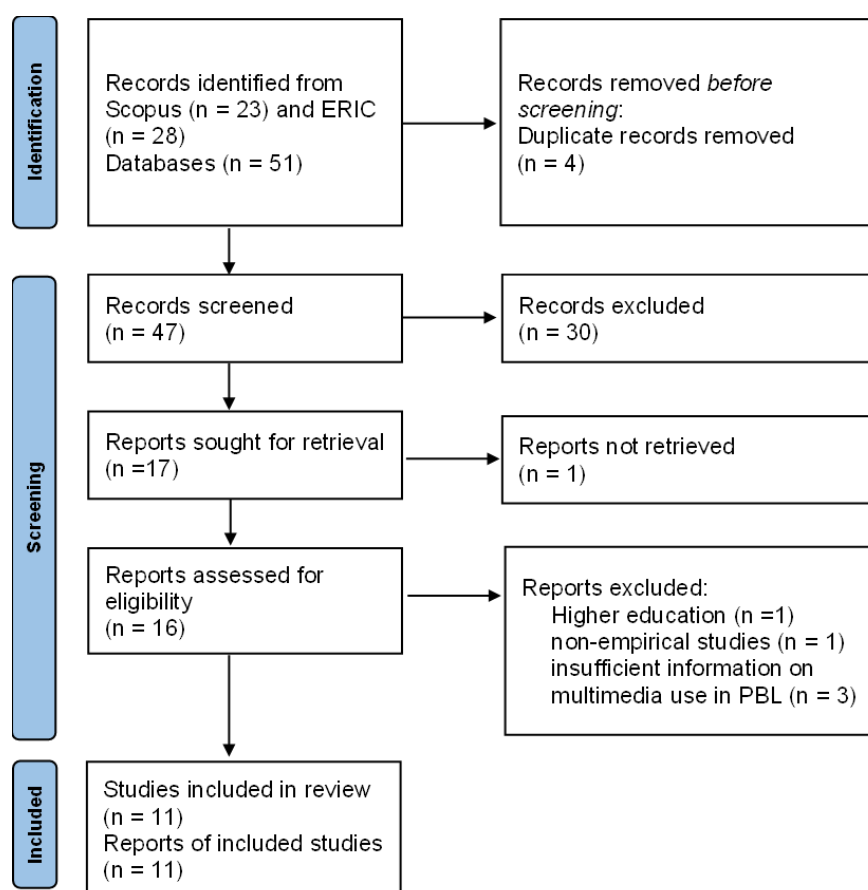


Figure 2: PRISMA flow diagram of the article selection process

2.3 Quality Appraisal

The remaining 11 articles were assessed for methodological quality using the 2018 version of the MMAT (Hong et al., 2018). Two reviewers independently assessed each study using the MMAT criteria appropriate to its research design. One included study employed a research and development (R&D) approach, which is not explicitly covered by the MMAT categories. Following Kholid et al. (2026), the study was first examined based on its methodological characteristics and then assessed using the MMAT category that most closely matched its research approach. Because the study primarily used descriptive quantitative analysis, it was appraised using the quantitative descriptive criteria.

Before applying the design-specific criteria, each article was assessed using the two MMAT screening questions. Each criterion was rated as Yes, No, or Can't tell. Yes indicated that the criterion was met, No indicated that it was not met, and Can't tell was used when the information provided in the article was insufficient to make a clear judgment (Hong et al., 2018). Interrater agreement was examined using Cohen's kappa, which yielded a coefficient of 0.81, indicating almost perfect agreement according to the interpretation of Landis and Koch (1977). Any differences between the reviewers were discussed until consensus was reached. MMAT findings were used to support transparent reporting of methodological quality rather than as a basis for excluding studies (Sullivan et al., 2024).

Overall, most studies met the majority of the MMAT criteria, although several limitations were identified, particularly in the reporting of research procedures. Consequently, some criteria were rated as No or Can't tell. The appraisal results are presented in Table 3. For each study, the ratings are reported in sequence, beginning with the two screening questions and followed by the five design-specific MMAT criteria, with Y = Yes, N = No, and C = Can't tell.

2.4 Data Extraction and Coding

Data extraction followed a four-layer conceptual framework linking multimedia types, their integration across PBL phases, pedagogical roles, and learning outcomes. The PBL phase categories were defined a priori based on Arends' (2012) five-phase model, while categories for multimedia types, pedagogical roles, and impacts were developed inductively from the included studies. The coding scheme was refined as new patterns emerged during the review. Once the categories were finalized, studies coded earlier were revisited to ensure consistency across the dataset.

After the coding scheme was finalized, three studies (27% of the sample) were independently double-coded to assess the consistency of its application. The studies were purposively selected to include different types of multimedia, namely GeoGebra, simulation, and AR. Following O'Connor and Joffe (2020), intercoder reliability was assessed using a subset of the studies rather than the entire dataset. Cohen's kappa yielded a coefficient of 0.85, indicating almost perfect agreement according to Landis and Koch (1977). Any coding differences were discussed and resolved by consensus.

3. Results and Findings

3.1 Research Trends and Methodological Characteristics (RQ1)

The search covered publications from 2007 to 2026, while the 11 studies included in this review were published between 2018 and 2026. As summarized in Table 3, the studies were conducted across five countries and involved students from Grade 5 through upper secondary school. Quasi-experimental designs were the most common, followed by mixed-methods, qualitative, and research and development (R&D) studies. Overall, Yes ratings were more frequent than No or Can't tell ratings, although the pattern varied across studies.

Table 3: Characteristics of studies included in the review

Authors	Level	Design	Participant	MMAT Appraisal
Ramadhani and Narpila (2018)	Senior high school	Quasi-experimental study	114 students from Senior high school in North Sumatra, Indonesia (38 experimental I, 38 experimental II, 38 control)	YYYYYNY
Cetin et al. (2019)	Grade 9 - high school	Case study (qualitative)	25 students from Grade 9 high school in Türkiye; 12 selected for in-depth interviews	YYYYYYC
Nugraha et al. (2019)	Grade 7 - Junior High School	Quasi-experimental study	116 Junior high school students from 3 classes in West Java, Indonesia	YYYYYYC
Atahan and Mert Uyangör (2021)	Grade 6	Mixed methods study	20 students from Grade 6 in Balıkesir, Türkiye	YYCCCCC
Yerizon et al. (2022)	Grade 11 - Senior high school	R&D (Plomp)	32 students from Grade 11 senior high school in West Sumatera, Indonesia	YYCYCYC
Negara et al. (2022)	Grade 11 - Senior high school	Quasi-experimental study	70 students from Grade 11 senior high school in West Java, Indonesia (35 experimental, 35 control)	YYCYYYC
Sy Nam et al. (2023)	Grade 9 - secondary school	Quasi-experimental study	48 students from Grade 9 secondary school in Ho Chi Minh City, Vietnam (25 control, 23 experimental)	YYCCYYY
Lailiyah et al. (2026)	Elementary and junior high school	Quasi-experimental study	126 students from grade 5 (Islamic primary school) and grade 9 (Islamic junior high school) in Indonesia	YYCCCNC
Martín-Cudero et al. (2026)	Upper secondary	Mixed methods study	42 students from public secondary school Madrid, Spain (19 students from scientific-technological and 23 students	YYYYYCY

			form social sciences specializations)	
Auliya et al. (2026)	Grade 8 secondary school	Quasi-experimental study	90 students from Grade 8 secondary school in Thailand (30 per group)	YYCYYYY
Düzenli Çil and Ustun (2026)	Grade 9 - Senior high school	Mixed methods study	51 students from Grade 9, high school Eastern Anatolia Region, Türkiye (26 experimental, 25 control)	YYYYYCY

Note. Each study's MMAT rating is reported as a 7-character sequence corresponding, in order, to S1, S2 (the two screening questions) and C1–C5 (the five design-specific criteria); Y = Yes, N = No, C = Can't tell.

3.2 Multimedia Types and Their Integration Across PBL Phases (RQ2)

The studies were examined across the five PBL phases proposed by Arends (2012): orienting students to the problem (P1), organizing students for learning (P2), assisting independent and group investigation (P3), developing and presenting artifacts and exhibits (P4), and analyzing and evaluating the problem-solving process (P5). Table 4 summarizes the types of multimedia used and how they were integrated across these phases.

Table 4: Multimedia types and their integration across PBL phases in the included studies

Authors	Multimedia	Integration in PBL	PBL Phase(s)
Ramadhani and Narpila (2018)	GeoGebra	Representation and visualization of statistical problem-solving results through digital charts and diagrams	P4
Cetin et al. (2019)	GeoGebra, Smartboard	Used within TEPLA (technology-enhanced problem-based learning activities) to contextualize real-life problem situations and support visualization and exploration of graph-function relationships during guided investigation	P1, P3
Nugraha et al. (2019)	Geometer's Sketchpad	Visualization of geometric concepts	P3
Atahan and Mert Uyangör (2021)	Video, audio, multimedia production tools	Multimedia design, production, presentation, and evaluation of student-created artifacts	P4, P5
Yerizon et al. (2022)	GeoGebra-assisted worksheet (LKPD-PBL-G)	problem presentation, visualization and exploration of calculus concepts, and self-assessment via answer verification	P1, P3, P5
Negara et al. (2022)	GeoGebra	Visualization and exploration of limit function concepts in an online PBL environment	P3
Sy Nam et al. (2023)	GeoGebra	Visualization of geometric loci and verification of students' solutions through error detection and correction	P3, P5
Lailiyah et al. (2026)	PhET Simulation	Presentation of contextual mathematical problems, support for information gathering and	P1, P2, P3

		exploratory investigation through interactive simulations	
Martín-Cudero et al. (2026)	GeoGebra	Investigation of real-world epidemic modelling through parameter exploration and graphical analysis	P3
Auliya et al. (2026)	AR - GLARE	Problem exploration, known-unknown identification, investigation, and evaluation of geometry problem situations	P1, P2, P3, P5
Düzenli Çil & Ustun (2026)	Arloon AR, Onshape	Geometric modelling to support solution development	P3

Dynamic geometry software (DGS) was the most commonly used type of multimedia, appearing in seven studies, with GeoGebra used in six and Geometer's Sketchpad in one. Other studies used AR, simulations, and multimedia production tools. Across the PBL phases, multimedia use was most evident in P3, where it supported visualization, exploration, and investigation. In P1, multimedia was used to introduce or explore the problem. Its use in P2 included activities such as identifying known and unknown information and gathering information needed to address the problem. In P4, multimedia supported the creation, representation, and presentation of students' work, whereas its use in P5 mainly involved checking and evaluating solutions.

3.3 Pedagogical Roles of Multimedia-Supported PBL (RQ3)

The identified pedagogical roles were derived from the reported uses of multimedia across the reviewed studies and are summarized in Table 5.

Table 5: Pedagogical roles of multimedia in mathematics PBL

Pedagogical role	Description	Supporting studies
Visualization and Representation	Multimedia supported the visualization of abstract mathematical concepts, geometric objects, graphs, and mathematical relationships through dynamic and interactive representations	Ramadhani and Narpila (2018); Cetin et al. (2019); Nugraha et al. (2019); Yerizon et al. (2022); Negara et al. (2022); Sy Nam et al. (2023); Martín-Cudero et al. (2026); Auliya et al. (2026); Düzenli Çil and Ustun (2026)
Exploration and Investigation	Multimedia enabled students to manipulate mathematical objects, explore patterns, test hypotheses, and investigate problem situations during inquiry activities	Cetin et al. (2019); Yerizon et al. (2022); Negara et al. (2022); Sy Nam et al. (2023); Lailiyah et al. (2026); Martín-Cudero et al. (2026); Auliya et al. (2026); Düzenli Çil and Ustun (2026)
Concept Construction and Understanding	Multimedia facilitated the development of conceptual understanding by supporting students in constructing mathematical ideas through	Cetin et al. (2019); Yerizon et al. (2022); Negara et al. (2022); Lailiyah et al. (2026); Auliya et al. (2026); Düzenli Çil and Ustun (2026)

	dynamic representations and exploratory activities	
Solution Verification and Error Detection	Multimedia supported students in reviewing problems or solutions, verifying mathematical results when applicable, identifying errors, and evaluating mathematical reasoning during reflection and evaluation	Yerizon et al. (2022); Sy Nam et al. (2023); Auliya et al. (2026)

Visualization and representation was the most commonly identified role of multimedia, followed by exploration and investigation. Multimedia also supported students in constructing conceptual understanding, whereas its use for solution verification and error detection was reported in fewer studies. These roles often overlapped, as the same multimedia tool could serve more than one purpose during the learning process. Atahan and Mert Uyangör (2021) differed from this pattern. In their study, multimedia was used primarily to produce and manage student projects rather than to directly support mathematical understanding or problem solving. The study was therefore not classified under any of the four pedagogical roles presented in Table 5.

3.4 Impacts and Challenges of Multimedia-Supported PBL (RQ4)

The reported outcomes covered cognitive, affective, and interdisciplinary skills, while the implementation challenges fell into two broad categories: technical and student-related issues (Table 6).

Table 6: Reported impacts and challenges of multimedia-supported PBL in mathematics education

Category	Result	Supporting studies
Cognitive outcomes	Studies reported outcomes related to problem-solving ability, statistical thinking, mathematical reasoning, computational thinking, critical thinking, and mathematics achievement	Ramadhani and Narpila (2018); Cetin et al. (2019); Nugraha et al. (2019); Yerizon et al. (2022); Negara et al. (2022); Sy Nam et al. (2023); Lailiyah et al. (2026); Auliya et al. (2026)
Affective outcomes	Studies reported affective outcomes including attitudes towards mathematics and technology-integrated mathematics activities, self-efficacy, and anxiety	Cetin et al. (2019); Atahan and Mert Uyangör (2021) ; Düzenli Çil and Ustun (2026)
Perceived interdisciplinary skills	Students' perceptions of interdisciplinary skills across four dimensions: educational impact, awareness, methodological impact, and practical application	Martín-Cudero et al. (2026)

Technical challenges	Device incompatibility; internet connectivity issues; inconsistent application loading speeds across devices	Auliya et al. (2026); Düzenli Çil and Ustun (2026)
Student-related challenges	Resistance to adoption technology, lack of enthusiasm, initial difficulty operating GeoGebra due to unfamiliarity, distraction from other applications/games	Cetin et al. (2019); Yerizon et al. (2022); Lailiyah et al. (2026); Auliya et al. (2026)

Cognitive outcomes were reported in eight studies, with findings varying across studies and comparison conditions. Ramadhani and Narpila (2018) found significantly higher statistical thinking scores than with conventional instruction, but no significant difference compared with standard PBL. Nugraha et al. (2019) reported greater improvement in problem-solving with Geometer's Sketchpad-assisted PBL than with PBL alone or conventional instruction. Cetin et al. (2019) identified perceived benefits for mathematics achievement, including visualization, time efficiency, and learning through discovery, although these findings were based on qualitative data.

Yerizon et al. (2022) reported problem-solving scores above the minimum mastery criterion based on postintervention measurement without a comparison group. Negara et al. (2022) found significant gains in mathematical reasoning with GeoGebra-assisted PBL, although the gains were lower than those obtained with GeoGebra-supported scientific learning. Sy Nam et al. (2023) reported higher mathematics achievement in the intervention group based on posttest comparisons. Lailiyah et al. (2026) reported that the PBL-PhET intervention was significantly related to students' problem-solving and critical thinking skills in both primary and junior high school. Auliya et al. (2026) found greater gains in problem-solving and computational thinking than with PBL without AR or conventional instruction.

Affective outcomes were examined in three studies and showed varied results. Cetin et al. (2019) reported generally positive student attitudes toward mathematics, while Atahan and Mert Uyangör (2021) found positive attitudes toward technology-integrated mathematics activities. Düzenli Çil and Ustun (2026) reported more positive attitudes and lower anxiety in the AR-supported PBL group after controlling for baseline scores, but no significant difference in posttest self-efficacy. Martín-Cudero et al. (2026) additionally examined perceived interdisciplinary skills. Students in the scientific-technological group generally reported more positive perceptions than those in the social sciences group, although significant differences were limited to some indicators.

Intervention duration was explicitly reported in six of the 11 studies. The reported durations varied considerably, from a single implementation or two 50-minute sessions to interventions lasting up to 12 weeks. The remaining five studies did not provide sufficient information to determine the intervention duration.

3.5 Research Gaps and Future Directions (RQ5)

The included studies identified several limitations and suggested directions for future research related to participant scope, intervention duration, technology accessibility, and the range of mathematical topics addressed, as summarized in Table 7.

Table 7: Research gaps and future directions identified in the included studies

Gap / limitation identified	Suggested future direction	Source
Studies were limited to specific participant populations and geographical contexts	Expand research to other school levels, geographical settings, and broader participant populations	Sy Nam et al. (2023); Negara et al.(2022)
Studies were limited to specific mathematical topics or abilities	Extend research to other mathematical topics, problem types, and mathematical abilities	Sy Nam et al. (2023); Negara et al.(2022)
TEPLA implementation focused on a specific mathematical topic and did not quantitatively examine motivation and retention	Investigate motivation and learning retention using quantitative measures and different mathematical topics	Cetin et al. (2019)
A single PBL intervention may be insufficient to capture longer-term changes	Conduct longitudinal studies with repeated PBL implementation over longer periods	Martín-Cudero et al. (2026); Lailiyah et al. (2026)
Technical challenges were reported, including device incompatibility and internet connectivity issues	Develop more accessible multimedia applications across different devices	Auliya et al. (2026)
AR-supported PBL was implemented only in geometry and within a relatively short intervention period	Examine the approach in other mathematics topics and over longer instructional periods	Düzenli Çil and Ustun (2026)
Study limited to primary and junior high school levels, with skills examined restricted to critical thinking and problem solving	Explore PBL-PhET interactions with other mathematical skills (creative thinking and communication) and across primary, junior high, and senior high school levels	Lailiyah et al. (2026)

4. Discussion

Research on multimedia-supported PBL in school mathematics remains limited and geographically concentrated, with most of the included studies conducted in Indonesia and Türkiye. This concentration indicates that the current evidence base represents a relatively narrow range of educational contexts, limiting the extent to which the findings can be generalized across settings. However, this pattern should be interpreted cautiously because the geographical distribution of

studies identified in a systematic review is also influenced by database coverage and search terminology. As Fitzgerald et al. (2025) noted, no single educational database provides complete coverage of the relevant literature.

The predominance of quasi-experimental studies suggests that research has largely focused on whether multimedia-supported PBL improves learning outcomes. While this provides useful evidence regarding effectiveness, less is known about how multimedia supports learning within PBL and under what conditions particular forms of integration are most useful. A similar tendency toward quantitative research was reported by Kirabo et al. (2024) in their review of technology-supported PBL in mathematics education. Future studies could therefore place greater emphasis on the processes and conditions underlying multimedia integration, moving beyond whether an intervention works to better understand how and why it works (Cobb et al., 2003).

The current evidence is also concentrated at the secondary school level and within a relatively narrow range of mathematics topics. As a result, less is known about multimedia-supported PBL among younger learners and across other areas of school mathematics. Research across a broader range of school levels and mathematical topics is therefore needed to determine whether the patterns identified in this review extend beyond the contexts currently represented.

GeoGebra emerged as the most frequently used multimedia tool, appearing in six of the 11 included studies. Its prominence may be related to its free accessibility and its ability to connect algebraic and geometric representations within a dynamic environment (Hohenwarter & Jones, 2007). GeoGebra also allows users to visualize, explore, and dynamically connect multiple representations of mathematical concepts (Zengin et al., 2012). These features align well with the investigative nature of PBL, in which students explore mathematical relationships and develop possible solutions.

In Lailiyah et al. (2026), PhET simulations were used to support problem presentation, information gathering, and exploratory investigation. This use is consistent with Jonassen's (2011) view of simulations as components of PBL environments that allow learners to manipulate problem variables, observe their effects, and test relationships within a problem. AR was used in two recent geometry studies, but its role differed between them. Auliya et al. (2026) used AR to support problem exploration, visualization, and investigation, whereas Düzenli Çil and Ustun (2026) used AR and digital modelling to support spatial visualization and solution development. These uses are consistent with previous research showing that AR-based STEM learning environments frequently support exploration and interaction with digital representations (Ibáñez & Delgado-Kloos, 2018).

Across the PBL process, multimedia use was concentrated most strongly in the investigation phase (P3), where it supported activities such as exploring representations, manipulating mathematical objects, testing ideas, and gathering information for solving problems. Its use in the later phases was less evident.

Atahan and Mert Uyangör (2021) provided a notable exception, as students created multimedia products to represent and present their solutions and subsequently evaluated these products, extending multimedia use into P4 and P5. Overall, this pattern suggests that multimedia integration in mathematics PBL has focused more on supporting investigation than on the later processes of communicating and evaluating solutions.

This review identified four major pedagogical roles of multimedia in mathematics PBL: visualization and representation, exploration and investigation, concept construction and understanding, and solution verification and error detection. Among these, visualization and representation was the most frequently identified role, suggesting that multimedia primarily helped make mathematical objects, relationships, and representations more accessible during problem solving. This role is consistent with CTML, which emphasizes the integration of verbal and visual information in learning (Mayer, 2009), and with Duval's (2006) view that mathematical understanding depends on coordinating different forms of representation.

Exploration and investigation was another prominent role, extending multimedia use beyond the presentation of mathematical representations to active engagement with them. Dynamic tools allowed students to manipulate mathematical objects, examine relationships, and test ideas as part of the problem-solving process. This role aligns with the investigative nature of PBL (Hmelo-Silver, 2004; Savery, 2006) and with the affordances of dynamic mathematics software for constructing, manipulating, and exploring mathematical objects (Healy & Hoyles, 2002). Concept construction and understanding represents a further step beyond visualization and exploration. Across the reviewed studies, multimedia supported students in developing mathematical ideas by allowing them to work with dynamic representations and explore relationships that may be difficult to observe directly. This role is consistent with a constructivist view of learning, in which understanding develops through learners' active interaction with the learning environment (Deliyannis et al., 2008).

Solution verification and error detection was a less frequently identified role, but it extended multimedia use beyond exploration and concept development. In the reviewed studies, multimedia supported students in checking solutions, identifying errors, and evaluating the outcomes of their problem-solving processes. These activities are closely related to self-regulatory processes such as monitoring, self-evaluation, and reflection (Zimmerman, 2002), as well as the monitoring and evaluation components of metacognitive regulation described by Schraw et al. (2006). These four roles describe the pedagogical functions served by multimedia in the reviewed PBL studies. Similar functions may also occur in non-digital PBL. In the reviewed studies, however, multimedia supported these functions through affordances such as dynamic representation, manipulation, simulation, and interactive exploration.

Regarding outcomes, the reviewed studies examined a range of cognitive and affective outcomes, with findings varying across studies and comparison conditions. These included problem-solving, statistical thinking, mathematical

reasoning, computational thinking, critical thinking, and mathematics achievement, as well as attitudes, self-efficacy, and anxiety. The evidence was generally favorable, but not uniformly so, consistent with Liu and Pásztor's (2022) meta-analysis, which found that although problem-based learning generally produced a meaningful effect on critical thinking, the results varied considerably across studies because of differences in the instruments, methods, and outcomes measured. For example, some effects depended on the comparison condition, while others were not statistically significant. These findings should therefore be interpreted with caution. Intervention duration was not consistently reported and varied considerably among studies that provided this information, limiting conclusions about the longer-term effects of multimedia-supported PBL. The wide variation in outcomes and measures also makes it difficult to determine which effects are most consistent across learning contexts.

Taken together, these findings show that multimedia use in PBL involves interconnected relationships among where multimedia is integrated into the PBL process, the pedagogical roles it serves, and the learning outcomes reported across the studies. Figure 3 synthesizes these recurring patterns across the reviewed literature. The line thickness in Figure 3 represents how frequently each association was identified across the included studies, rather than the strength or statistical significance of the relationship. This distinction is important because the effects of multimedia could not always be separated from those of the broader PBL intervention. For example, Ramadhani and Narpila (2018) found no significant difference between GeoGebra-supported PBL and PBL without GeoGebra, although GeoGebra-supported PBL significantly outperformed conventional instruction. The framework should therefore be interpreted as a synthesis of recurring patterns in the reviewed literature rather than as a validated model of causal relationships.

Despite the reported impacts, the review also identified technical and student-related challenges that may constrain multimedia-supported PBL. Technical problems related to devices, connectivity, and application performance can disrupt students' access to multimedia resources, while unfamiliarity with the technology and competing digital distractions may interfere with their engagement in problem-solving activities. These findings reinforce the importance of considering technological readiness and implementation conditions rather than treating multimedia access alone as sufficient for successful integration. Similar concerns have been identified by Staneviciene and Žekienė (2025), who emphasize infrastructure disparities and insufficient technical support as persistent barriers to multimedia-based learning implementation.

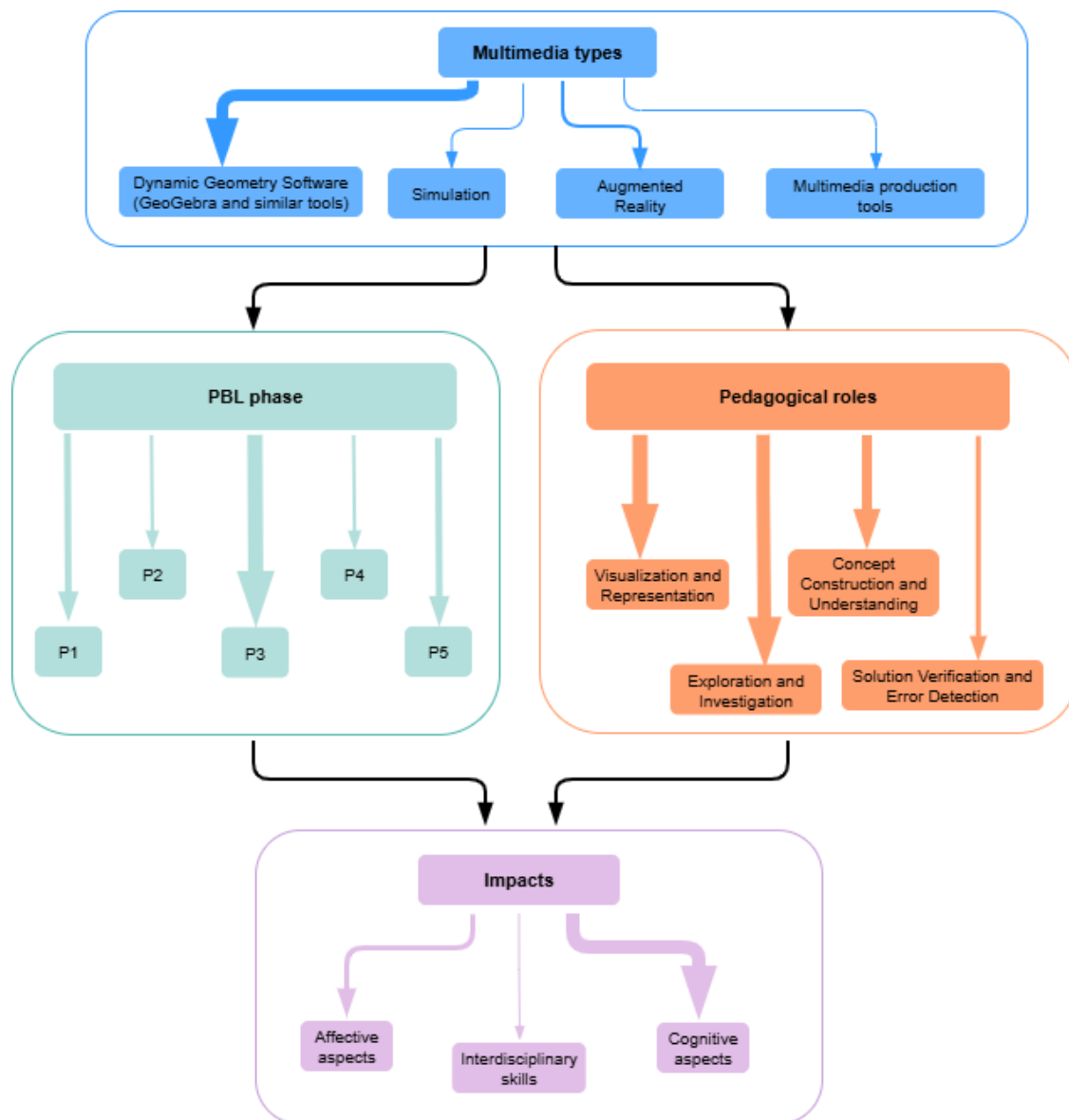


Figure 3: Synthesized framework of multimedia integration in mathematics PBL

This review also identified several research gaps that remain to be addressed. First, few of the studies included in this review focused on the primary school level. Several studies also suggested examining a wider range of participants, geographical settings, mathematical topics, and student abilities (Sy Nam et al., 2023; Negara et al., 2022). Second, several studies highlighted the need for longer or repeated implementations to examine whether the observed effects are sustained over time (Düzenli Çil & Ustun, 2026; Lailiyah et al., 2026; Martín-Cudero et al., 2026). Other gaps concern the range of outcomes examined, including motivation, retention, creative thinking, and communication skills (Cetin et al., 2019; Lailiyah et al., 2026), as well as the accessibility of multimedia across different devices and technological conditions (Auliya et al., 2026). Together, these gaps point to the need for research that tests multimedia-supported PBL across more diverse contexts, over longer periods, and with a broader range of learning outcomes.

5. Implications

The findings point to several implications for classroom practice and policy. The predominant use of multimedia during the investigation phase suggests that its integration in PBL has largely centered on supporting students' exploration and investigation. For classroom practice, teachers and instructional designers could consider not only which multimedia tools to use, but also when and for what pedagogical purpose they are used, particularly to support the organizing and artifact development phases, both of which received markedly less multimedia support than the investigation phase in the reviewed studies. At the policy level, recurring problems with device compatibility and connectivity point to the need for reliable and accessible technological infrastructure. Professional development and sustained support are also important for enabling teachers to implement integrated learning practices meaningfully (Kozan et al., 2023). In multimedia-supported PBL, such support could help teachers make more deliberate decisions about when and for what pedagogical purpose multimedia is integrated across the PBL phases.

6. Conclusion

This review synthesized 11 studies on multimedia-supported PBL in school mathematics by examining multimedia types, their integration across PBL phases, and the pedagogical roles they serve. The findings show that the contribution of multimedia lies not simply in the use of digital tools, but in how they are integrated into the problem-solving process. Multimedia integration was concentrated most strongly in the investigation phase of PBL. From a pedagogical perspective, four main roles were identified: visualization and representation, exploration and investigation, concept construction and understanding, and solution verification and error detection. The reviewed studies examined a range of cognitive and affective outcomes, with generally favorable but varied findings across studies and comparison conditions. Taken together, these findings suggest that the potential of multimedia in mathematics PBL depends on the pedagogical function it serves and how that function is connected to the broader PBL process.

Future research should examine how different forms and pedagogical uses of multimedia support learning across the PBL process, rather than focusing only on whether multimedia-supported PBL is effective. More research is also needed across different educational levels and contexts, particularly at the primary school level, over longer periods, and with a broader range of learning outcomes.

7. Limitations

Several limitations should be considered when interpreting the findings of this review. First, the search was limited to Scopus and ERIC and to published journal articles, which may have introduced publication bias, excluded relevant studies, and failed to capture all terminology related to multimedia. The search terms were also formulated in English without an explicit language restriction, which may have reduced the retrieval of studies published in other languages. In addition, study screening was conducted by one reviewer, which may have increased the risk of selection bias. The MMAT appraisal, however, involved two reviewers,

while 27% of the included studies were double coded during data extraction and coding.

Second, only 11 studies met the inclusion criteria, representing a relatively small body of evidence and limiting the generalizability of the findings. Third, variations in research designs, intervention durations, types of multimedia used, and learning outcomes measured limited direct comparisons across studies. These variations resulted in a narrative and descriptive synthesis rather than a quantitative one. The MMAT appraisal also identified methodological and reporting limitations in several studies, which should be considered when interpreting the findings.

Conflict of Interest

No potential conflict of interest was reported by the authors.

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