



Bridging Technology and Cognition: A Systematic Review of Animation-Based Mathematics Learning Trends

Desi Sulastr^{1,*}, Iik Nurhikmayati¹, & Dexter C. Aligaya²

¹Department of Mathematics Education, Universitas Majalengka, Indonesia

²Department of Science and Mathematics Education, Mindanao State University - Iligan Institute of Technology, Philippines

Abstract: This systematic literature review analyzes 27 empirical studies published between 2020 and 2024 on the use of animation in mathematics learning by applying the PRISMA protocol within a Critical Interpretive Synthesis (CIS) framework, complemented by keyword co-occurrence analysis, heatmap visualization, thematic analysis of 27 abstracts, and a relational mapping Sankey diagram. Descriptively, publication trends show a fluctuating pattern with the most significant surge occurring in 2023 (9 publications), predominantly from Indonesia ($\approx 40\%$), followed by African and European countries, and by experimental (33.3%) and R&D (25.9%) designs. The most frequently investigated mathematical competency is conceptual understanding (37.0%), whereas higher-order skills such as HOTS, reasoning, and mathematical connections remain marginal. The distribution of animation platforms is dispersed, with no single dominant tool, including Powtoon, GeoGebra, and animated videos (each at 11.1%). Keyword co-occurrence analysis yields six clusters, centered on the GeoGebra–geometry cluster, with the mathematical connection node positioned the most independently, indicating weak theoretical integration in that area. The heatmap and Sankey diagram reveal unbalanced cross-dimensional relationships, highlighting that links among methodology, mathematical competencies, and platforms are more strongly shaped by institutional preferences and technological readiness than by cognitive demands. The thematic analysis identifies five major themes: (1) the effectiveness of animation in supporting conceptual representation, (2) cognitive mechanisms such as segmentation and cognitive load reduction, (3) enhancement of motivation and engagement, (4) technology integration and teacher readiness, and (5) implementation constraints, including reliance on demonstration and lack of theoretical integration. The methodological quality assessment indicates small sample sizes, short intervention durations, inconsistent instruments, and potential publication bias. Future research should integrate stronger theoretical frameworks, expand its focus on higher-order competencies, and conduct longitudinal and comparative studies across platforms to strengthen the empirical basis for the use of animation in mathematics education.

Keywords: animation, mathematics education, technology, systematic literature review.

▪ INTRODUCTION

The rapid advancement of Information and Communication Technology (ICT) has fundamentally transformed mathematics education, introducing new paradigms for teaching abstract concepts (Nikolaevna et al., 2024). Digital transformation has not only altered pedagogical approaches but also reshaped how students construct mathematical understanding (Tashtoush et al., 2023). Given the inherent characteristics of mathematics, requiring abstraction, systematic logic, and multi-representational thinking, innovative learning approaches are essential to bridge the gap between theoretical concepts and students' practical comprehension (Braithwaite & Sprague, 2021).

Animation-based media has emerged as a particularly promising tool in mathematics education due to its capacity to transform static, abstract concepts into

dynamic visual representations (Ploetzner et al., 2020). Meta-analytic evidence demonstrates a consistent moderate positive effect size ($d = 0.504$) for visualization interventions in mathematics, with animation showing particular effectiveness for students with strong prior knowledge (Schoenherr et al., 2024). Berney & Bétrancour (2016) further confirmed that animated visualizations yield higher learning outcomes compared to static images, particularly when the learning content involves dynamic processes or transformations. These benefits are theoretically grounded in Cognitive Load Theory, which holds that well-designed animations can reduce extraneous cognitive load by explicitly depicting changes and relationships that learners would otherwise need to mentally construct (Skulmowski & Xu, 2022).

Recent empirical studies have demonstrated the diverse applications of animation in mathematics education. Habsyi & Saleh (2022) developed an e-learning program based on animated content that successfully improved students' mathematical connection abilities. Yildiz & Arpacı (2024) examined pre-service mathematics teachers' intentions to use *GeoGebra* through the lens of technological pedagogical content knowledge. According to research by Chechan et al. (2023), *desmos* effectively enhances comprehension of functions through interactive visualization. Munyaruhengeri et al. (2023) investigated both the potentials and limitations of *GeoGebra* in teaching limits and continuity of functions. Furthermore, a bibliometric study by Awaji et al. (2025) mapped two decades of *GeoGebra* research in mathematics education, revealing the software's sustained relevance and evolving applications. These studies collectively illustrate the breadth of animation-based approaches in mathematics education, yet they also highlight the need systematic synthesis to understand overarching patterns and gaps.

However, the effectiveness of animation in mathematics education is not unconditional. Research has identified several boundary conditions where animation may fail to produce expected benefits or even hinder learning. Ljubojevi et al. (2025) and Pink & Newton (2020) noted that animations can impose excessive cognitive demands when they present information too rapidly or include irrelevant decorative elements. Similarly, Ploetzner et al. (2020) emphasized that animations are most effective when the features of change are central to the learning objectives; otherwise, their dynamic nature may distract rather than facilitate understanding. Furthermore, the "transient information effect" suggests that the fleeting nature of animated content can overwhelm working memory, particularly for novice learners who lack the schemas to process rapidly changing visual information (Skulmowski & Xu, 2022). These findings underscore that animation is not a universal solution but a tool whose effectiveness depends on careful instructional design aligned with specific learning goals and learner characteristics.

Despite the growing body of research on animation-based mathematics learning, the field faces significant fragmentation that limits cumulative knowledge building. Three specific gaps warrant attention. First, there is methodological heterogeneity: studies employ diverse research designs ranging from quasi-experiments to R&D approaches, yet no systematic comparison has examined whether these methodological choices yield different conclusions about animation effectiveness (Muhammad et al., 2022). Second, there is an inconsistency in outcome measurement: while some studies focus on conceptual understanding, others emphasize procedural fluency, mathematical representation, or affective outcomes, making cross-study synthesis challenging (Sirait et al., 2023). Third, there is limited attention to higher-order mathematical competencies:

preliminary observations suggest that existing research predominantly addresses foundational skills while neglecting critical thinking, creativity, and mathematical connections, competencies increasingly emphasized in 21st-century mathematics curricula (Yang, 2019). A systematic literature review is therefore needed not merely to catalogue existing studies but to critically analyze these patterns and identify strategic directions for future research.

Unlike previous reviews, which were largely descriptive and did not examine interdimensional relationships in depth, this study offers a more critical synthesis by highlighting the structural patterns in research on animation-based mathematics learning. It address prior limitations through four core analytical components: (a) mapping multidimensional relationships among research methodologies, geographical contexts, and mathematical competencies; (b) identifying co-association patterns between the affordances of animation platforms and the cognitive demands of learning; (c) conducting thematic network analysis to uncover research clusters and theoretical fragmentation; and (d) synthesizing pedagogical approaches and implementation challenges reported across the literature. By focusing on the 2020–2024 period, this study captures a significant phase of digital transformation that has not yet been systematically documented in previous reviews. This approach not only provides a more integrated overview but also offers an empirically grounded critique that clarifies future directions for developing animation-based mathematics research a more balanced and theoretically robust manner.

This study aims to answer six research questions: (1) how are publications temporally and geographically distributed during 2020–2024, and what contextual factors explain these patterns?, (2) which animation platforms are most widely used, and how are they distributed when examined by geographical context, educational level, and mathematical content domain?, (3) how do co-associations between animation platforms and mathematical competencies reveal the alignment between technological affordances and the cognitive demands of learning?, (4) what are the relational configurations among research methodologies, geographical contexts, technological platforms, and targeted mathematical competencies, and to what extent are these configurations shaped by theoretical frameworks as opposed to institutional preferences or technological readiness?, (5) what thematic clusters and network patterns emerge from keyword co-occurrence, and to what extent do these findings indicate research fragmentation, topic isolation, or levels of theoretical integration?, (6) what pedagogical approaches, implementation challenges, and instructional implications recur across the literature, and how are these linked to the characteristics of animation platforms and the methodological designs employed?

▪ **METHOD**

Research Design

This study adopted a Systematic Literature Review (SLR) approach informed by the Critical Interpretive Synthesis (CIS) framework (Dixon-Woods et al., 2006). Selected for its capacity to synthesize literature encompassing diverse methodologies (experimental, R&D, qualitative, DBR, and mixed methods), its critical orientation toward methodological assumptions and structural gaps, and its support for constructing a conceptual framework through multidimensional analyses, including thematic co-occurrence, relational visualizations, and qualitative synthesis, beyond the descriptive

categorization typical of conventional systematic mapping reviews (Grant & Booth, 2009; Petersen et al., 2015). CIS guides the analytical and synthetic procedures, enabling methodological rigor in literature selection while maintaining the interpretive depth necessary to uncover implicit patterns and provide a structural critique of the existing body of research (Depraetere et al., 2021). Methodological transparency is ensured by using the 2020 PRISMA guidelines as a reporting protocol to systematically document the article selection process (Page et al., 2021). The PRISMA framework provided a structured approach through four sequential stages: identification, screening, eligibility, and inclusion, enabling systematic documentation of decision-making processes throughout the review.

Search Strategy

The literature search was conducted in four electronic databases: Scopus, ERIC, Google Scholar, and Dimensions. Scopus was selected a comprehensive multidisciplinary database with rigorous indexing standards; ERIC was included as the premier database for educational research; Google Scholar was utilized to capture broader grey literature and conference proceedings; and Dimensions was incorporated to access recent publications that may not yet be indexed elsewhere. Web of Science was not included due to institutional access limitations, which is acknowledged as a limitation of this study.

The search strategy employed Boolean operators to combine three conceptual categories: animation technology, mathematics content, and educational context. Table 1 presents the complete search string used across databases, with minor syntax adaptations for each database's requirements.

Table 1. Search terms and boolean strategy

Concept	Search Terms
Animation	("animation" OR "multimedia animation" OR "digital animation" OR "interactive animation" OR "animated video" OR "dynamic visualization")
Mathematics	("mathematics" OR "mathematical" OR "math" OR "geometry" OR "algebra" OR "calculus")
Education	("education" OR "learning" OR "teaching" OR "instruction" OR "classroom" OR "students")
Combined	(Animation terms) AND (Mathematics terms) AND (Education terms)

Note: The exact search syntax for Scopus was: TITLE-ABS-KEY ("animation" OR "multimedia animation" OR "digital animation" OR "interactive animation" OR "animated video") AND ("mathematics" OR "mathematical" OR "math") AND ("education" OR "learning" OR "teaching")) AND PUBYEAR > 2019 AND PUBYEAR < 2025.

Inclusion and Exclusion Criteria

Explicit inclusion and exclusion criteria were established prior to screening to ensure consistent and reproducible selection decisions. Table 2 presents these criteria with operational definitions.

Table 2. Inclusion and exclusion with operational definitions

Criterion	Inclusion	Exclusion	Operational Definition
Publication period	2020–2024	Before 2020 or after 2024	Based on the publication date in the database record

Document type	Peer-reviewed journal articles and conference proceedings	Book chapters, theses, dissertations, editorials, reviews	Verified through the publisher's website or journal indexing status
Subject domain	Mathematics education	Other subjects (science, language, etc.)	Primary focus on mathematical content, skills, or pedagogy
Intervention type	Animation-based media as a primary instructional tool	Animation as a peripheral or supplementary element	Animation must be central to the learning intervention, not merely decorative.
Research type	Empirical studies (quantitative, qualitative, mixed methods, R&D)	Theoretical papers, opinion pieces, literature reviews	Must include data collection and analysis
Language	English	Non-English	Full text available in English
Access type	Open access	Non-open access	The article can be freely accessed and downloaded without restrictions

The publication range was set for 2020–2024. This period was selected because (1) it captures the most recent developments in the use of animation for mathematics learning during and after the COVID-19 pandemic, and (2) it aligns with common practice in mapping reviews that adopt a five-year scope to ensure the relevance of the findings. *Animation-based media* was defined as any digital visual representation that uses continuous change to create the impression of movement for instructional purposes (Ploetzner et al., 2020). This includes: (a) narrative animated videos (e.g., *Powtoon*, *Vyond*), (b) dynamic geometry software with animation capabilities (e.g., *GeoGebra*, *Desmos*), (c) interactive simulations with animated elements, and (d) custom-developed animated learning objects. Static visualizations, gamification without animation, and virtual reality environments were excluded unless animation was explicitly the focus. Peer-review verification for Google Scholar sources was conducted by checking: (a) journal indexing in Scopus/ERIC, (b) presence of DOI, (c) clear peer-review statement on the journal website, or (d) publication in recognized conference proceedings with a review process.

Data Selection Process

The selection process followed PRISMA stages with dual-reviewer verification for reliability. Figure 1 presents the PRISMA flow diagram documenting article flow through each stage.

Stage 1: Identification

Initial database searches yielded 26,542 records from four databases: Scopus (n = 99), ERIC (n = 274), Google Scholar (n = 17,000), and Dimensions (n = 9,169). Before screening, 460 duplicate records were removed using reference management software (Mendeley). Additionally, 25,208 records were removed for other reasons, including: publications outside the 2020–2024 timeframe (n=11,376), (b) non-English publications (n=4,400), (c) non-open access articles (n=5,682), (d) document types other than journal

articles or conference proceedings (e.g., book chapters, theses, editorials) (n=3,750). This resulted in 874 records proceeding to the screening stage.

Stage 2: Screening

Title and abstract screening were conducted independently by two reviewers (first and second authors) against the inclusion criteria. A total of 791 records were excluded during this stage for the following reasons: not focused on mathematics education (e.g., animation in science, language, or general education) (n=513), did not utilize animation-based media as the primary instructional tool (n=201), theoretical or conceptual papers without empirical data (n=55), and review articles or meta-analyses (n=22). Inter-rater agreement was calculated using Cohen's Kappa ($\kappa = 0.84$), indicating strong agreement. Disagreements were resolved through discussion until a consensus was reached. From the screened records, 83 reports were sought for full-text retrieval.

Stage 3: Eligibility

Full-text assessment was conducted for 83 articles retrieved successfully. Articles were excluded if they did not meet the eligibility criteria, specifically: participants were not students or educators in formal educational settings (n = 24), the research methodology was unclear or lacked adequate empirical rigor (n = 20), and mathematical competencies or learning outcomes were not explicitly measured (n = 12). A total of 56 articles were excluded at the eligibility stage, resulting in 27 studies that met all inclusion criteria.

Stage 4: Inclusion

The final dataset comprised 27 articles meeting all inclusion and quality criteria. To guarantee the research's reproducibility and transparency, the PRISMA flow diagram is used during the documentation phase.

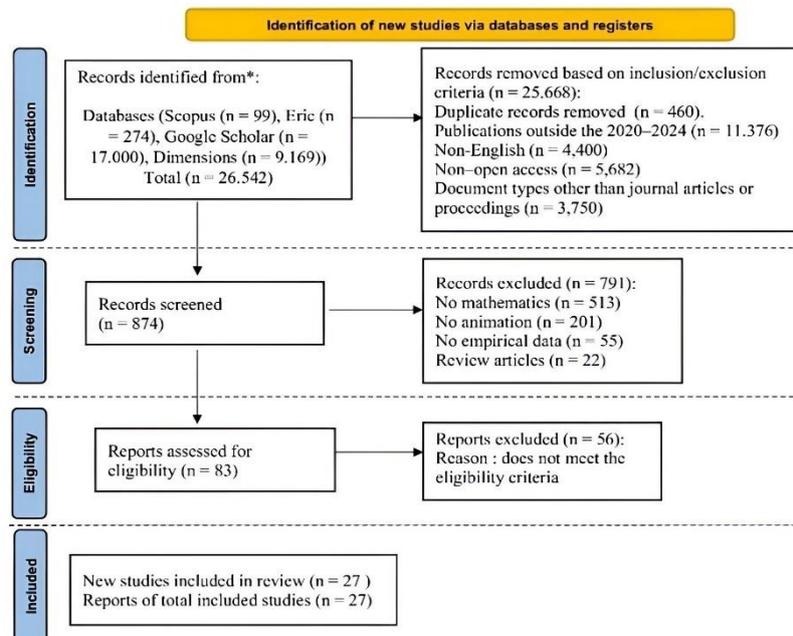


Figure 1. PRISMA flow chart

Data Analysis

Data extraction was performed using a standardized extraction form that was developed and pilot-tested on five randomly selected articles before full implementation. The first author conducted the primary extraction, while the second author independently verified the extracted data. Any discrepancies were resolved through discussion until consensus was reached.

The inter-rater reliability process involved both authors independently extracting data from all 27 articles. The first author conducted the primary extraction, while the second author conducted an independent parallel extraction. Agreement among reviewers was evaluated using Cohen's Kappa, yielding substantial reliability for the categorical variables research methodology, animation software type, and mathematical competencies ($\kappa = 0.81$). For SLR data, the agreement was nearly perfect ($\kappa = 0.96$) because the variables were objective. Any inconsistencies were identified through systematic comparison of extraction sheets and resolved through discussion, with a third reviewer consulted when consensus could not be reached.

The extraction form captured three categories of variables. First, general publication information including author(s), publication year, article title, journal or conference name, country of author affiliation, and DOI. Second, methodological characteristics encompass research design (experimental, quasi-experimental, R&D, qualitative, mixed methods, or design-based research), sample size, participants' educational level (primary, secondary, or tertiary), and intervention duration. Third, substantive content comprising the type of animation platform or software used, the mathematical content area (geometry, algebra, calculus, statistics, or others), the mathematical competencies targeted (conceptual understanding, procedural fluency, mathematical representation, problem-solving, critical thinking, mathematical connections, or creativity), and the key findings reported.

The study employed five complementary analytical approaches. First, descriptive frequency analysis was used to identify temporal publication patterns across the 2020-2024 period. Second, cross-tabulation and relational mapping through heatmap visualization were employed to examine the distribution and associations between animation platforms and targeted mathematical competencies. Third, multidimensional relational analysis using Sankey diagrams was conducted to map the interconnections among country of origin, research methodology, animation platforms, educational levels, and mathematical competencies, with the resulting patterns interpreted qualitatively due to the small sample size ($n = 27$). Fourth, keyword co-occurrence analysis using VOSviewer generated network maps that revealed thematic clusters and interconnections among research topics, with a minimum keyword occurrence threshold of two to ensure clarity and comprehensiveness. Finally, thematic synthesis was conducted by qualitatively analyzing the abstracts and findings of all included studies to identify recurring themes related to pedagogical approaches to animation use, reported challenges, and practical implications for future research and practice.

▪ RESULT AND DISSCUSSION

This systematic review analyzed 27 empirical studies published between 2020 and 2024 to identify trends, patterns, and gaps in animation-based research on mathematics learning. Articles were classified based on: publication year, country of origin, research methodology, mathematical competencies investigated, animation platforms employed,

educational level, and reported outcomes. The analysis addressed six research questions through multiple analytical approaches: descriptive frequency analysis, keyword co-occurrence mapping using VOSviewer, heatmap visualization of platform-competency relationships, Sankey diagram relational mapping of cross-dimensional patterns, and thematic synthesis of pedagogical approaches and implementation challenges.

Table 3. Article distribution

Study	Title	Study	Title
(Febiani et al., 2023)	Problem-based Learning Model Assisted by Interactive Animation Videos on Numeracy Ability in Spatial Building Materials	(Ojo, 2022)	Effects of Animated Instructional Packages on Achievement and Interest of Junior Secondary School Student in Algebra
(Ferdiani et al., 2023)	Animation Video using <i>Adobe Animate</i> CC Application Based on Problem-based Learning	(Coskun, 2024)	Animations And Depictions As a Tool To Improve Pre-Service Elementary Teachers' Noticing Of Students' Mathematical Thinking
(Sabitu & Khalid, 2024)	Effects of Computer Animation Instructional Package (CAIP) on Senior Secondary School Students' Academic Achievement in Geometry in Oyo Metropolis, Oyo State, Nigeria	(Grizioti et al., 2024)	Computational Thinking In The Service Of Mathematics Education: The Case Of Animating Programmable 3D Models In Malt2
(Habsyi & Saleh, 2022)	Developing E-Learning Based On Animation Content To Improve Students' Mathematical Connection Abilities	(Voorde et al., 2023)	Dynamic Visualization In Animated Mathematics Videos I: A Classification Of Didactic Roles
(Panjaitan et al., 2024)	Development Of A Digital Integral Calculus Book Assisted By Animation Videos To Enhance Students' Critical Thinking Skills	(Lieshout & Xenidou-Dervou, 2020)	Simple pictorial mathematics problems for children: locating sources of cognitive load and how to reduce it
(Wahyuliana et al., 2023)	Interactive Learning Media using <i>Adobe Animate</i> CC to Improve Students' Learning Motivation and Mathematics Learning Outcomes.	(Latifi et al., 2022)	Modeling with Differential Equations and <i>GeoGebra</i> in High School Mathematics Education
(Leite et al., 2024)	Enhancing Mathematics Education with Geometrix: A Study on the Effectiveness of Gamified 2D and 3D Animation Tools	(Yaniawati et al., 2023)	Mathematics Mobile Blended Learning Development: Student-Oriented High-Order Thinking Skill Learning
(Mwangi & Githua, 2021)	Effects of Computer Animations on Students' Geometrical Mathematics Misconceptions in Secondary Schools, Kitui County, Kenya	(Nós et al., 2021)	Using <i>GeoGebra</i> In Generalization Processes Of Geometrical Challenging Problems
(Mandalawati et al., 2024)	<i>Powtoon</i> Media for the Understanding of Deaf Mathematics	(Kynigos & Karavakou, 2023)	Coding Dancing Figural Animations: Mathematical Meaning-Making Through Transitions Within And Beyond A Digital Resource
(Puspaningrum et al., 2023)	Development of Animated Video-Based Mathematics Learning Media using <i>Powtoons</i> on	(Rijal & Azimi, 2021)	Development of digital mathematics teaching materials in elementary schools using

	Quadrilateral and Triangular Materials		whiteboard animation for primary teacher education students, STKIP PGRI Lubuklinggau
(Yildiz & Arpaci, 2024)	Understanding pre-service mathematics teachers' intentions to use <i>GeoGebra</i> : The role of technological pedagogical content knowledge	(Munyaruh engeri et al., 2023)	Potentials and limitations of <i>GeoGebra</i> in teaching and learning limits and continuity of functions at selected senior four Rwandan secondary schools Jean
(Akmalia et al., 2021)	Development Of <i>Powtoon</i> Animation Learning Media In Improving Understanding Of Mathematical Concepts	(Chechan et al., 2023)	Effect of using Desmos on high school students' understanding and learning of functions
(Yani & Rosma, 2020)	Improving Students ' Spatial Ability by Using Macromedia Flash on Geometry Materials	(Günbaş, 2020)	Students Solve Mathematics Word Problems in Animated Cartoons
(Barana et al., 2020)	The creation of animated graphs to develop computational thinking and support STEM education		

Distribution of Research by Publication Year

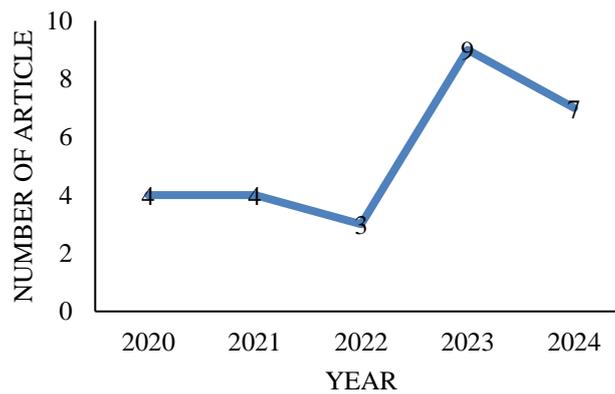


Figure 2. Distribution of publication years

The publication trend exhibits a fluctuating pattern, with a sharp rise in 2023 and a high level of stabilization in 2024, reflecting the strengthening academic attention to technology-enhanced mathematics learning. These findings are consistent with the analyses of Tashtoush et al. (2023) and the meta-analysis by Hwang et al. (2023), both of which reported an acceleration of ICT-related research in mathematics education in the post-pandemic period. The year 2023 marked a phase of expansion, as numerous studies reported a significant increase in both the volume and methodological diversity of publications, indicating that 2023 constituted a period of scientific consolidation (Febiani et al., 2023; Kynigos & Karavakou, 2023; Munyaruhengeri et al., 2023; Voorde et al., 2023; Yaniawati et al., 2023). The sustained high number of publications in 2024 aligns with the perspective of Temirkhanova et al. (2024), who emphasize the need for systemic ICT integration to support 21st-century skills, a trend reflected in the continued research

productivity (Leite et al., 2024; Mandalawati et al., 2024; Panjaitan et al., 2024; Yildiz & Arpaci, 2024).

However, Abedi & Ackah-jnr (2023) caution that digital acceleration is not always linear due to disparities in institutional readiness and user competence, a point reflected in the decline in publications in 2022. In that year, only a few studies emerged, indicating that several national contexts (e.g., Morocco, Nigeria, and Indonesia) were still in a post-pandemic adaptation phase, resulting in unstable research productivity (Habsyi & Saleh, 2022; Latifi et al., 2022; Ojo, 2022). Thus, the upward trend observed in 2023–2024 represents a point at which digital readiness, researcher capacity, and international research agendas mutually reinforced one another, producing far more consistent growth in publication output than in previous years.

Analytical Synthesis of Animation Platforms and Targeted Mathematical Abilities

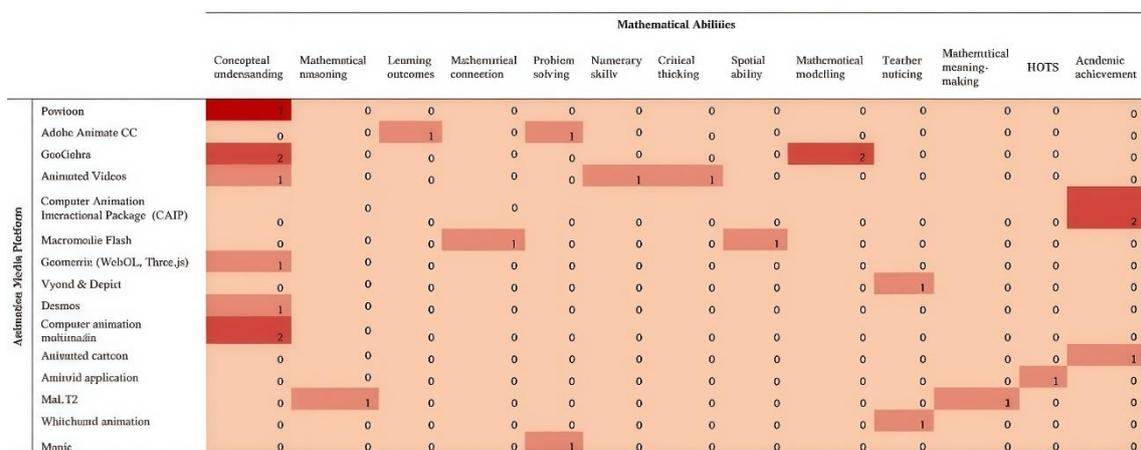


Figure 3. Matrix heatmap of animation platforms and targeted mathematical abilities

The distribution of relationships between animation platforms and mathematical competencies demonstrates patterns that align with the cognitive demands of each competency. Platforms such as *Powtoon*, *GeoGebra*, and generic animated videos are dominant in supporting conceptual understanding, as sequential visualization facilitates the integration of verbal, symbolic, and geometric representations while reducing initial cognitive load (Akmalia et al., 2021; Puspaningrum et al., 2023; Wahyuliana et al., 2023). *GeoGebra* also stands out in *mathematical modeling*, enabling interactive exploration and inquiry-based learning (Latifi et al., 2022; Yildiz & Arpaci, 2024), although the mathematical connection remains underexamined (Habsyi & Saleh, 2022).

Other platforms exhibit domain-specific specializations. Desmos is effective for functional representations and graphing (Chechan et al., 2023), Vyond and whiteboard animation are commonly used in teacher noticing and attention-oriented contexts (Coskun, 2024; Rijal & Azimi, 2021), while CAIP and Maple animated graphs are frequently employed to assess procedural outcomes and algebraic understanding (Barana et al., 2020; Sabitu & Khalid, 2024). Comparative analysis reveals several trade-offs: *Powtoon* and *Adobe Animate* offer ease of use but remain linear in structure (Ferdiani et al., 2023; Mandalawati et al., 2024), *GeoGebra* provides rich interactivity but demands

higher levels of teacher TPACK (Yıldız & Arpacı, 2024), and Desmos occupies a middle ground in terms of complexity and interactivity.

The heatmap also indicates a strong research bias toward lower-order competencies: conceptual and procedural understanding, while higher-order thinking appears only sporadically and is typically addressed through qualitative or mixed-method designs (Grizioti et al., 2024; Kynigos & Karavakou, 2023; Yaniawati et al., 2023). These findings suggest that animation effectiveness is highly contingent on alignment between platform affordances and cognitive demands, while also highlighting methodological gaps that future research needs to address.

Interpreting Cross-Dimensional Patterns in Animation-Based Mathematics Education

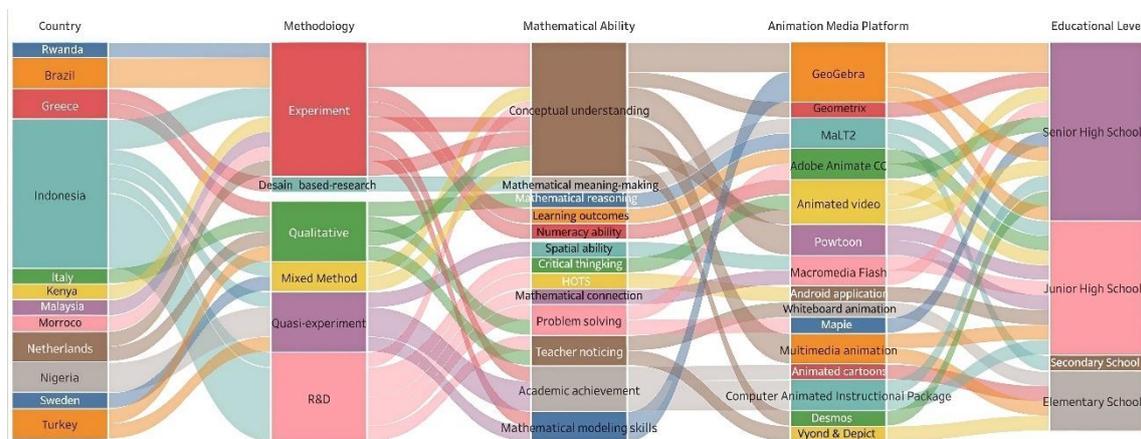


Figure 4. Sankey mapping of animation media usage in global mathematics education

The Sankey diagram analysis reveals systematic patterns in mathematics animation research shaped by each country’s educational policy orientation, technological capacity, and pedagogical traditions. Indonesia and Malaysia (Febiani et al., 2023; Ferdiani et al., 2023; Günbaş, 2020; Panjaitan et al., 2024; Wahyuliana et al., 2023) predominantly employ R&D and experimental approaches, driven by digital-learning policies that emphasize the production of affordable instructional media using simple tools such as *Powtoon*, animated videos, or Macromedia Flash to support foundational concept mastery. In Europe, countries such as the Netherlands, Italy, Sweden, and Greece (Barana et al., 2020; Grizioti et al., 2024; Kynigos & Karavakou, 2023; Lieshout & Xenidou-Dervou, 2020; Voorde et al., 2023) tend to adopt qualitative and design-based research approaches to explore mathematical meaning-making and reasoning, with Greece standing out through the use of MaLT2, a programmable 3D animation environment, to examine the formation of mathematical meaning in digital settings—reflecting a strong tradition of technology-mediated constructivist pedagogy. African countries (Nigeria, Kenya, Rwanda) (Munyaruhengeri et al., 2023; Mwangi & Githua, 2021; Sabitu & Khalid, 2024) rely more heavily on quasi-experimental designs to assess the effectiveness of animations on classroom learning outcomes, reflecting policy priorities for numeracy improvement and infrastructural constraints. Research in Turkey includes qualitative studies employing depiction-based animations to examine teacher

noticing (Coskun, 2024), while research in Brazil uses experimental designs with Geometrix (a gamified 2D/3D animation platform) to test the effectiveness of dynamic representations (Leite et al., 2024). Meanwhile, Morocco (Latifi et al., 2022) employs a theoretical–exploratory approach using GeoGebra for mathematical modeling.

The pathway toward mathematical competencies shows a dominance of conceptual understanding and academic achievement across various contexts, spanning geometry, arithmetic, functions, and calculus (Chechan et al., 2023; Mandalawati et al., 2024; Mwangi & Githua, 2021; Panjaitan et al., 2024). However, competencies such as modeling appear almost exclusively in GeoGebra-based studies at the upper-secondary and tertiary levels (Latifi et al., 2022; Yildiz & Arpaci, 2024), while HOTS is addressed in only one mixed-methods study from Indonesia (Mandalawati et al., 2024), and mathematical connection competency appears in a single R&D study (Habsyi & Saleh, 2022). These patterns indicate that current research remains heavily oriented toward basic competencies, whereas higher-order competencies remain significantly underexplored.

Platform variation aligns with educational levels and cognitive readiness. Studies at the primary level primarily use simple animations, such as animated cartoons or basic multimedia (Günbaşı, 2020; Lieshout & Xenidou-Dervou, 2020). Junior high school research often uses *Powtoon*, Macromedia Flash, or animated videos because they are well-suited for foundational content (Puspaningrum et al., 2023; Wahyuliana et al., 2023; Yani & Rosma, 2020). At the senior high school level, tools such as GeoGebra, *Geometrix*, and CAIP are commonly used to enable dynamic geometric representations or calculus visualizations (Latifi et al., 2022; Leite et al., 2024; Sabitu & Khalid, 2024; Yildiz & Arpaci, 2024). Other platforms, such as *Vyond*, *whiteboard* animation, MaLT2, Maple animated graphs, and *Geometrix*, are used in studies on teacher noticing, 3D meaning construction, symbolic modeling, and gamified visualization (Barana et al., 2020; Coskun, 2024; Grizioti et al., 2024; Kynigos & Karavakou, 2023; Leite et al., 2024; Rijal & Azimi, 2021). These patterns indicate a universal tendency for platform complexity to increase with educational level and content depth.

The use of animation media in mathematics education, as illustrated in the Sankey diagram, demonstrates how platform affordances, technological readiness, and curricular priorities jointly shape global research patterns in mathematics animation. Although animations have the potential to enrich mathematical representations and conceptual understanding, current studies remain focused on short-term effects and basic competencies. Longitudinal designs, cross-platform comparisons, and research on higher-order thinking skills remain limited. Inadequate animation design can increase extraneous cognitive load or suppress learning performance (Berney & Bétrancourt, 2016; Pink & Newton, 2020). Dynamic visualizations may also induce cognitive overload among students with low spatial ability or when animations are presented too quickly without adequate segmentation (Koć-Januchta et al., 2020; Yang, 2024). Future research is recommended to: (1) employ mixed-methods or longitudinal designs to evaluate the stability and transfer of learning; (2) compare different types of animation media (2D vs 3D, narrative vs interactive); and (3) expand geographical contexts and educational levels to strengthen theoretical contributions to media affordances and mathematical cognition.

Emerging Research Topics and Future Trends

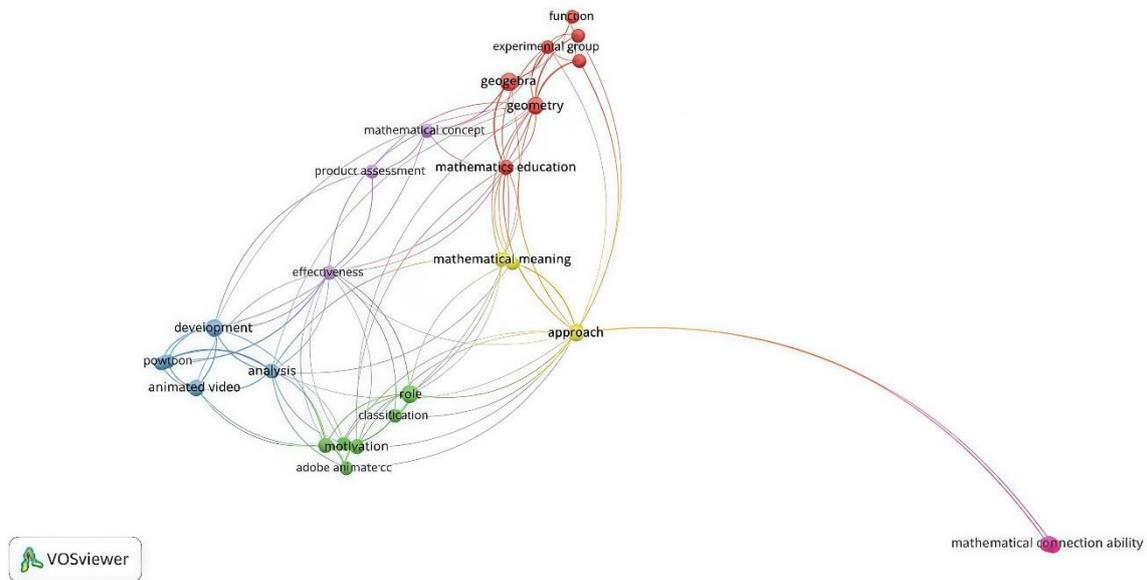


Figure 5. Visualization of research topic networks (VOSviewer)

Keyword co-occurrence analysis of the titles and abstracts of 27 articles yielded six thematic clusters. (1) The geometry–GeoGebra cluster, which forms the core of the network, encompasses topics such as geometry, functions, experimental groups, and the use of GeoGebra in instruction. (2) The media-development and linear-animation cluster, containing keywords such as development, analysis, Powtoon, and animated video. (3) The affective-dimension cluster, which includes motivation, the role of animation, and its implications for learning participation. (4) The theoretical–interpretive cluster, comprising mathematical meaning, constructivist approaches, and related pedagogical concepts. (5) The assessment and mathematical-concept cluster, containing *product assessment*, *mathematical concept*, and *effectiveness*. (6) The specific mathematical-ability cluster, characterized by the isolated appearance of the keyword mathematical connection ability, indicates a relatively standalone competency focus within the network.

The red cluster forms the core of the network and includes *mathematics education*, *geometry*, *GeoGebra*, *functions*, and *the experimental group*, underscoring the strong tradition of *GeoGebra*-based geometry research (Latifi et al., 2022; Munyaruhengeri et al., 2023; N6s et al., 2021; Yildiz & Arpacı, 2024). The close linkage between *GeoGebra* and *geometry* reflects the platform’s suitability for geometric representational needs (Leite et al., 2024; Mwangi & Githua, 2021), while the dominance of the experimental group node indicates a prevalent reliance on quasi-experimental designs (Ojo, 2022; Sabitu & Khalid, 2024; Yani & Rosma, 2020). However, this pattern results in geometry being disproportionately underrepresented compared to algebra, calculus, or modeling (Panjaitan et al., 2024; Voorde et al., 2023).

The blue cluster reflects a dominant R&D orientation in mathematics animation studies conducted in developing countries. Core nodes: *development*, *animated video*, *analysis*, and *Powtoon* form an ecosystem focused on producing instructional media. Strong ties between development and animated video suggest that R&D outputs primarily

take the form of sequential-narrative animations (Akmalia et al., 2021; Ferdiani et al., 2023; Puspaningrum et al., 2023). The analysis node shows that studies typically begin with learning-needs analyses in line with systematic R&D models (Rijal & Azimi, 2021). *Powtoon* occupies a semi-peripheral role, widely used for its simplicity but less adopted than mainstream tools like *GeoGebra* (Mandalawati et al., 2024). Limited connections to specific mathematical content nodes reveal that much of this research emphasizes media production techniques rather than deep alignment with mathematical pedagogical content knowledge. Consequently, animations are often visually appealing but not fully grounded in misconceptions, learning trajectories, or representational design principles (Ferdiani et al., 2023; Wahyuliana et al., 2023).

The green cluster functions as a connector, with moderate connectivity between cognitive and affective dimensions, characterized by nodes such as *motivation*, *role*, *classification*, and *Adobe Animate CC*. The prominence of motivation reflects the growing recognition that technological interventions influence not only cognitive outcomes but also emotional engagement (Günbaş, 2020; Wahyuliana et al., 2023). However, *Adobe Animate CC*'s semi-peripheral status indicates that, although the platform has pedagogical potential, it remains underutilized (Wahyuliana et al., 2023; Ferdiani et al., 2023). The limited connectivity of the green cluster suggests that affective dimensions have not yet been consistently integrated into studies of technological effectiveness or mathematical content learning.

The yellow cluster, which includes the node's *mathematical meaning and approach*, represents a more abstract theoretical orientation. Its moderate connection to the red cluster indicates that some studies have adopted theoretical perspectives, such as semiotic approaches, to analyze mathematical meaning-making within digital environments (Kynigos & Karavakou, 2023; Grizioti et al., 2024). However, the relative isolation of the node approach highlights a gap between theoretical analyses and empirical practice; most studies remain effectiveness-oriented, failing to examine the conceptual mechanisms underlying learning processes (Chechan et al., 2023; Barana et al., 2020). This condition signals the need for more theory-driven research to better understand how technology mediates mathematical learning.

The purple cluster comprising the nodes product assessment, mathematical concept, and effectiveness, represents the evaluative dimension of animation-based mathematics research. The prominence of *product assessment* indicates that evaluation practices remain embedded within R&D-oriented studies, emphasizing feasibility, validity, and practicality rather than deeper analyses of how technologies support conceptual understanding (Yaniawati et al., 2023; Panjaitan et al., 2024). Although the mathematical concept node reflects attention to conceptual learning outcomes (Chechan et al., 2023; Leite et al., 2024; Lieshout & Xenidou-Dervou, 2020; Mandalawati et al., 2024; Nós et al., 2021), its moderate connectivity suggests that assessments rarely capture complex competencies such as modeling or higher-order thinking (Latifi et al., 2022; Yıldız & Arpacı, 2024). The effectiveness node reinforces this pattern, as most studies report positive impacts based on short-term pre-post score gains (Febiani et al., 2023; Mwangi & Githua, 2021; Puspaningrum et al., 2023), revealing limited methodological depth and a tendency to evaluate learning outcomes superficially.

The pink cluster, comprising mathematical connection ability, is the most isolated node in the network, indicating that this topic is highly underrepresented. Although

mathematical connection ability is a fundamental competency in many curriculum standards, only one study in the corpus addresses it in a technological context (Habsyi & Saleh, 2022). This isolation suggests that researchers have not explicitly leveraged technological potential, such as *GeoGebra*, Desmos (Chechan et al., 2023), MaLT2 (Kynigos & Karavakou, 2023; Grizioti et al., 2024), *Geometrix* (Leite et al., 2024), or other animation tools, to support cross-representational and conceptual connections in mathematics. This finding is not a mere artifact of the network but reflects a substantive gap requiring urgent attention.

Overall, the intercluster relationships reveal persistent research silos: the dominance of *GeoGebra*-based geometry studies (Nós et al., 2021; Munyaruhengeri et al., 2023; Leite et al., 2024), while other topics such as spatial ability (Yani & Rosma, 2020; Febiani et al., 2023), modeling (Latifi et al., 2022; Yıldız & Arpacı, 2024), noticing abilities (Coskun, 2024; Rijal & Azimi, 2021), and *mathematical connection ability* (Habsyi & Saleh, 2022) remain marginal. These findings point to several important implications: the necessity of research on technology-enhanced *mathematical connection ability*; the need to strengthen theoretical foundations within empirical studies; the importance of developing assessment frameworks capable of capturing complex competencies; the urgency of diversifying technologies beyond the dominance of *GeoGebra*; and the need for more varied methodologies, such as mixed methods, qualitative research, and design-based research, to generate richer understandings of technologically mediated mathematical learning.

Thematic Analysis of Pedagogical Approaches, Challenges, and Implications

The synthesis of the 27 studies reveals systematic patterns in pedagogical approaches, implementation challenges, and methodological limitations that shape a critical interpretation of animation's effectiveness in mathematics learning. This analysis integrates substantive findings with an evaluation of research rigor to offer a more comprehensive perspective.

Table 4. Pedagogical approaches, challenges, and instructional implications

Study	Pedagogical Approach	Reported Challenges	Suggested Implications
(Febiani et al., 2023)	Sequential animation (experiment)	Limited interactivity	Visual simplification & segmentation
(Ferdiani et al., 2023)	Linear animation (R&D)	Risk of decorative load	Coherence & signaling
(Sabitu & Khalid, 2024)	CAIP geometry (quasi-experiment)	Variation in prior knowledge	Remedial & enrichment
(Habsyi & Saleh, 2022)	<i>Flash</i> connection (R&D)	Difficulties with multi-representation	Representational scaffolding
(Panjaitan et al., 2024)	Animation videos critical(R&D)	High visual workload	Restriction of rapid transitions
(Wahyuliana et al., 2023)	<i>Adobe Animate</i> outcomes(experiment)	Distracting decorative elements	Reduction of non-essential elements
(Leite et al., 2024)	<i>Geometrix</i> (experiment)	High cognitive load	Stepwise segmentation
(Mwangi & Githua, 2021)	Computer animation conceptual (experiment)	Low concept transfer	Task connectivity
(Mandalawati et al., 2024)	<i>Powtoon</i> conceptual (mixed method)	Media linearity	Reflective questioning

(Puspaningrum et al., 2023)	<i>Powtoon</i> representational (R&D)	Limited manipulability	Worksheet integration
(Yani & Rosma, 2020)	<i>Flash</i> spatial ability (quasi-experiment)	Device limitations	Low-bandwidth version
(Akmalia et al., 2021)	R&D conceptual <i>Powtoon</i>	Minimal theoretical grounding	Integration of CLT
(Ojo, 2022)	Instructional package (Quasi-experiment)	Algebraic difficulties	Explicit animated examples
(Coskun, 2024)	Vyond noticing (Qualitative)	Limited reasoning focus	Classroom context integration
(Grizioti et al., 2024)	<i>MaLT2</i> modelling (Qualitative)	Coding workload	Basic coding training
(Voorde et al., 2023)	<i>YouTube</i> conceptual (Qualitative)	Variability in quality	Curation standards
(Latifi et al., 2022)	<i>GeoGebra</i> modelling (experiment)	Excessive interactivity	Guided inquiry
(Yildiz & Arpaci, 2024)	<i>GeoGebra</i> modelling (quasi-experiment)	Low teacher TPACK	Intensive training
(Yaniawati et al., 2023)	Android HOTS (R&D)	Curriculum integration issues	Teacher modules
(Chechan et al., 2023)	<i>Desmos</i> function (mixed method)	Limited free exploration	Investigative scenarios
(Nós et al., 2021)	<i>GeoGebra</i> conceptual (experiment)	Overreliance on demo	Manipulative interaction
(Kynigos & Karavakou, 2023)	<i>MaLT2</i> meaning-making (DBR)	Lengthy iteration	Formative evaluation
(Munyaruhengeri et al., 2023)	<i>GeoGebra</i> limits (experiment)	Abstract concept difficulty	Continuous–discrete visualization
(Günbaş, 2020)	Animated cartoon achievement (experiment)	Passive students	Follow-up activities
(Lieshout & Xenidou-Dervou, 2020)	Multimedia animation conceptual (experiment)	Initial visual overload	Segmentation & pretraining
(Rijal & Azimi, 2021)	Whiteboard animation noticing (R&D)	Low engagement	Narration–analogy integration
(Barana et al., 2020)	Maple problem solving (Qualitative)	Parameter complexity	Interactive navigation

The thematic analysis identified five main themes underlying the variation in animation usage, while also highlighting the trade-offs between technological accessibility and cognitive depth. First, linear animations (*Powtoon*, *Adobe Animate*, *Vyond*, whiteboard animations, animated videos) were employed in eight R&D and experimental studies to present concepts sequentially through visual representations (Akmalia et al., 2021; Coskun, 2024; Febiani et al., 2023; Ferdiani et al., 2023; Mandalawati et al., 2024; Panjaitan et al., 2024; Puspaningrum et al., 2023; Rijal & Azimi, 2021; Wahyuliana et al., 2023). These platforms face fundamental limitations, including minimal interactivity, risk of decorative overload, rapid transitions that strain working memory, and linearity that hinders independent exploration.

Second, interactive platforms (*GeoGebra*, *Desmos*, *MaLT2*, *Geometrix*, *Maple*) dominated nine studies on modeling and meaning-making (Barana et al., 2020; Chechan et al., 2023; Grizioti et al., 2024; Kynigos & Karavakou, 2023; Latifi et al., 2022; Leite

et al., 2024; Munyaruhengeri et al., 2023; N6s et al., 2021; Yildiz & Arpacı, 2024). Although these platforms offer high dynamic affordances, they require complex navigation that can increase extraneous cognitive load and necessitate scaffolding to maintain cognitive balance. Additional challenges arise in coding-based platforms (e.g., MaLT2), which impose coding workload (Grizioti et al., 2024), and symbolic systems such as Maple, which require users to understand intricate parameters (Barana et al., 2020).

Third, hybrid platforms and specialized environments, including *Geometrix*, which balances gamification with geometric representation (Leite et al., 2024), Android-based HOTS applications (Yaniawati et al., 2023), interactive Flash (Habsyi & Saleh, 2022; Yani & Rosma, 2020), and curated YouTube content (Voorde et al., 2023), enhance visual appeal and foster initial engagement. However, long-term effectiveness depends heavily on curatorial quality and curricular alignment, meaning that initial motivation often does not fully translate into sustained deep learning.

Fourth, the effectiveness of interactive platforms depends on teachers' TPACK competencies. Many studies report that limitations in technology training, task selection, and cognitive management lead animations to function as passive demonstrations rather than active exploration tools (N6s et al., 2021). Instructional recommendations align with these challenges: linear animations require coherence, signaling, and segmentation to reduce extraneous load (Ferdiani et al., 2023; Lieshout & Xenidou-Dervou, 2020; Wahyuliana et al., 2023), whereas interactive platforms necessitate guided inquiry, reflective questioning, and teacher training to balance exploratory autonomy with structured learning (Chechan et al., 2023; Coskun, 2024; Latifi et al., 2022; Mandalawati et al., 2024).

Fifth, the analysis reveals structural tensions in animation research: simple platforms generate studies with larger samples but limited cognitive depth, whereas complex platforms facilitate the development of higher-order competencies but involve fewer participants and longer intervention durations. Beyond platform characteristics, implementation challenges include variability in students' prior knowledge requiring differentiation (Sabitu & Khalid, 2024), hardware and bandwidth limitations in low-resource settings (Yani & Rosma, 2020), difficulties in transferring concepts to new contexts (Mwangi & Githua, 2021), overreliance on demonstrations that reduce opportunities for active manipulation (N6s et al., 2021), and passive student engagement that necessitates follow-up activities (Günbař, 2020). The universal positive findings across studies suggest potential publication bias and novelty effects, indicating that reported effectiveness may be overestimated.

A critical evaluation of methodological rigor reveals systemic weaknesses that limit the validity and generalizability of findings. First, most quasi-experimental and R&D studies employed small samples (20–35 participants) with short intervention durations (2–4 sessions), inhibiting the detection of long-term effects and learning stability (Febiani et al., 2023; Mandalawati et al., 2024; Ojo, 2022). Second, several R&D designs relied on one-group pretest–posttest formats without control groups, rendering causal attribution to animation interventions fragile due to susceptibility to testing effects and maturation (Akmalia et al., 2021; Ferdiani et al., 2023). Third, reporting of instrument validity and reliability was inconsistent, thereby weakening the corpus's evidential robustness. Fourth, the majority of studies reported significant positive outcomes, a pattern indicative of

strong publication bias, consistent with meta-analytic findings on dynamic visualizations (Berney & Bétrancourt, 2016; Pink & Newton, 2020). This universal positivity contrasts sharply with the significant challenges reported in the studies: student passivity despite claims of effectiveness (Günbaş, 2020), reliance on demonstrations that undermine interactivity (Nós et al., 2021), and variability in the quality of digital content that should theoretically produce inconsistent results (Voorde et al., 2023). Such misalignment reinforces the likelihood that studies yielding neutral or negative results were not published. Consequently, reported effectiveness is likely overestimated, influenced by novelty effects, sample-selection bias, Hawthorne effects, and the absence of studies documenting intervention failures. The dominance of quantitative approaches (59.2%) and the scarcity of qualitative and mixed-methods studies (29.6%) also limit understanding of the deeper mechanisms that explain how and why animation does or does not support mathematics learning.

For pedagogical practice, platform selection should be aligned with cognitive demands: segmented narrative animations (*Powtoon*, *Adobe Animate*) are appropriate for fundamental to intermediate procedural concepts, whereas dynamic geometry systems (*GeoGebra*, *Desmos*) are better suited for modeling and reasoning at secondary and post-secondary levels. The corpus produced 27 instructional recommendations across five categories: (1) multimedia design principles (segmentation, coherence, signaling) (Lieshout & Xenidou-Dervou, 2020; Ferdiani et al., 2023), (2) cognitive scaffolding (reflective questions, task connections, continuous–discrete visualizations) (Mandalawati et al., 2024; Munyaruhengeri et al., 2023), (3) teacher support (TPACK training, content-curation standards) (Yıldız & Arpacı, 2024; Voorde et al., 2023), (4) differentiation (remediation–enrichment, low-bandwidth versions) (Sabitu & Khalid, 2024), and (5) instructional approaches (guided inquiry, manipulative interactions) (Latifi et al., 2022; Nós et al., 2021), highlighting the need for balance between technical design principles and contextual pedagogical support.

Future research should prioritize: (1) longitudinal studies (minimum 6–8 weeks) to evaluate retention; (2) cross-platform comparative designs that control cognitive demand; (3) mixed-methods integrating quantitative and qualitative analyses; (4) standardized reporting including non-significant outcomes; and (5) expanded focus on higher-order competencies, which remain severely underexamined. Theoretically, integrating frameworks such as Cognitive Load Theory, embodied cognition, and instrumental genesis is essential to explain underlying cognitive mechanisms. The finding that *mathematical connection ability*, arguably the competency most aligned with the theoretical affordances of animation, emerges as the most isolated node in the co-occurrence network signals a critical gap between theoretical potential and empirical focus.

▪ CONCLUSION

The review of 27 studies indicates a significant increase in publications since 2023, dominated by research from Indonesia and several African countries. Methodologically, the corpus remains concentrated in experimental designs (33.3%) and R&D studies (25.9%), characterized by short intervention durations and quasi-experimental designs without control groups. In terms of technology, *GeoGebra*, *Powtoon*, and linear animations are the most frequently used platforms, although their selection appears to be

driven more by practical availability than theoretical alignment. Mathematical competencies are heavily focused on conceptual understanding (37.0%), whereas higher-order skills such as modeling, HOTS, reasoning, and mathematical connection ability are rarely investigated. Keyword co-occurrence analysis reveals six thematic clusters, dominated by the *GeoGebra*–geometry cluster, while the mathematical connection cluster appears isolated. Heatmap and Sankey visualizations show that cross-dimensional relationships, across platforms, methodologies, and competencies, remain imbalanced, reflecting strong siloed patterns in the literature. Thematic analysis of the 27 abstracts identifies five major themes: (1) the role of animation in dynamic representation, (2) cognitive mechanisms such as segmentation and cognitive load reduction, (3) increased motivation and engagement, (4) technology integration and teacher competence, and (5) implementation challenges and effectiveness bias. Methodological rigor assessment further reveals small sample sizes, short intervention periods, absence of control groups, inconsistent reporting of instrument validity and reliability, and evidence of publication bias.

The implications of this review underscore the need for methodological diversification through longitudinal research, cross-platform comparative studies, and stronger theoretical integration, such as Cognitive Load Theory and embodied cognition, to explain the cognitive mechanisms underlying the effectiveness of animation in mathematics learning. Pedagogically, platform selection must be aligned with cognitive demands: dynamic geometry environments (*GeoGebra*, *Desmos*, *MaLT2*) are more suitable for modeling and multi-representation exploration, whereas segmented narrative animations (*Powtoon*, *Adobe Animate*) are appropriate for procedural concept acquisition. Animation design should adhere to the principles of segmentation, coherence, and signaling to minimize extraneous cognitive load, accompanied by adequate scaffolding for interactive platforms. These findings should be interpreted with caution, given corpus-level limitations, including small sample sizes, short intervention durations, inconsistent reporting of validity–reliability, and the absence of negative findings that might indicate publication bias. At the review level, language restrictions, the limited dataset, and a five-year time window also constrain the scope of analysis. Future studies should prioritize higher-order competencies, strengthen methodological rigor, broaden geographic representation, and conduct systematic comparisons across animation types to build a more robust empirical foundation for the use of animation in mathematics education.

▪ REFERENCES

- Abedi, E. A., & Ackah-jnr, F. R. (2023). First-order barriers still matter in teachers' use of technology: an exploratory study of multi-stakeholder perspectives of technology integration barriers. *International Journal of Education and Development Using Information and Communication Technology (IJEDICT)*, 19(2), 148–165.
- Akmalia, R., Fajriana, F., Rohantizani, R., Nufus, H., & Wulandari, W. (2021). Development of *Powtoon* animation learning media in improving understanding of mathematical concept. *Malikussaleh Journal of Mathematics Learning (MJML)*, 4(2), 105. <https://doi.org/10.29103/mjml.v4i2.5710>
- Awaji, B. M., Khalil, I., & AL-Zahrani, A. (2025). A bibliometrics study of two decades of *GeoGebra* research in mathematics education. *Journal of Educational and Social*

- Research*, 15(1), 130–150. <https://doi.org/10.36941/jesr-2025-0011>
- Barana, A., Conte, A., Fissore, C., Floris, F., Marchisio, M., & Sacchet, M. (2020). The creation of animated graphs to develop computational thinking and support STEM education. *AperTO - Archivio Istituzionale Open Access Dell'Università Di Torino*, 1125, 189–204. https://doi.org/10.1007/978-3-030-41258-6_14
- Berney, S., & Bétrancourt, M. (2016). Does animation enhance learning? A meta-analysis. *Computers and Education*, 101, 150–167. <https://doi.org/10.1016/j.compedu.2016.06.005>
- Braithwaite, D. W., & Sprague, L. (2021). Conceptual knowledge, procedural knowledge, and metacognition in routine and nonroutine problem solving. *Cognitive Science*, 45(10). <https://doi.org/10.1111/cogs.13048>
- Chechan, B., Ampadu, E., & Pears, A. (2023). Effect of using Desmos on high school students' understanding and learning of functions. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(10). <https://doi.org/10.29333/ejmste/13540>
- Coskun, S. D. (2024). Animations and depictions as a tool to improve pre-service elementary teachers' noticing of students' mathematical thinking. *Journal of Pedagogical Research*, 8(1), 191–207. <https://doi.org/10.33902/JPR.202424231>
- Depraetere, J., Vandeviver, C., Keygnaert, I., & Vander, T. (2021). The critical interpretive synthesis : an assessment of reporting practices. *International Journal of Social Research Methodology*, 24(6), 669–690. <https://doi.org/10.1080/13645579.2020.1799637>
- Dixon-woods, M., Cavers, D., Agarwal, S., Annandale, E., Arthur, A., Harvey, J., Hsu, R., Katbamna, S., Olsen, R., Smith, L., Riley, R., & Sutton, A. J. (2006). Critical interpretive synthesis of the literature on access to healthcare by vulnerable groups. *BMC Medical Research Methodology*, 6(35), 1–13. <https://doi.org/10.1186/1471-2288-6-35>
- Febiani, S., Susanti, N., Rahayu, C., Garba, M. D., & Dhakal, A. (2023). Problem-based learning model assisted by interactive animation videos on numeracy ability in spatial building materials. *Numerical: Jurnal Matematika Dan Pendidikan Matematika*, 7(2), 345–358. <https://doi.org/10.25217/numerical.v7i2.3642>
- Ferdiani, R. D., Fayeldi, T., & Suci, T. P. (2023). Animation video using Adobe Animate cc application based on problem-based learning. *JPI (Jurnal Pendidikan Indonesia)*, 12(2), 375–385. <https://doi.org/10.23887/jpiundiksha.v12i2.49843>
- Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, 26, 91–108. <https://doi.org/10.1111/j.1471-1842.2009.00848.x>
- Grizioti, M., Kynigos, C., & Milrad, M. (2024). Computational thinking in the service of mathematics education: the case of animating programmable 3D models in MaLT2. *Revista de Investigação em Educação Matemática*, 33(2), 110–129. <https://doi.org/10.48489/quadrante.37379>
- Günbaş, N. (2020). Students solve mathematics word problems in animated cartoons. *Malaysian Online Journal of Educational Technology Students*, 8(2), 43–57. <https://doi.org/10.17220/mojet.2020.02.004>
- Habsyi, R., & Saleh, R. R. . (2022). Developing e-learning based on animation content to improve students' mathematical connection abilities. *International Journal of Trends in Mathematics Education Research*, 5(4), 429–434. <https://doi.org/>

10.33122/ijtmr.v5i4.167

- Hwang, S., Flavin, E., & Lee, J. E. (2023). Exploring research trends of technology use in mathematics education: a scoping review using topic modeling. *Education and Information Technologies*, 28(8), 10753–10780. <https://doi.org/10.1007/s10639-023-11603-0>
- Koć-Januchta, M. M., Höffler, T. N., Prechtel, H., & Leutner, D. (2020). Is too much help an obstacle? Effects of interactivity and cognitive style on learning with dynamic versus non-dynamic visualizations with narrative explanations. *Educational Technology Research and Development*, 68(6), 2971–2990. <https://doi.org/10.1007/s11423-020-09822-0>
- Kynigos, C., & Karavakou, M. (2023). Coding dancing figural animations: mathematical meaning-making through transitions within and beyond a digital resource. In *Digital Experiences in Mathematics Education* (Vol. 9, Issue 2). Springer International Publishing. <https://doi.org/10.1007/s40751-022-00118-x>
- Latifi, M., Esegir, A., Elmaroufi, A., Hattaf, K., & Achtaich, N. (2022). Modeling with differential equations and *GeoGebra* in high school mathematics education. *Journal of Educational and Social Research*, 12(3), 47–91. <https://doi.org/10.36941/jesr-2022-0065>
- Leite, V. M. A. F., Duarte, F. V., Freitas, H. B., Pinheiro, T. A. de S., Marques, R. X., Vidal, C. A., & Cavalcante-Neto, J. B. (2024). Enhancing mathematics education with geometrix: a study on the effectiveness of gamified 2d and 3d animation tools. *Cbie*, 750–760. <https://doi.org/10.5753/sbie.2024.242318>
- Lieshout, E. C. D. M. van, & Xenidou-Dervou, I. (2020). Simple pictorial mathematics problems for children: locating sources of cognitive load and how to reduce it. *ZDM*, 52(1), 73–85. <https://doi.org/10.1007/s11858-019-01091-3>
- Ljubojevi, M., Savić, M., Mijić, D., & Vico, G. (2025). Improving the efficiency of multimedia learning and the quality of experience by reducing cognitive load. *Appl. Sci*, 15, 1054. <https://doi.org/https://www.mdpi.com/2076-3417/15/3/1054>
- Mandalawati, I. S., Jihad, A., & Sugilar, H. (2024). *Powtoon* media for the understanding of deaf mathematics. *KnE Social Sciences*, 2024, 562–571. <https://doi.org/10.18502/kss.v9i8.15615>
- Muhammad, I., Mukhibin, A., Naser, A. M., & Dasari, D. (2022). Bibliometric analysis: research trend of interactive learning media in mathematics learning in Indonesia. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, 11(1), 10. <https://doi.org/10.33394/j-ps.v11i1.6595>
- Munyaruhengeri, J. P. A., Umugiraneza, O., Ndagijimana, J. B., & Hakizimana, T. (2023). Potentials and limitations of *GeoGebra* in teaching and learning limits and continuity of functions at selected senior four Rwandan secondary schools. *Cogent Education*, 10(2), 1–20. <https://doi.org/10.1080/2331186X.2023.2238469>
- Mwangi, S. W., & Githua, B. N. (2021). Effects of computer animations on students' geometrical mathematics misconceptions in secondary schools, Kitui County, Kenya. *JME (Journal of Mathematics Education)*, 6(2). <https://doi.org/10.31327/jme.v6i2.1661>
- Nikolaevna, K. L., Akzhanovna, K. A., Nurgazievna, I. S., Doolotbayevna, B. A., & Oskonovna, K. A. (2024). Development of algorithmic competence of students in studying mathematics: an experimental study of the effectiveness of the use of

- information and communication technologies. *Qubahan Academic Journal*, 4(3), 851–860. <https://doi.org/10.48161/qaj.v4n3a1094>
- Nós, R. L., Sano, M., & Lago, R. C. (2021). Using *GeoGebra* in generalization processes of geometrical challenging problems. *Revista Do Instituto GeoGebra Internacional de São Paulo*, 10(1), 49–64. <https://doi.org/10.23925/2237-9657.2021.v10i1p049-064>
- Ojo, S. G. (2022). Effects of animated instructional packages on achievement and interest of junior secondary school student in algebra. *Mathematics Teaching-Research Journal*, 14(1), 99–113.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement : an updated guideline for reporting systematic reviews. *BMJ*, 372. <https://doi.org/10.1136/bmj.n71>
- Panjaitan, M., Simanullang, M. C., & Mariani, M. (2024). Development of a digital integral calculus book assisted by animation videos to enhance students' critical thinking skills. *The 10th Annual International Seminar on Trends in Science and Science Education (AISTSSE) 2023*, 453–457. <https://doi.org/10.2478/9788367405782-056>
- Petersen, K., Vakkalanka, S., & Kuzniarz, L. (2015). Guidelines for conducting systematic mapping studies in software engineering: an update. *Information and Software Technology*, 64, 1–18. <https://doi.org/10.1016/j.infsof.2015.03.007>
- Pink, A., & Newton, P. M. (2020). Decorative animations impair recall and are a source of extraneous cognitive load. *Adv Physiol Educ.*, 44(3), 376–382. <https://doi.org/10.1152/advan.00102.2019>
- Ploetzner, R., Berney, S., & Bétrancourt, M. (2020). A review of learning demands in instructional animations: the educational effectiveness of animations unfolds if the features of change need to be learned. *Journal of Computer Assisted Learning*, 36(6), 838–860. <https://doi.org/10.1111/jcal.12476>
- Puspaningrum, A., Nofriyandi, N., Adrian, D., & Widiati, I. (2023). Development of animated video-based mathematics learning media using *Powtoons* on quadrilateral and triangular materials. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, 11(4), 1048. <https://doi.org/10.33394/j-ps.v11i4.9244>
- Rijal, A., & Azimi, A. (2021). Development of digital mathematics teaching materials in elementary schools using whiteboard animation for primary teacher education students STKIP PGRI Lubuklinggau. *AperTO - Archivio Istituzionale*, 1987, 012002. <https://doi.org/10.1088/1742-6596/1987/1/012002>
- Sabitu, K. A., & Khalid, S. (2024). Effects of computer animation instructional package (CAIP) on senior secondary school students' academic achievement in geometry in Oyo Metropolis, Oyo State, Nigeria. *European Journal of Contemporary Education and E-Learning*, 2(1), 150–161. [https://doi.org/10.59324/ejceel.2024.2\(1\).12](https://doi.org/10.59324/ejceel.2024.2(1).12)
- Schoenherr, J., Strohmaier, A. R., & Schukajlow, S. (2024). Learning with visualizations helps: A meta-analysis of visualization interventions in mathematics education. *Educational Research Review*, 45, 100639. <https://doi.org/10.1016/j.edurev.2024>

100639

- Sirait, S., Syafitri, E., & Nisa, K. (2023). The development of animation-based learning on students' numeracy literacy skills. *AL-ISHLAH: Jurnal Pendidikan*, 15(2), 1696–1705. <https://doi.org/10.35445/alishlah.v15i2.2858>
- Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: a new perspective on extraneous cognitive load. *Educational Psychology Review*, 34(1), 171–196. <https://doi.org/10.1007/s10648-021-09624-7>
- Tashtoush, M. A., AlAli, R., Wardat, Y., Alshraifin, N., & Toubat, H. (2023). The impact of information and communication technologies (ICT)-based education on the mathematics academic enthusiasm. *Journal of Educational and Social Research*, 13(3), 284–293. <https://doi.org/10.36941/jesr-2023-0077>
- Temirkhanova, M., Abildinova, G., & Karaca, C. (2024). Enhancing digital literacy skills among teachers for effective integration of computer science and design education: a case study at Astana International School, Kazakhstan. *Frontiers in Education*, 9(October). <https://doi.org/10.3389/educ.2024.1408512>
- Voorde, A. ten, Piroi, M., & Bos, R. (2023). Dynamic visualization in animated mathematics videos I: a classification of didactic roles. *Research Square*, 0–25. <https://www.researchsquare.com/article/rs-3358135/v1>
- Wahyuliana, N., Andrian, D., Nofriyandi, N., & Widiati, I. (2023). Interactive learning media using *Adobe Animate cc* to improve students' learning motivation and mathematics learning outcomes. *Jurnal Pendidikan MIPA*, 24(1), 172–182. <https://doi.org/10.23960/jpmipa/v24i1.pp172-182>
- Yang, D.-C. (2019). Examining the effects of digital animation integrated into the mathematics teaching. *Annals of Social Sciences & Management Studies*, 3(3), 71–75. <https://doi.org/10.19080/asm.2019.03.555613>
- Yang, H. (2024). The expression of multimedia animation art design in the era of artificial intelligence. *Applied Mathematics and Nonlinear Sciences*, 9(1), 1–17.
- Yani, M., & Rosma, F. (2020). Improving students' spatial ability by using Macromedia Flash on geometry materials. *Malikussaleh Journal of Mathematics Learning (MJML)*, 3(1), 18–22. <https://doi.org/https://doi.org/10.29103/mjml.v3i1.2401>
- Yaniawati, P., Maat, S. M., Supianti, I., & Fisher, D. (2023). Mathematics mobile blended learning development: student-oriented high-order thinking skill learning. *European Journal of Educational Research*, 12(4), 1657–1665.
- Yildiz, E., & Arpacı, I. (2024). Understanding pre-service mathematics teachers' intentions to use *GeoGebra*: the role of technological pedagogical content knowledge. *Education and Information Technologies*, 18817–18838. <https://doi.org/10.1007/s10639-024-12614-1>