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INSTRUCTIONAL MEDIA AND MULTIMODAL REPRESENTATIONS IN PRIMARY SCHOOL MATHEMATICS: A SYSTEMATIC REVIEW AND BIBLIOMETRIC MAPPING

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ABSTRACT

Primary school mathematics increasingly draws on diverse representational modes and instructional media, yet syntheses that bring the two together remain scarce. Following the PRISMA 2020 guideline, this systematic literature review maps publication trends, media and modes, topics, grade levels, research designs, and findings of studies published between 2022 and 2026. Eligible studies were journal articles on multimodality or instructional media in primary school mathematics. A Scopus search on 25 October 2026 yielded 798 records. After database limits, title and abstract screening, and eligibility assessment, 35 studies were thematically synthesized and mapped through keyword co-occurrence analysis in VOSviewer; risk of bias was not formally assessed. Twenty-five studies (71.4%) were published in 2025–2026, and Indonesia dominated author affiliations (16 studies; 45.7%). Seven categories of media and modes were identified, the largest being interactive multimedia and software (10 studies). Studies adopting a multimodal lens were mostly small-scale and qualitative, whereas media-focused studies were dominated by development research and quasi-experiments reporting positive outcomes. The keyword map centred on *educational technology*, while terms related to representational modes, such as *embodied cognition*, lay at the periphery, and only eight studies explicitly used the term multimodal. The two research streams thus tend to run separately. Evidence is limited by the use of a single database, a single reviewer, and abstract-level assessment. Future research should design media within explicit multimodal frameworks, test their effects on students' thinking processes, and position teachers as mediators of modes.
Keywords: multimodality; primary school mathematics; PRISMA 2020; systematic literature review.

ABSTRAK

Pembelajaran matematika di sekolah dasar (SD) kian memanfaatkan beragam moda representasi dan media pembelajaran, tetapi sintesis yang mempertemukan keduanya masih langka. Tinjauan literatur sistematis ini memetakan tren publikasi, media dan moda representasi, topik, jenjang, desain penelitian, serta temuan studi tahun 2022–2026 dengan mengikuti pedoman PRISMA 2020. Studi yang memenuhi syarat adalah artikel jurnal tentang multimodalitas atau media pembelajaran matematika di SD. Penelusuran Scopus pada 25 Oktober 2026 menghasilkan 798 rekaman. Setelah pembatasan, penyaringan judul dan abstrak, serta penilaian kelayakan, 35 studi disintesis secara tematik dan dipetakan melalui analisis ko-kemunculan kata kunci dengan VOSviewer; risiko bias tidak dinilai secara formal. Sebanyak 25 studi (71,4%) terbit pada 2025–2026, dan Indonesia mendominasi afiliasi penulis (16 studi; 45,7%). Tujuh kategori media dan moda teridentifikasi, dengan kategori terbesar berupa multimedia dan perangkat lunak interaktif (10 studi). Studi berlensa multimodal umumnya kualitatif dan berskala kecil, sedangkan studi media didominasi penelitian pengembangan dan

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kuasi-eksperimen yang melaporkan hasil positif. Peta kata kunci berpusat pada *educational technology*, sementara istilah moda representasi seperti *embodied cognition* berada di pinggiran, dan hanya delapan studi yang secara eksplisit memakai istilah multimodal. Kedua arus riset ini cenderung berjalan sendiri-sendiri. Temuan dibatasi oleh penggunaan satu basis data, satu penelaah, dan penilaian pada tingkat abstrak. Penelitian selanjutnya perlu merancang media dalam kerangka multimodal yang eksplisit, menguji dampaknya terhadap proses berpikir siswa, dan menempatkan guru sebagai mediator moda.
Kata kunci: multimodalitas; media pembelajaran; matematika sekolah dasar; tinjauan literatur sistematis; PRISMA 2020

INTRODUCTION

Picture a third grader learning fractions. She folds a sheet of paper, draws a strip, says “one half”, and then writes ½. These four simple steps conceal a great deal of cognitive work: uniting action, image, speech, and symbol into a single meaning. Mathematical objects are abstract and can be accessed only through representations (Duval, 2006; Goldin, 2003), which is why the ability to create and use representations is placed at the heart of mathematical understanding (National Council of Teachers of Mathematics, 2000). For primary school students, this foundation shapes the quantitative and spatial reasoning they will carry into later schooling.

The idea that knowledge can be presented in multiple modes has long shaped instructional design. Bruner (1966) distinguished enactive, iconic, and symbolic representation, while Lesh et al. (1987) identified five modes experience-based scripts, manipulable models, pictures or diagrams, spoken language, and written symbols and stressed the importance of translations among them. The message is clear: the quality of learning depends not on how many representations are offered but on the opportunities students have to connect them. Recent studies confirm that actions and gestures are far from mere add-ons. A six-year-old's gestural routines when counting with manipulatives can evolve from ritualised to explorative (Zhang et al., 2026), and geometric abstraction can grow out of students' *embodied* actions (Boonstra et al., 2023).

In the classroom, primary students' difficulties stem more often from coordinating representations than from a lack of them. Many students, for instance, struggle to represent fractions verbally, visually, and symbolically (Nurhidayah et al., 2026), even though mathematical understanding depends on coordinating several sign systems (Duval, 2006) and the benefits of multiple representations hinge on their design, the task, and how students use them (Ainsworth, 2006). These coordination demands also vary by topic. *Fraction sense* can be developed through realistic contexts and animation (Pramudiani & Dolk, 2025), geometric understanding blends action, perception, and symbol (Videla et al., 2026), and in data and combinatorics students reason through speech, inscriptions, and gestures (Tytler et al., 2023; Wathne & Carlsen, 2024) and reveal spatial thinking through data physicalization (Zhu et al., 2023). In short, choices of media and modes cannot be standardised across topics.

The urgency of this issue is keenly felt in Indonesia. In PISA 2022, Indonesian students' mean mathematics score was only 366 points, far below the OECD average of 472 points (Organisation for Economic Co-operation and Development, 2023). Although PISA assesses 15-year-olds, this performance is built from primary school onwards, when students first learn to connect mathematical ideas with their representations. More integrated evidence is therefore needed on how media and representations are designed at the primary level.

A multimodal perspective offers a lens for reading these processes. It views communication and learning as practices that combine several semiotic modes and media

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(Kress & van Leeuwen, 2001). In mathematics education, attention has accordingly shifted from written symbols alone to speech, inscriptions, and gestures that complement one another in students' reasoning (Arzarello et al., 2009; Wathne & Carlsen, 2024), so that learning can be understood as transduction, that is, connecting and reshaping meaning across modes (Tytler et al., 2023). Yet students rarely move between modes on their own. Teachers need to recognise students' multimodal expressions and use them as a starting point for instruction (Boonstra et al., 2026). Language and culture also shape how modes work. *Translation*, *translanguaging*, and *trans-semiotizing* in bilingual classrooms improved first graders' outcomes (Fauzan et al., 2023), teachers' *languaging* was stronger in teacher-led than in student-generated representations (Kim et al., 2025), and geometric patterns and ethnomathematics can serve as contextual learning resources (Lestari et al., 2025; Pramulia et al., 2025).

Instructional media, both digital and non-digital, in turn determine which modes are available to students and how those modes can be transformed. The cognitive theory of multimedia learning explains that words and pictures are processed through dual channels of limited capacity (Mayer, 2009), consistent with dual coding theory (Paivio, 1986) and cognitive load theory (Sweller et al., 2011). Scholarly output on technology in mathematics learning keeps rising (Magaña et al., 2022), and the range of media keeps widening: interactive software in Kenya and Rwanda (Lysenko et al., 2022; Uwineza et al., 2023), digital games for early counting and mental arithmetic (Freitas et al., 2025; Kusuma et al., 2025), AR and VR for geometry (Hidayati et al., 2026; Videla et al., 2026), culture-based comics for numeracy (Raharjo et al., 2026), and manipulatives combined with *video modelling* for students with autism (Alabdulaziz & Alamoudi, 2026). Even so, technology does not automatically produce meaningful learning. Instant feedback can boost motivation yet limit reflection (Medová et al., 2026), and the advantages of media may differ between conceptual and procedural knowledge (Mavrikis et al., 2022).

Unfortunately, this growth has not been matched by a synthesis that brings the different types of media together. Existing systematic reviews are each confined to *augmented reality* in mathematics education (Pahmi et al., 2023), information and communication technology (ICT) in primary school (Zuhri et al., 2024), or multimedia in *problem-based learning* (Sari et al., 2026). Moreover, research appears split into two streams. Studies with a multimodal lens offer detailed accounts of students' thinking but rarely translate them into media design. Conversely, media studies mostly assess product feasibility and learning outcomes but seldom trace how students move between and connect modes while using the media (Ainsworth, 2006; Mayer, 2009). To the authors' knowledge, no synthesis has yet examined both together. Yet media designed without attention to mode coordination risk merely adding representations without helping students connect them (Ainsworth, 2006).

This review addresses that gap by synthesising publications from 2022–2026, a period that extends the most recent bibliometric analysis, which ended with articles from 2021 (Magaña et al., 2022). In this review, *mode* refers to a semiotic resource for constructing mathematical meaning (speech, writing and symbols, pictures and diagrams, gesture, and actions on concrete objects), whereas *media* refers to the digital or non-digital means that present, store, or enable the transformation of those modes (Kress & van Leeuwen, 2001). The review makes three contributions: (a) an evidence map of 35 studies by media, mode, topic, grade level, and research design; (b) a keyword co-occurrence map generated with VOSviewer; and (c) a proposed framework linking media design with mode coordination by students and teachers. Four research questions guide the review.

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RQ1. What are the publication trends (year, country, journal, and collaboration patterns) in research on multimodal representations and media in primary school mathematics learning in 2022–2026?
RQ2. At which grade levels and on which mathematical topics, and with which research designs, were these studies conducted?
RQ3. Which media and representational modes were used, which theoretical frameworks underpinned them, and what is the conceptual structure of their keywords?
RQ4. What main findings, challenges, and research gaps were reported?

METHODS

1.1 Design and protocol

This study is a systematic literature review reported in accordance with the PRISMA 2020 guideline (Page et al., 2021), with search reporting informed by PRISMA-S (Rethlefsen et al., 2021). The flow diagram follows the PRISMA 2020 template (Haddaway et al., 2022), and the PRISMA 2020 checklist is provided in Supplementary Material S1. The review protocol was not registered in a public repository. Screening and data extraction were performed by a single reviewer using a structured screening sheet, so inter-rater agreement could not be calculated; this is discussed as a limitation. The review was conducted in the following six stages.

1. **Planning:** formulating the research questions (RQ1–RQ4) and PICoS-based eligibility criteria.
2. **Searching:** constructing the search string and applying Scopus limits.
3. **Selection:** screening records by title and abstract, then assessing their eligibility.
4. **Extraction:** recording the characteristics and findings of each study on an extraction sheet.
5. **Synthesis:** synthesising findings thematically and mapping the conceptual structure with VOSviewer.
6. **Reporting:** presenting results according to the PRISMA 2020 items, including the flow diagram (Figure 1) and checklist (Supplementary Material S1).

1.2 Information sources and search strategy

The search was run in Scopus on 25 October 2026 and returned 798 initial records. Scopus was chosen for its broad coverage of reputable education journals and because its metadata include the author and index keywords required for co-occurrence analysis. The search strategy combined three concept blocks in titles, abstracts, and keywords: media or representational modes, mathematics or numeracy, and primary school level. The search string was as follows.

TITLE-ABS-KEY ((multimodal* OR "multiple representation*" OR multimedia OR "instructional media" OR "learning media" OR "educational technolog*" OR "digital game*" OR "augmented reality" OR manipulative* OR gesture* OR embodied) AND (mathematic* OR numeracy) AND ("primary school*" OR "elementary school*" OR "primary education" OR "elementary education" OR "primary student*" OR "elementary student*"))

Scopus limits were applied in three stages, leaving 91 records (Table 1). Because these limits were applied before manual screening, the 707 records removed are reported as records removed before screening (Figure 1). All 91 records were final journal articles published in 2022–2026, and 89 of them were *open access*.

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Table 1. Stages of record limitation in the Scopus search

Stage	Limit applied	Records remaining	Records removed
Initial	TITLE-ABS-KEY string in Section 2.2	798	–
1	Publication year 2022–2026	530	268
2	Document type (journal article) and subject area (*Social Sciences*)	176	354
3	Keywords related to mathematics, students, and primary education	91	85
Total		91	707

Note. Records removed are calculated relative to the previous stage. All remaining records had final status.

1.3 Eligibility criteria

Eligibility criteria were formulated using the PICoS (framework *population*, *phenomenon of interest*, *context*, and *study design*) supplemented by limits on publication type and year range (Table 2).

Table 2. Inclusion and exclusion criteria

Component	Inclusion criteria	Exclusion criteria
Population (P)	Primary school (*primary/elementary*; grades 1–6, aged about 6–12 years)	Preschool/early childhood, lower and upper secondary, higher education
Phenomenon of interest (I)	Multimodality (speech, gesture, inscription, language/semiotics, bodily movement, concrete objects) or digital and non-digital instructional media substantively related to mathematical representation or learning processes	Technology or media with no substantive link to representation or learning processes; a sole focus on teachers' beliefs, efficacy, or perceptions
Context (Co)	Mathematics or numeracy as the learning focus	Fields outside mathematics (e.g., astronomy)
Study design (S)	Empirical studies (experimental, quasi-experimental, qualitative, development research, *design research*) and design or conceptual articles grounded in literature or teacher data	Secondary reviews and bibliometric analyses (used only as background)
Publication type	Final journal articles	Proceedings, book chapters, articles in press
Year range	2022–2026	Before 2022

1.4 Study selection process

Selection proceeded in stages. First, each record was assessed on its title and abstract against three components: (a) multimodality or instructional media, (b) mathematics or numeracy, and (c) a primary school context. Assessments were grouped into five decisions: Include, Provisionally include, Check further, Theoretical support only, and Exclude from the

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main corpus. Records rated Include or Provisionally include (n = 37) were assessed for eligibility on the basis of title, abstract, and keywords, and 35 studies were included. Records rated Check further (n = 22) were not included because their substantive relevance was not evident at the abstract level. Records rated Theoretical support only (n = 9) were secondary reviews, studies of teacher perceptions, or studies outside mathematics, and were used only as background. Full texts of the 35 studies were not examined, so all decisions were based on titles, abstracts, and keywords.

1.5 Data collection and data items

For each study, the following were extracted: authors and year, country of affiliation, journal, grade level, mathematical topic, media or mode, research design, theoretical framework cited, and main findings as reported in the abstract. Media/mode and topic categories were developed inductively, and each study was assigned to its single most prominent category (Supplementary Material S2).

1.6 Quality appraisal and synthesis methods

Data were analysed descriptively and through narrative thematic synthesis. No meta-analysis was conducted because of heterogeneity in designs, sample sizes, and outcome measures. No formal risk-of-bias assessment, for example with the *Mixed Methods Appraisal Tool* (Hong et al., 2018), was performed either, so the findings should be read as an evidence map rather than as effect estimates. Possible reporting bias is discussed narratively in Sections 3.5 and 3.8.

1.7 Bibliometric analysis

The conceptual structure of the corpus was mapped through keyword co-occurrence analysis using VOSviewer version 1.6.20 (van Eck & Waltman, 2010) on Scopus export data for the 35 included studies. The analysis used *full counting* with a minimum threshold of two occurrences, *association strength* normalisation, and default clustering settings (*resolution* 1.00 and minimum cluster size 1). The analysis was run twice: on author keywords (49 items) as the main analysis and on all keywords, that is, author and index keywords (82 items), as a sensitivity analysis. Author keywords were chosen for the main analysis because they reflect how authors frame their topics, whereas index keywords include generic terms added by the database (e.g., *human*, *female*, and *male*) that are less informative about conceptual structure. No thesaurus file was used, so term variants are displayed as they are. Maps are presented in network and *overlay* (average publication year) views, and density views and the sensitivity-analysis maps are provided in Supplementary Material S3. Cross-country collaboration patterns were computed directly from author affiliations (Supplementary Material S2).

RESULTS AND DISCUSSION

Results

Study selection flow

The Scopus search returned 798 records, and three stages of limits left 91 records (707 records removed before screening; Figure 1). Of the 91 records screened by title and abstract, 54 were excluded (23 out of scope, 9 as theoretical support only, and 22 without evidence of substantive relevance at the abstract level), leaving 37 records assessed for eligibility. Two records were excluded at this stage: one because the term multimodal referred to the measurement of error responses rather than to mathematics learning, and one because it focused on a learning trajectory within an individualised education programme without a clear link to media or modes. The final corpus comprised 35 studies.

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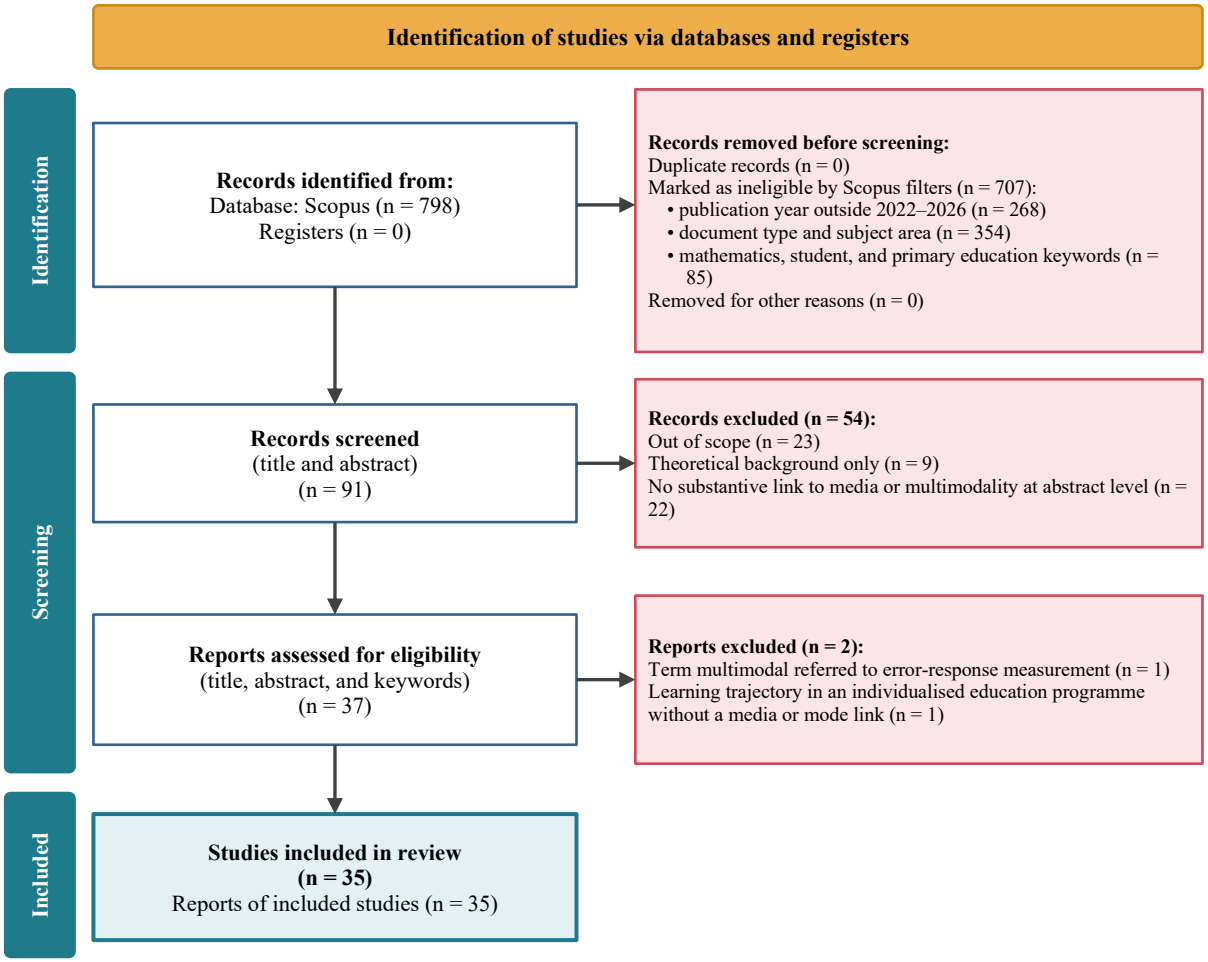


Figure 1. PRISMA 2020 flow diagram for the identification, screening, and inclusion of studies

Note. Template adapted from Page et al. (2021). There were no duplicate records because a single database was searched. Scopus limits are reported as records removed before screening. Eligibility was assessed at the level of title, abstract, and keywords.

Publication characteristics and collaboration (RQ1)

The 35 studies were published between 2022 and 2026 (Figure 2a): 3 in 2022, 6 in 2023, 1 in 2024, 14 in 2025, and 11 in 2026 (up to the export date). Thus, 25 studies (71.4%) appeared in the last two years. Authors were affiliated with institutions in 25 countries (Figure 2b). Indonesia dominated with 16 studies (45.7%), followed by the Netherlands (4 studies) and the United States (3 studies). Chile, Saudi Arabia, Malaysia, Canada, and the Philippines each appeared in two studies, and the remaining 17 countries each appeared in one study.

Fourteen of the 35 studies (40.0%) involved authors from more than one country (13 studies from two countries and 1 from three), whereas 21 studies were written by authors from a single country. Indonesia was the largest collaboration hub. Eight of its studies involved partners from six countries (the Netherlands, the Philippines, Canada, Malaysia, New Zealand, and the United States), with repeated collaboration with Malaysia and the Philippines (two studies each). Other collaborations were spread across pairs or small groups, such as Chile–Peru, Argentina–Chile–United States, Germany–United Kingdom, Japan–Rwanda, and Jordan–Saudi Arabia. Eight countries never appeared in cross-country collaboration: Australia,

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Finland, Hong Kong, Italy, Norway, Portugal, Slovakia, and Vietnam. All these counts derive from author affiliations (Supplementary Material S2).

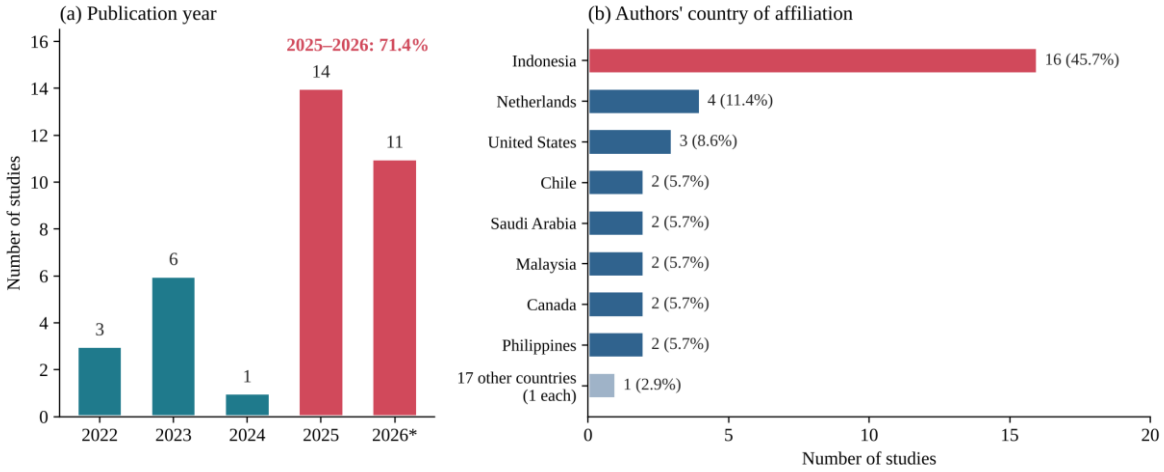


Figure 2. Number of studies by publication year and authors' country of affiliation

Note. $n = 35$. Each country is counted once per study, and a study may involve more than one country. Data for 2026 (*) are up to the export date, 25 October 2026.

Frontiers in Education published three studies, while *Educational Process: International Journal*, *Mathematics Education Journal*, *Multidisciplinary Science Journal*, *International Research Journal of Multidisciplinary Scope*, and *Participatory Educational Research* each published two. The 35 studies had received 142 citations in total at the time of export. Mavrikis et al. (2022) was the most cited with 35 citations, followed by Tytler et al. (2023) with 18. The low citation counts of most other studies reflect their recent publication.

The term *multimodal* appeared in the title, abstract, or keywords of eight studies, and the term *multimedia* in six (full list in Supplementary Material S2). Only one study, Hidayati et al. (2026), used both terms. This pattern indicates that the vocabularies of multimodality and multimedia barely meet in the corpus.

1.8 Grade levels, topics, and research designs (RQ2)

By grade level, 11 studies (31.4%) focused on the lower grades (grades 1–3), 13 (37.1%) on the upper grades (grades 4–6 or aged about 10–12), and 11 (31.4%) referred to primary school without specifying grades. Six of the 11 lower-grade studies addressed numbers and counting, for example Kusuma et al. (2025), whereas geometry and fractions stood out in the upper grades, in six of 13 studies. This division is understandable because number is foundational in the early grades, while geometry and fractions demand more complex coordination of representations (Duval, 2006). By topic (Figure 3a), the largest group was numeracy or general mathematical ability (10 studies), followed by geometry and numbers/operations (7 studies each), data and combinatorics (5 studies), fractions (4 studies), and ratio and proportion (2 studies).

Research designs (Figure 3b) were almost evenly divided among qualitative approaches (case studies, ethnography, *photovoice*, and video analysis; 10 studies), research and development (9 studies), and quasi-experiments (9 studies). The remainder comprised *design research* or *didactical design research* (4 studies), *mixed methods* (2 studies), and one conceptual design article. Nine studies used comparison groups, and sample sizes in quantitative studies ranged from 20 students (Manoy et al., 2026) to 283 students in the experimental group (Lysenko et al., 2022). This range reflects large variation in scale. Qualitative studies were generally much smaller, from one child (Zhang et al., 2026) to 37

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children (Zhu et al., 2023), in keeping with their aim of examining processes in depth rather than measuring effects.

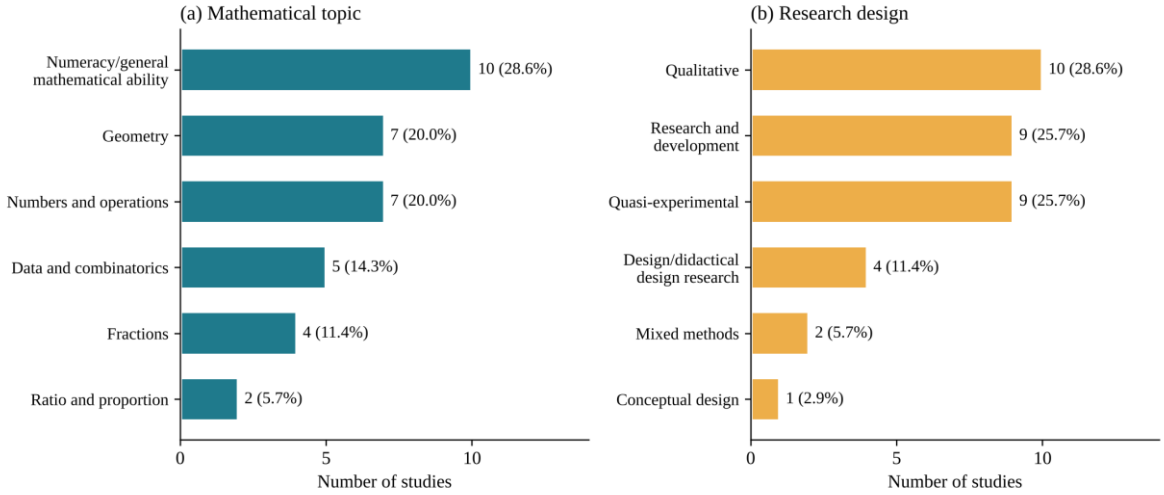


Figure 3. Mathematical topics and research designs of the synthesised studies
Note. n = 35. Percentages are based on the number of studies.

Media, modes, and conceptual structure (RQ3)

Seven categories of media and modes were identified (Table 3). Interactive multimedia, software, and e-books formed the largest category (10 studies; 28.6%), followed by games and *mobile* applications (6 studies; 17.1%). Mapping categories against topics (Figure 4) reveals a clear pattern. Immersive technology was concentrated in geometry (three of three studies), games and apps mainly in numbers and operations (four of six studies), and *embodied* or manipulative approaches in fractions and geometry (four of five studies). Ratio and proportion appeared only in two STEM studies, and no multimodal discourse study addressed fractions.

Table 3. Categories of media and representational modes

Category	*n*	%	Example studies
Interactive multimedia, software, and e-books	10	28.6	Lysenko et al. (2022); Lai et al. (2026)
Games, play, and *mobile* apps	6	17.1	Kusuma et al. (2025); Medová et al. (2026)
Multimodal discourse (speech, gesture, inscription, language)	5	14.3	Tytler et al. (2023); Zhang et al. (2026)
Embodied and manipulatives/concrete objects	5	14.3	Zhu et al. (2023); Nurhidayah et al. (2026)
Comics, memes, and culture-based media	4	11.4	Wathani et al. (2022); Raharjo et al. (2026)
Immersive technology (AR/VR/AI)	3	8.6	Hidayati et al. (2026); Videla et al. (2026)
STEM media and learning trajectories	2	5.7	Guntur et al. (2023); Guntur et al. (2025)

Note. n = number of studies; each study is assigned to its single most prominent category. Full list in Supplementary Material S2.

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	Numeracy	Numbers and operations	Geometry	Fractions	Data and combinatorics	Ratio and proportion	**Total**
Interactive multimedia, software, and e-books	4	2	1	2	1	–	**10**
Games and *mobile* apps	2	4	–	–	–	–	**6**
Multimodal discourse	2	1	–	–	2	–	**5**
Embodied and manipulatives	–	–	2	2	1	–	**5**
Comics, memes, and culture-based media	2	–	1	–	1	–	**4**
Immersive technology	–	–	3	–	–	–	**3**
STEM media and learning trajectories	–	–	–	–	–	2	**2**
	10	**7**	**7**	**4**	**5**	**2**	

Figure 4. Evidence map: number of studies by media/mode category and mathematical topic
Note. $n = 35$. A dash (–) indicates no studies. Coding of categories and topics is based on titles, abstracts, and keywords (Supplementary Material S2).

The theoretical frameworks cited in the abstracts were highly diverse. Cognitive multimedia theory appeared in media-focused studies (e.g., Hidayati et al., 2026), *Realistic Mathematics Education* in studies on fractions and mathematical literacy (Pramudiani & Dolk, 2025), and transduction in multimodal discourse studies (Tytler et al., 2023). Other frameworks, such as *4E cognition* and the *Concrete–Representational–Abstract* (CRA) approach, each appeared in only one study. This diversity indicates the absence of a shared framework across studies.

The conceptual structure of the corpus is clearer in the author keyword co-occurrence map (49 items; Figure 5). The network centres on technology and grade-level terms. The largest node is *educational technology*, followed by *mathematics education*, *primary school*, *primary education*, and *mathematics*. Grade-level terms (*primary school*, *primary education*, *elementary school*, and *elementary education*) appear as separate nodes scattered across several clusters, reflecting inconsistent terminology across studies. Several clusters can be recognised by their colours and node labels: a technology and remote teaching cluster (*educational technology*, *remote teaching*, *early childhood*), a multimedia and problem-based learning cluster (*multimedia*, *problem-based learning*), a geometry and abstraction cluster (*geometry*, *abstraction*), a literacy and numeracy cluster (*literacy*, *numeracy*, *arithmetic*, *digital personalised learning*), and a representation and interactive learning environment cluster (*mathematical representation*, *interactive learning environment*, *elementary education*).

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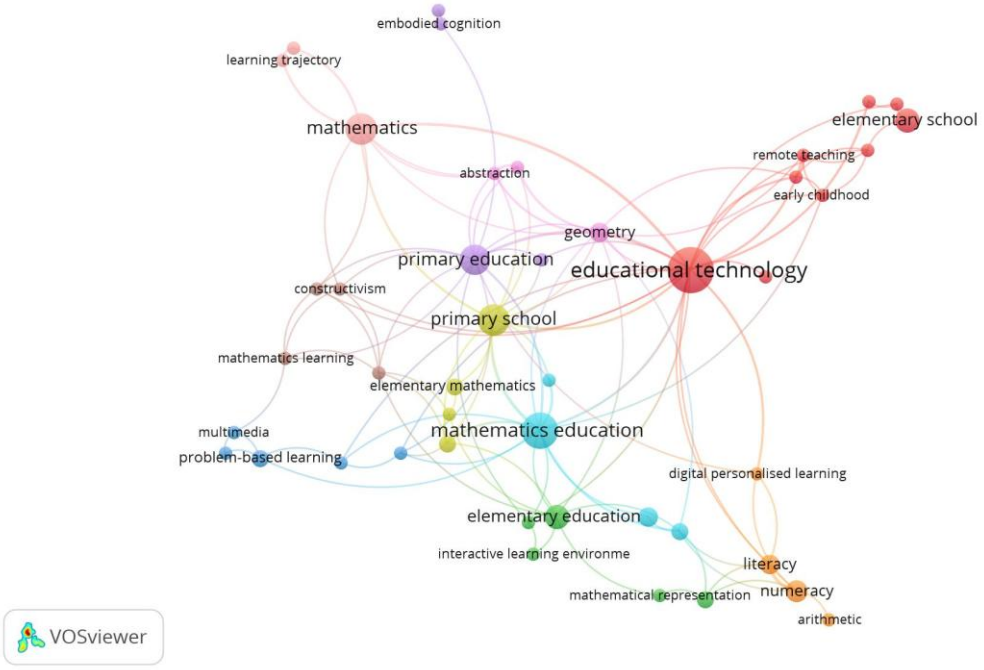


Figure 5. Network map of author keyword co-occurrence

Note. Created with VOSviewer 1.6.20. Each node is one author keyword (49 items); node size indicates frequency of occurrence, colour indicates cluster, and lines indicate co-occurrence. Not all labels are shown to avoid overlap. Minimum threshold of two occurrences.

Terms directly related to modes and representation lie at the periphery of the map. *Embodied cognition* is only weakly connected to other clusters, *learning trajectory* sits at the upper left edge, and *mathematical representation* lies at the bottom of the map, far from the technology nodes. The terms *multimodal* and *gesture* do not appear as labelled nodes on the author keyword map; *gesture* appears only on the all-keyword map, at its lower edge (Supplementary Material S3). The sensitivity analysis with all keywords (82 items) shows a similar structure. *Educational technology* remains the largest node, accompanied by many generic index terms (*human*, *humans*, *female*, *male*, and *student*) that form one large cluster but are uninformative about conceptual structure. The term *indonesia* appears as a node on this map, consistent with the dominance of Indonesian affiliations in the corpus.

The *overlay* view (Figure 6) shows a shift in focus by average publication year. The keywords *remote teaching*, *early childhood*, and *learning trajectory* lie around 2024, whereas *educational technology*, *mathematics*, and *geometry* are slightly more recent, at about 2024.5. Keywords around 2025.3 to 2025.7 include *primary education*, *numeracy*, *literacy*, *multimedia*, and *mathematical representation*, while *constructivism*, *digital personalised learning*, and *elementary mathematics* appear most recent, close to 2026. This pattern suggests a shift from educational technology in general, including remote teaching contexts, towards numeracy, literacy, mathematical representation, and digital personalisation. Because average years are computed from a small corpus with only one study published in 2024, this shift should be read as an early indication rather than an established trend.

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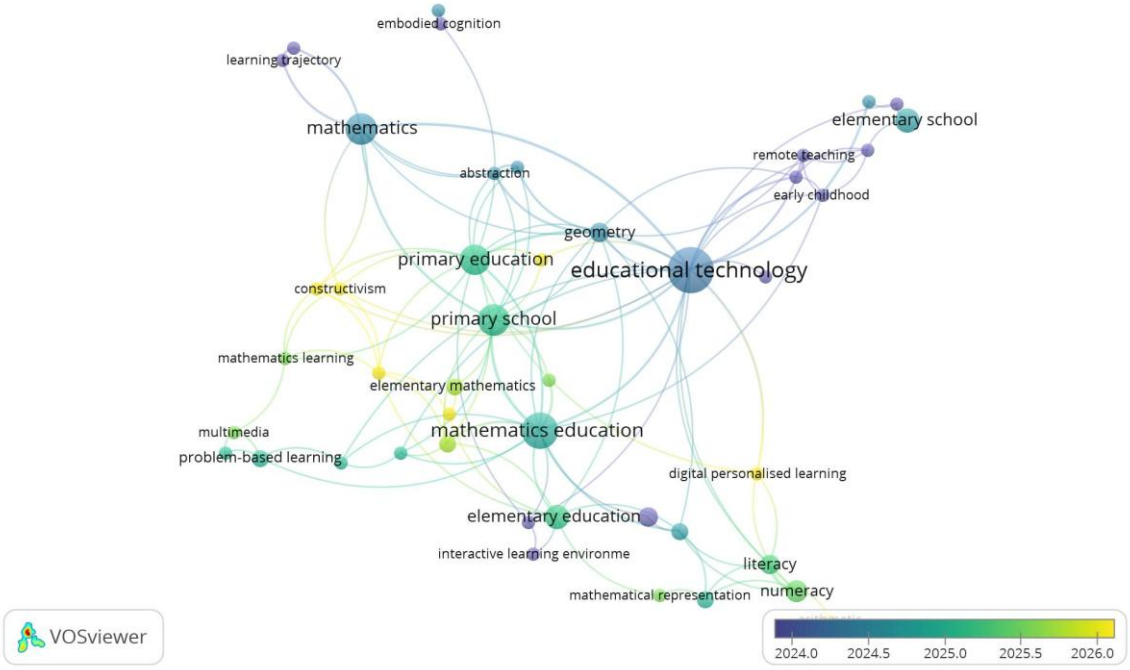


Figure 6. Overlay view of author keywords by average publication year

Note. Created with VOSviewer 1.6.20. Node colour indicates the average publication year of documents containing the keyword (purple: earlier; yellow: more recent). Author keywords, 49 items.

Main findings, challenges, and gaps (RQ4)

Findings are presented by media and mode category and then summarised as cross-study patterns. Quantitative results reported in the abstracts are summarised in Table 4, so the following account discusses only the studies that best explain the pattern of each category.

Multimodal discourse. Studies in this category show that representational modes compensate for one another. Among 13 third graders in Norway, pointing gestures mediated mathematical meaning only when combined with inscriptions displaying all combinations, whereas sliding gestures compensated for inscriptions that did not yet display them (Wathne & Carlsen, 2024). This finding underlines that gestures and inscriptions should be designed as a single sequence rather than as separate activities. A similar pattern appears in a six-year-old whose counting routines with manipulatives developed from ritualised to explorative through a pre-ritual phase marked by commognitive conflict (Zhang et al., 2026). Changes in how students use modes are therefore gradual and observable. Meaning does not develop across modes by itself, because teachers need to guide first graders in constructing and revising data displays through four phases: orientation, representational challenge, consensus building, and application and extension (Tytler et al., 2023). The teacher's guiding role also emerges in two studies focusing on language. *Translation* improved first graders' academic and social outcomes, although it took more time (Fauzan et al., 2023), and teachers' *languaging* practices were stronger in teacher-led than in student-generated representations (Kim et al., 2025).

Embodied and manipulatives. Studies in this category agree that abstraction grows out of action, but the strongest evidence concerns teacher readiness. Teachers were ready to use manipulatives but not yet aware of the implementation aspects that invite abstraction (Boonstra et al., 2023). This suggests that the main issue lies in implementation rather than in teachers' acceptance of manipulatives. Training appears to help, as two trained teachers subsequently

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enacted seven teaching practices, including using students' multimodal expressions as a starting point, although they occasionally reverted to teacher-centred practices (Boonstra et al., 2026). On the student side, concrete actions elicit distinctive ways of thinking. *Data physicalization* prompted 37 children to display seven themes of spatial thinking (Zhu et al., 2023), and manipulatives combined with *video modelling* improved fraction accuracy for all 40 students with autism (Alabdulaziz & Alamoudi, 2026). Evidence from these different groups of students shows that concrete action benefits understanding, including for students with special needs. A CRA approach packaged in a game shows that the concrete–representational–abstract sequence (Bruner, 1966) can be carried into digital media (Nurhidayah et al., 2026).

Immersive technology. This category is concentrated in geometry and shows two sides. In terms of process, three learning environments for sixth graders (material *bricolage* construction, AI-assisted body classification, and immersive 3D modelling in VR) showed that geometric understanding does not precede action but emerges from *embodied* coordination (Videla et al., 2026). This finding shifts attention from technological display to students' actions. In terms of outcomes, the AR application ARGeo Math improved fifth graders' mathematical creative thinking and linked visual with symbolic representations (Hidayati et al., 2026). The value of immersive technology thus lies in how it organises students' actions and perceptions, not merely in an attractive display. AR comics based on the ethnomathematics of the Al Akbar Mosque in Surabaya complement this picture by adding cultural context (Pramulia et al., 2025).

Interactive multimedia and software. This largest category reported positive results across topics. Interactive software improved the conceptual understanding of 138 third graders in Rwanda (Uwineza et al., 2023). Such positive results are not confined to one country. The same was found in Kenya, where the ELM software yielded effect sizes of +0.37 for overall skills and +0.77 for word problems (Lysenko et al., 2022). This consistency across two very different contexts strengthens the case for digital media, but the benefits are not always uniform across types of knowledge. An exploratory learning environment combined with a tutoring system, for example, produced greater conceptual knowledge than the tutoring system alone, while procedural knowledge was equivalent (Mavrikis et al., 2022). This is a reminder that the advantage of media depends on the type of knowledge measured. In geometry, *tessellation* with GeoGebra and 3D printing raised the scores of a fourth-grade experimental group but not those of the control group (Scippo et al., 2025). Unlike these experimental studies, development studies generally emphasised products, such as Scratch-based media for data analysis judged valid and practical (Putra et al., 2025) and culturally contextualised Android multimedia that improved numeracy (Kusmanto et al., 2025).

Games and mobile apps. This category mainly targets numbers and operations. The adventure game B'Math produced higher early-counting achievement than conventional instruction among 184 first graders (Kusuma et al., 2025). Such cognitive gains are often accompanied by affective effects. *Serious games* integrated into *exploratory teaching*, for example, improved first graders' mental arithmetic, motivation, and engagement (Freitas et al., 2025). Some game studies measured product feasibility rather than achievement: the Multiplication House game was judged valid and highly practical (Manoy et al., 2026), and the E-Lens board game was deemed suitable for rural schools with limited internet access (Rahayu & Subekti, 2025). One study offered an important caution about automated features. With the MathCityMap app in grade 3, teacher interventions helped struggling students in the Analysis and Exploration phases, whereas the app's instant feedback boosted motivation but sometimes limited reflection (Medová et al., 2026).

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Comics, memes, and culture-based media. Evidence of effectiveness in this category is more limited than in others. The deep learning–based E-Math Comic produced only a moderate gain in numeracy among 114 fourth graders compared with a control group (Raharjo et al., 2026), and meme-based media using the Indonesian Realistic Mathematics Education (PMRI) approach were judged feasible but obtained a learning evaluation score of 60% (Wathani et al., 2022). Other studies remain at the needs analysis and design stage. A needs analysis pointed to the need for interactive media linking abstract concepts with local cultural contexts (Rahardjo et al., 2025), and the geometric patterns of the Papuan crown were identified as an inclusive learning resource without testing with students (Lestari et al., 2025).

STEM media and learning trajectories. Two *didactical design research* studies, each with 27 fifth graders, traced learning trajectories for proportional reasoning and numerical problem solving. Thinking patterns differed across groups according to mathematical disposition, and some findings went beyond the hypothesised trajectories (Guntur et al., 2023, 2025).

Table 4. Summary of quantitative results reported in abstracts

Study	Design and sample	Indicator	Direction
Lysenko et al. (2022)	Quasi-experiment; 283 experimental, 171 control	ES +0.37 (overall); +0.77 (word problems)	Positive
Lai et al. (2026)	Quasi-experiment; 60 students	$d = 1.26$	Positive
Nurhidayah et al. (2026)	*Mixed methods*; 48 students	N-gain 0.77; $p < 0.05$	Positive
Hidayati et al. (2026)	Quasi-experiment; 49 students	N-gain 76.84%	Positive
Ramos Becerra et al. (2026)	Quasi-experiment; 20 students	$Z = -3.846$; $p < 0.001$	Positive
Mavrikis et al. (2022)	Two quasi-experiments; $n = 121$ and 151	Conceptual higher; procedural equivalent	Mixed
Uwineza et al. (2023)	Quasi-experiment; 138 students	Conceptual understanding and achievement increased	Positive
Kusuma et al. (2025)	Development and comparison test; 184 students	Higher achievement than conventional instruction	Positive
Raharjo et al. (2026)	Development and quasi-experiment; 114 students	Moderate gain	Positive (moderate)
Scippo et al. (2025)	Quasi-experiment; grade 4	Experimental increased; control did not	Positive
Pramudiani and Dolk (2025)	*Design research*; 135 students	*Fraction sense* increased	Positive
Alabdulaziz and Alamoudi (2026)	*Single-case*; 40 students with autism	Accuracy increased for all students	Positive
Wathani et al. (2022)	Development, pre-experiment	Learning evaluation 60%	Moderate

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Note. ES = *effect size*; N-gain = *normalized gain*. All values are quoted from study abstracts; statistical tests were not verified against full texts.

Cross-study patterns. First, reported learning outcomes were almost uniformly positive. Of the 16 studies reporting learning or performance outcomes at the abstract level, 15 reported improvement and one a moderate gain, and none reported an overall negative effect. This uniformity should be read with caution because it may reflect publication bias. Second, media-focused studies reported expert validity and practicality more often than changes in students' thinking processes. Third, studies with a multimodal lens explained how students and teachers combine modes but were small in scale and rarely tested effects on achievement. Fourth, cultural context and inclusion were addressed in only a handful of studies, for example by Lestari et al. (2025) for culture and Alabdulaziz and Alamoudi (2026) for inclusion.

Discussion

Two research streams that have yet to meet. The evidence map reveals two streams running side by side (Figure 7). The first treats multimodality as an analytical lens; its ten multimodal discourse and *embodied* studies are generally qualitative and small in scale. The second treats media as an intervention; its 25 studies on multimedia, games, comics, immersive technology, and STEM media are dominated by development research and quasi-experiments measuring validity, practicality, and achievement. The keyword map provides bibliometric evidence consistent with this pattern: the network centres on *educational technology*, while terms referring to modes and representation lie at the periphery and are not strongly connected to the technology clusters (Figure 5).

In the authors' reading, four studies bridge the two streams. Freitas et al. (2025) combined *serious games* with multimodal narratives, while Videla et al. (2026) and Hidayati et al. (2026) situated technology within explicit frameworks of modes, through an *embodied* framework for AI and VR and multimodal cues in AR, respectively. These three combine technological design with attention to modes. Nurhidayah et al. (2026) took a different route by sequencing representations through a game. These four studies are already included in the counts of 10 and 25 studies by their main category.

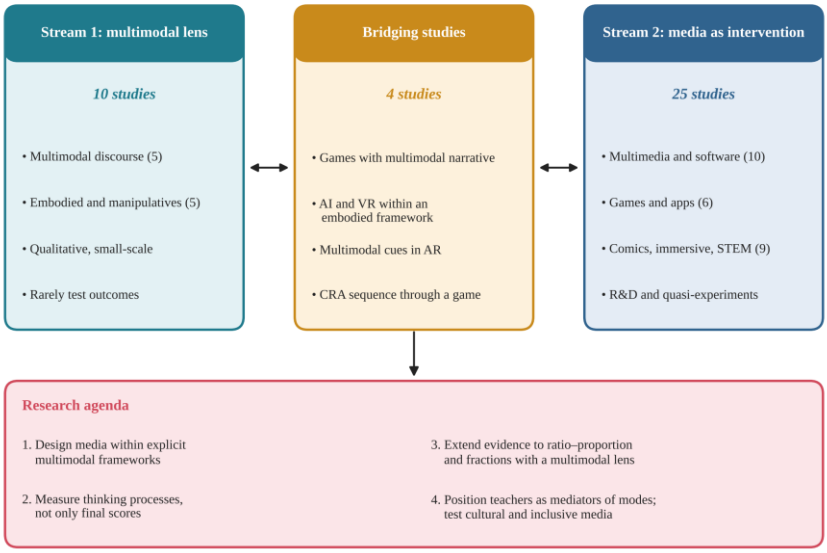


Figure 7. Two research streams, bridging studies, and research agenda

Note. The authors' synthesis of the 35 studies. Bridging studies are also counted in their main category.

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This difference is not merely terminological but conceptual. Multimedia theory yields design principles for presenting words and pictures (Mayer, 2009), whereas semiotic frameworks explain how students coordinate sign systems (Duval, 2006). Many media are designed with the first framework but rarely test whether students actually move between and connect modes as the second framework assumes. Consequently, media features should be read through the learning processes they activate, not only through final scores. This caution echoes the finding of Videla et al. (2026) that the value of AI and VR lies in reorganising perception–action relations rather than in adding representations, and the finding of Medová et al. (2026) that instant feedback can limit reflection.

The collaboration pattern adds to this picture. Indonesia's dominance stems mainly from development research, including six studies using the ADDIE model, such as Kusuma et al. (2025), whose samples were often small. Conversely, studies with a multimodal and *embodied* lens came mostly from Europe, Australia, and Hong Kong, which are almost unconnected to Indonesia's collaboration network. This separation helps explain why the findings of the two groups are hard to compare and also points to opportunities for cross-stream partnerships. The surge of publications in 2025–2026 is also in line with the trend seen in the bibliometric analysis of technology in mathematics learning (Magaña et al., 2022).

Teachers, cultural context, language, and inclusion. The success of media is not automatic, and teachers emerged as mediators in six studies. Teachers need to recognise students' multimodal expressions and use them as a starting point (Boonstra et al., 2026), and to guide students in moving between representations (Tytler et al., 2023). This role demands complex skills. The challenge is real because student-generated representations remain weaker than teacher-led ones (Kim et al., 2025). Teacher training should therefore include how to manage transitions between modes. Other aspects cultural context, language, and inclusion have been touched on in only a few studies. Ethnomathematics comics (Pramulia et al., 2025) and bilingual instruction (Fauzan et al., 2023) show their potential, whereas evidence on inclusion is limited to a single study with autistic students (Alabdulaziz & Alamoudi, 2026). Contextual media need to be tested directly with students, not merely assessed for feasibility.

Proposed framework, implications, and research agenda

Based on these patterns, the authors propose that primary school mathematics media be designed and evaluated through three layers: (1) the modes provided by the media, (2) students' coordination of modes, and (3) mediation by teachers and tasks, with evidence covering both process and outcome (Table 5). This framework is the authors' interpretation of the corpus and has not yet been tested.

Table 5. Guiding questions for designing and evaluating media within a multimodal framework

Dimension	Guiding question	Example in the corpus
Modes provided	Which modes does the medium afford and constrain (speech, gesture, pictures, symbols, actions on objects)?	Videla et al. (2026): AI and VR reorganise perception–action relations
Representational sequence	Is there a concrete–representational–abstract sequence and room for students to connect the representations?	Nurhidayah et al. (2026): CRA in a game
Mode coordination	How do students move between and connect modes, and how is this observed?	Tytler et al. (2023): four phases of transduction pedagogy

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Dimension	Guiding question	Example in the corpus
Teacher mediation	What is the teacher's role in using students' expressions and managing automated feedback?	Boonstra et al. (2026); Medová et al. (2026)
Student context	Are language, culture, and inclusion needs considered and tested with students?	Fauzan et al. (2023); Alabdulaziz and Alamoudi (2026)
Evidence	Does evaluation cover thinking processes, not only scores, with comparison groups and follow-up?	Mavrikis et al. (2022): conceptual and procedural

Note. Compiled by the authors from the synthesis.

In practice, the framework leads to three implications. First, media should include an explicit sequence of representations and room for students to connect modes, as exemplified by Nurhidayah et al. (2026). Second, physical activity and gesture should be retained when technology is used, because in geometry *embodied* action appears to precede understanding (Boonstra et al., 2023; Videla et al., 2026). Third, media should be accompanied by teacher strategies for using students' expressions and managing automated feedback, as well as mode choices that take students' language and context into account.

For future research, five agendas should be prioritised:

1. testing media with explicit multimodal frameworks, such as transduction or multimedia theory, and measuring thinking processes in addition to final scores;
2. extending evidence to under-researched topics, namely ratio and proportion, and to fractions through a multimodal discourse lens;
3. using comparison groups, larger samples, and follow-up measurements, and reporting null or negative results;
4. testing culture-based and inclusive media directly with students, with teachers and their training as key variables; and
5. building cross-cluster partnerships between media developers and multimodal discourse researchers.

Limitations

The findings of this review should be read in light of several limitations. First, only Scopus was searched, and the staged limits removed 707 records without manual review. Second, screening and extraction were performed by a single reviewer at the level of title, abstract, and keywords, so details of methods and follow-up measurements were often unavailable, and the reported figures need to be confirmed through full-text verification. Third, no formal quality appraisal was conducted, each study was assigned to a single category, and the 2026 data are incomplete. Fourth, the uniformly positive results may reflect publication bias, and collaboration counts are based on countries of affiliation without reflecting each author's role. Fifth, the keyword maps depend on occurrence thresholds and terminological consistency, and unmerged variants of grade-level terms split similar nodes. Finally, the primary school level in Al-Barakat et al. (2025) is not stated in the abstract, and Clements et al. (2025) focus on early childhood mathematics, so only part of it concerns primary grades.

CONCLUSION

This review of 35 studies from 2022–2026 shows that research on multimodal representations and media in primary school mathematics has grown rapidly since 2025 and is

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dominated by Indonesian affiliations, with 40.0% of studies involving cross-country collaboration. Media most often take the form of interactive multimedia and software and games, whereas multimodal and *embodied* lenses appear in small-scale qualitative studies and sit at the periphery of the keyword map. Reported learning outcomes are almost uniformly positive, but evidence on how students and teachers coordinate modes remains thin. Future research should bring the two streams together through multimodally framed media, stronger evaluation designs, and attention to teachers, culture, and inclusion.

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