E-ISSN: 2775-7854
Jurnal Inovasi, Evaluasi, dan Pengembangan Pembelajaran (JIEPP)
Volume 6, Issue 2, August 2026, pp 69-82
https://doi.org/10.54371/jiepp.v6i1.1446

A Systematic Literature Review: The Effects of Split-Attention and Modality Effects on Cognitive Load in Online Mathematics Learning

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Article History: Submission: 2026-05-05 || Accepted: 2026-07-08 || Published: 2026-08-20

Abstract

Digital mathematics learning may increase cognitive load when interdependent text, symbols, diagrams, and solution steps are presented separately, while audio may introduce redundancy and transient information effects. This study synthesized empirical evidence on the *split-attention* and *modality effects*, identified conditions influencing these effects, and derived implications for digital mathematics learning design. A *Systematic Literature Review* (SLR) was conducted following PRISMA 2020, with narrative synthesis guided by SWiM. Searches across Scopus, DOAJ, Google Scholar, and ScienceDirect identified 35 records. After removing 10 duplicates and screening titles and abstracts, 22 articles underwent full-text assessment, of which 11 primary studies met the eligibility criteria. The findings show that studies were predominantly conducted in Indonesia, frequently employed research and development designs, and commonly used multimedia, while direct measurement of cognitive load remained limited. Empirical evidence specifically addressing *split-attention* and *modality effects* in digital mathematics learning was also scarce. Available evidence suggests that spatial-temporal integration and audio may support learning under certain conditions, but their effectiveness depends on prior knowledge, material complexity, narration pace, learner control, redundancy, and device characteristics. Thus, the *modality effect* should not be considered a universal principle for reducing cognitive load. Based on these findings, this study proposes the Conditional SAM-Math Model, integrating design decisions, boundary conditions, cognitive load measurement, and learning outcomes to guide more context-sensitive digital mathematics learning design.

Keywords: *Cognitive Load, Digital Mathematics Learning, Modality Effect, Split-Attention Effect, SAM-Math.*

I. INTRODUCTION

Education is a continuous and sustained process aimed at facilitating students' learning activities. Schools, both public and private, serve as formal educational institutions that play an important role in guiding and educating students through learning processes facilitated by teachers (Puspitasari et al., 2024). Along with societal developments, the provision of education has become increasingly intertwined with technological advancement. Advances in information technology have created opportunities for educational institutions to develop and implement online learning as an alternative mode of instruction (Haryati et al., 2023). Online learning utilizes the internet as a primary medium to support teaching and learning processes, including mathematics instruction, while allowing students to participate in learning activities according to predetermined schedules (Wahyuniar et al., 2021).

Within this context, mathematics is one of the subject areas that faces particular challenges in the implementation of digital learning. Mathematics has long been regarded as an important component of education because of its role in developing logical reasoning, analytical thinking, and problem-solving skills (Adhikari, 2025). Nevertheless, school mathematics is often perceived as challenging by students and may lead to conceptual misunderstandings and high cognitive load during the learning process (Adhikari, 2025). These challenges are partly associated with the abstract nature of mathematical concepts and the demands of problem solving, which often require students to process multiple pieces of information simultaneously. Therefore, *Cognitive Load Theory* (CLT), developed by Sweller, provides a theoretical framework for explaining how limitations in cognitive capacity affect the learning process (Asmara et al., 2024).

Cognitive Load Theory explains that human capacity to receive and process new information is limited, particularly when information is processed in working memory (Murtianto et al., 2025).

Within this theoretical framework, cognitive load can be distinguished according to its sources and roles in the learning process. *Intrinsic cognitive load* is associated with the complexity of the learning material, whereas *extraneous cognitive load* is related to the way information or instructional materials are presented. Meanwhile, cognitive load relevant to learning reflects the mental effort devoted to understanding and organizing information more deeply. These dimensions indicate that the design and presentation of information play an important role in determining how students' cognitive resources are allocated during learning (Murtianto et al., 2025).

One phenomenon that requires particular attention in instructional design from a cognitive load perspective is *split attention* (Adinda et al., 2025). Mayer (2014) explains that dividing students' attention across multiple sources of information presented separately can increase cognitive processing demands. *Split attention* occurs when students are required to process two or more interdependent sources of information simultaneously and mentally integrate them to construct a coherent understanding (Adinda et al., 2025). This issue is particularly relevant to mathematics learning because students are frequently required to integrate text, symbols, diagrams, and solution procedures in order to understand mathematical concepts and solve problems.

In addition to *split attention*, CLT also recognizes the *modality effect*, which concerns the presentation of information through different processing modalities. The *modality effect* suggests that presenting instructional material through a combination of visual and auditory channels, such as images accompanied by spoken explanations, can be more effective than presentations that place processing demands predominantly on a single channel (Adinda et al., 2025). This effect is associated with the existence of different information-processing channels within working memory. Under certain conditions, the simultaneous use of visual and auditory channels can help distribute information-processing demands and support students' development of understanding (Suek, 2018).

Despite this theoretical foundation, the effectiveness of *split-attention* and *modality effects*, particularly in online mathematics learning, requires further investigation. Research on *split attention* in mathematics education remains limited to particular contexts and mathematical topics; therefore, its application in online mathematics learning has not yet been fully established (Azisah et al., 2025). Similarly, research on multimedia-based learning has largely focused on its direct effects on learning outcomes or motivation, while studies specifically linking multimedia design to students' cognitive load remain relatively limited (F. F. Sari et al., 2025). This situation highlights the need to synthesize the available empirical evidence to obtain a more comprehensive understanding of these two phenomena in digital mathematics learning.

This gap is particularly important because claims that combining visual and auditory information consistently reduces cognitive load may overlook conditions that influence its effectiveness, including redundancy, narration pace, transient information, screen size, and the *expertise reversal effect*. An instructional design that benefits novice learners may not necessarily provide the same benefits for learners with higher levels of prior knowledge. Under certain conditions, additional information may instead become a source of extraneous cognitive load. Therefore, investigating *split attention* and the *modality effect* should extend beyond describing their theoretical foundations within CLT. It is also necessary to evaluate the strength of the available empirical evidence, identify the boundaries of their application, and translate this evidence into conditional considerations for instructional design.

Based on this gap, the present study aims to synthesize primary empirical evidence on *split attention* and the *modality effect* in digital mathematics learning, assess the methodological quality of the available studies, and formulate design implications that are proportionate to the strength of the evidence identified. Through this synthesis, the study seeks to provide a more structured understanding of research characteristics, the effects of *split attention* and the *modality effect* on cognitive load, and the application of these principles in the design of online mathematics learning. Accordingly, the following research questions were formulated:

RQ1: What are the characteristics of studies on *split attention* and the *modality effect* in mathematics learning?

RQ2: How does *split attention* affect students' cognitive load in online mathematics learning?

RQ3: How does the *modality effect* affect students' cognitive load in online mathematics learning?
RQ4: How are the principles of *split attention* and the *modality effect* applied in the design of online mathematics learning to reduce students' cognitive load?

II. METHOD

This study employed a *Systematic Literature Review* (SLR) to synthesize empirical evidence on *split attention*, the *modality effect*, and cognitive load in digital mathematics learning. Study identification and selection followed the PRISMA 2020 guidelines, while the findings were narratively synthesized with reference to *Synthesis Without Meta-analysis* (SWiM). Literature searches were conducted across Scopus, DOAJ, Google Scholar, and ScienceDirect using combinations of the keywords "*split-attention effect*," "*modality effect*," "*cognitive load*," "*online learning*," and "*mathematics learning*" with the Boolean operators AND and OR. The search was limited to full-text journal articles published between 2016 and 2026.

Studies were included if they reported primary research addressing *split attention*, the *modality effect*, or cognitive load within digital, multimedia, or online mathematics learning. Studies were excluded if they were outside the mathematics learning context, were review or theoretical articles, did not report relevant *Cognitive Load Theory* (CLT) outcomes, or were unavailable in full text. The selection process followed the PRISMA 2020 stages of identification, screening, eligibility assessment, and inclusion. Of the 35 records identified, 10 duplicates were removed, leaving 25 records for title and abstract screening. Three records were excluded, and 22 articles underwent full-text assessment. Eleven articles were subsequently excluded because they involved non-mathematics or irrelevant contexts (n = 6), were reviews or theoretical sources (n = 4), or did not report relevant CLT outcomes (n = 1). Consequently, 11 primary studies in mathematics education were included in the final synthesis. The selection process is presented in Figure 1.

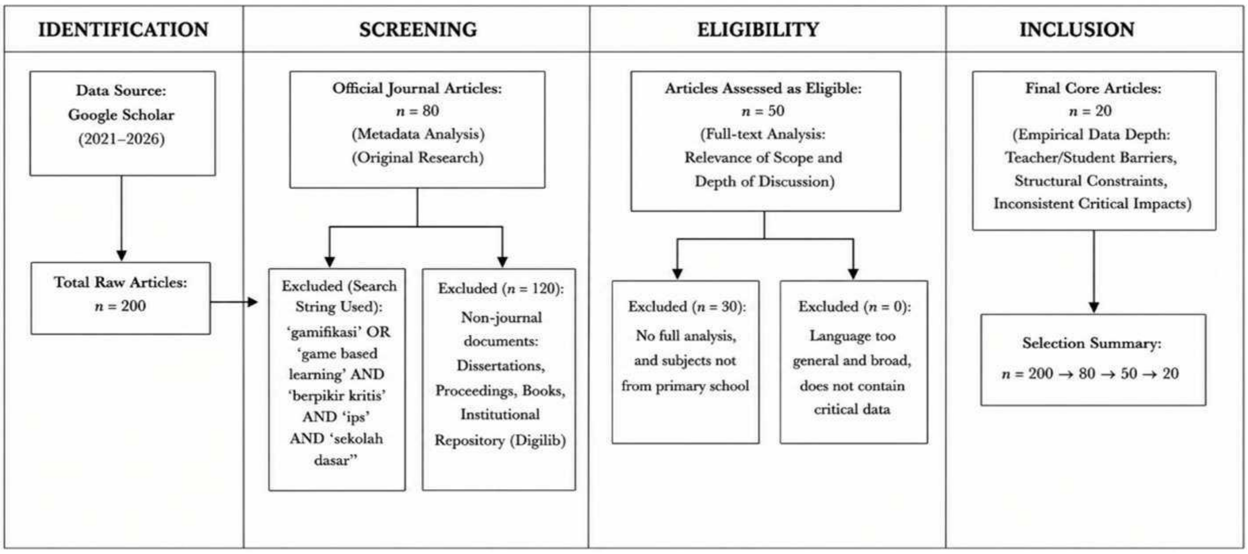

Figure 1. PRISMA 2020 Flow Diagram

The 11 primary studies that met the inclusion criteria were subsequently analyzed using a qualitative descriptive approach and synthesized narratively with reference to SWiM. The analysis involved identifying, categorizing, comparing, and synthesizing relevant information from each study according to the research questions. Specifically, the analysis addressed the characteristics of studies on *split attention* and the *modality effect* in mathematics learning (RQ1), the effects of *split attention* on students' cognitive load in online mathematics learning (RQ2), the effects of the *modality effect* on students' cognitive load (RQ3), and the application of both principles in the design of online mathematics learning to reduce students' cognitive load (RQ4).

The synthesis considered variations in study characteristics, including learning contexts, research designs, types of media, methods used to measure cognitive load, and reported learning outcomes. The findings were then presented through narrative synthesis to identify patterns, similarities and differences across the included studies, and conditions associated with the application of *split attention* and the *modality effect* in digital mathematics learning. The synthesis was subsequently used to formulate design implications in accordance with the strength of the available evidence.

III. RESULTS AND DISCUSSION

A. Results

1. Study Selection and Corpus Characteristics (RQ1)

The selection process resulted in 11 primary studies that met the inclusion criteria and were included in the final synthesis. Of the 35 records identified through Scopus, DOAJ, Google Scholar, and ScienceDirect, 10 duplicates were removed, leaving 25 records for title and abstract screening. Three records were excluded at this stage because they were outside the scope of the review, and 22 articles proceeded to full-text assessment. Following eligibility assessment, 11 articles were excluded: six involved non-mathematics contexts or were otherwise inconsistent with the review scope, four were review articles or theoretical sources, and one did not report relevant *Cognitive Load Theory* (CLT) outcomes. Consequently, 11 primary studies in mathematics education constituted the final corpus analyzed in this systematic review.

The final corpus varied in learning contexts, research designs, forms of media, and reported outcomes. Although all included studies were situated within mathematics learning, the corpus was dominated by studies conducted in Indonesia, studies employing research and development designs, and studies incorporating multimedia into the learning environment. These characteristics indicate that the evidence base concerning split attention and the modality effect in digital mathematics learning remains unevenly distributed across geographical contexts and methodological approaches.

Regarding research focus, empirical evidence specifically examining split attention and the modality effect in digital mathematics learning remained limited. Some studies addressed these principles through multimedia design or information-presentation characteristics, whereas others evaluated their implications through learning outcomes. Direct measurement of cognitive load was also not consistently employed across the included studies. Several studies relied instead on learning outcomes, media feasibility, motivation, or student responses as research outcomes. Consequently, the strength of the available evidence varied across studies and should be considered when interpreting findings concerning both effects.

To clarify the contribution of each study to the research questions, the 11 primary studies that met the inclusion criteria were mapped according to their relevance to RQ1–RQ4. RQ1 addressed the characteristics of studies on split attention and the modality effect in mathematics learning; RQ2 focused on the effect of split attention on cognitive load; RQ3 examined the modality effect on cognitive load; and RQ4 addressed the application of both principles in the design of online mathematics learning. The study mapping is presented in Table 1.

Table 1. Mapping of Included Primary Studies Across the Research Questions

Study	RQ1	RQ2	RQ3	RQ4
Primary Study 1	✓			
Primary Study 2	✓	✓		
Primary Study 3	✓		✓	✓
Primary Study 4	✓	✓		✓
Primary Study 5	✓		✓	✓
Primary Study 6	✓	✓	✓	✓
Primary Study 7	✓	✓		
Primary Study 8	✓		✓	✓
Primary Study 9	✓	✓		✓
Primary Study 10	✓	✓	✓	✓
Primary Study 11	✓		✓	✓

Overall, the findings for RQ1 reveal considerable methodological heterogeneity across the corpus. Differences in research design, multimedia presentation, learner characteristics, cognitive load measurement, and reported learning outcomes limit the extent to which the findings can be treated as evidence of equivalent strength. The predominance of research and development studies further suggests that part of the evidence base is oriented more toward instructional design development and feasibility than toward direct experimental testing of the *split-attention* or *modality effects*. Accordingly, the findings for RQ2–RQ4 should be interpreted in light of the methodological characteristics and strength of evidence provided by the individual studies.

2. Evidence on Split Attention (RQ2)

Direct empirical evidence examining split attention within the corpus remains limited. Adinda et al. (2025) explicitly applied a split-attention perspective to integrate multiple representations in Pythagorean learning materials and reported improvements in learning outcomes based on N-gain scores. These findings suggest that integrating representations that might otherwise divide learners' attention can support learning. However, the study did not directly measure cognitive load using mental effort scales, response time, or physiological indicators. The alignment of the instructional design with CLT principles was primarily evaluated through expert validation. Therefore, the available evidence supports the feasibility of applying the split-attention principle and indicates positive learning outcomes, but does not provide direct evidence regarding the magnitude of changes in students' cognitive load.

Similar patterns were observed in Asmara et al. (2024) and several other developmental studies that emphasized the importance of spatial and temporal proximity among text, symbols, and diagrams in mathematics instruction. These studies suggest that interdependent information should be presented in an integrated manner to reduce the need for learners to mentally integrate separated sources of information. Nevertheless, most studies did not employ comparative designs that directly contrasted integrated and separated presentation conditions while simultaneously measuring cognitive load. Consequently, the available evidence provides stronger support for the application of the design principle than for establishing a causal effect of split attention on cognitive load.

As supporting evidence, Zhang et al. (2023) showed in a non-mathematics context that instructional examples inducing split attention could reduce comprehension and learning efficiency. This finding supports the mechanism proposed by CLT but cannot be treated as direct evidence for split attention in online mathematics learning because of differences in instructional context. Accordingly, this evidence is more appropriately used to support the proposed mechanism of split attention than as primary evidence of its effectiveness in mathematics learning.

Overall, the synthesis for RQ2 indicates that the split-attention mechanism is consistent with the CLT framework and is supported by studies applying spatial-temporal integration in instructional design. However, the limited use of direct cognitive load measures and the scarcity of experimental comparisons between integrated and separated presentation conditions constrain the empirical evidence regarding the effects of split attention on cognitive load in online mathematics learning. Thus, the available findings provide stronger support for the feasibility of the design principle and its theoretical mechanism than for a strong causal claim that it reduces cognitive load.

3. Evidence on the Modality Effect and Boundary Conditions (RQ3)

Empirical evidence on the modality effect within the corpus indicates that the effects of combining visual and auditory modalities on cognitive load cannot yet be established conclusively. No study was identified that specifically compared diagrams accompanied by visual text with diagrams accompanied by audio narration in online mathematics learning while controlling for content equivalence, presentation pace, and learner control. This limitation makes it difficult to isolate modality as the factor responsible for changes in cognitive load or learning outcomes.

Among the available studies, Murtianto et al. (2025) provided the strongest evidence regarding the potential benefits of audio. In the second experiment, multimedia incorporating audio persuasion prompts resulted in higher learning achievement, lower cognitive load, and greater self-efficacy. However, the intervention did not manipulate presentation modality alone; rather, audio was combined with the type of prompt and worked-example design. Consequently, the observed effects cannot be attributed exclusively to the modality effect, because the influence of audio cannot be clearly separated from the effects of persuasion and other instructional design characteristics.

A different pattern was reported by Azisah et al. (2025), who found that interactive multimedia did not significantly moderate the relationship between motivation and cognitive load. This finding indicates that the use of multimedia or the distribution of information across multiple processing channels does not automatically produce cognitive benefits. Several other developmental studies reported validity, practicality, improved learning outcomes, motivation, or positive learner responses to multimedia. However, because most of these studies neither directly measured cognitive load nor isolated modality as an experimental factor, positive learning outcomes cannot be interpreted automatically as evidence of a modality effect.

The synthesis further indicates that the effectiveness of modality is associated with several boundary conditions. Audio narration may be beneficial when visual materials are complex, narration is concise and synchronized with visual information, and learners are able to pause or replay the material. Conversely, these benefits may diminish when narration is excessively fast, auditory information is transient, audio merely duplicates already available visual text, or learner and device characteristics do not adequately support dual-modality processing. Learners' prior knowledge and limitations associated with screen size should therefore also be considered when determining the effectiveness of multimodal instructional designs.

Evidence from outside the mathematics corpus further illustrates the importance of these conditions. Albus and Seufert (2023), for example, reported a reversal in a virtual reality environment. Although this study was not part of the primary corpus and was therefore not treated as direct evidence for RQ3, its findings support the interpretation that modality benefits may vary according to the learning environment and task demands. Overall, the findings for RQ3 do not support the claim that using two modalities consistently reduces cognitive load. Instead, the modality effect is more appropriately understood as a conditional effect influenced by material characteristics, presentation design, learner control, prior knowledge, and the learning environment.

4. Confidence-Based Design Recommendations (RQ4)

The synthesis indicates that the application of split-attention and modality effect principles in digital mathematics learning should consider both the strength of the available evidence and the conditions under which the principles are applied. Design recommendations cannot be applied uniformly because their effectiveness may depend on material characteristics, learners' prior knowledge, information presentation, learner control, and the devices used. Based on the consistency of findings, the relevance of the evidence to mathematics learning, and the methodological limitations of the included studies, the recommendations were classified into low-to-moderate, moderate, and high confidence levels, as presented in Table 2.

Table 2. Design Recommendations and Confidence Levels Based on the Synthesis

Confidence Level	Recommendation
Moderate	Spatially and temporally integrate interdependent text, symbols, diagrams, and solution steps. Use *signaling* to clarify relationships among information elements.
Moderate	Segment examples, procedures, and animations, and provide controls for pausing, replaying, and adjusting presentation speed to reduce *transient information* effects.

Low–moderate	Use audio narration when the visual channel contains dense information, but avoid narration that merely duplicates identical on-screen text. The design should be tested with the target learners and devices.
Moderate	Adapt instructional support to learners' prior knowledge. Reduce redundant explanations for more knowledgeable or experienced learners to minimize the risk of the *expertise reversal effect*.
High	Measure cognitive load separately from learning outcomes and motivation. Subjective instruments, performance or time-based indicators, and physiological measures should be explicitly reported.
High	Avoid inferring reductions in cognitive load solely from media validity, positive learner responses, or improved learning scores without relevant measures of cognitive load.

Recommendations assigned a moderate level of confidence primarily concern spatial-temporal integration, segmentation, learner control, and the adaptation of instructional support to prior knowledge. These principles received relatively consistent support, although direct experimental evidence within digital mathematics learning remains limited. In contrast, the recommendation concerning audio narration was assigned a low-to-moderate level of confidence because the available studies did not adequately isolate the modality effect from other instructional design features. Audio should therefore not be regarded as a component that automatically reduces cognitive load, but rather as a design option whose effectiveness depends on the conditions under which it is implemented.

Recommendations assigned a high level of confidence primarily concern methodological rigor in the interpretation of cognitive load. The synthesis indicates that improvements in learning outcomes, media feasibility, motivation, or positive learner responses do not, by themselves, demonstrate a reduction in cognitive load. Research and instructional evaluations should therefore measure cognitive load explicitly and distinguish it from learning outcomes and affective variables. Overall, the findings for RQ4 indicate that cognitive-load-oriented digital mathematics instruction should be conditional, adaptive, and evidence-based. Information integration, segmentation, audio use, and instructional support should be aligned with material and learner characteristics, while claims regarding design effectiveness should be supported by appropriate measures of cognitive load.

B. Discussion

1. Characteristics of Split Attention and the Modality Effect in Mathematics Learning

The findings indicate that *split attention* and the *modality effect* are two important principles within *Cognitive Load Theory* (CLT) that explain how the design and presentation of information can influence learners' use of cognitive resources during mathematics learning. CLT is grounded in the limited capacity of working memory to process novel information; therefore, learning effectiveness depends not only on the complexity of the material but also on how information is organized and presented to learners (Adhikari, 2025; Murtianto et al., 2025; Skulmowski & Xu, 2022). This issue becomes particularly important in digital mathematics learning, where learners are often required to process text, symbols, diagrams, animations, and solution steps simultaneously. Within the CLT framework, cognitive load is generally distinguished into intrinsic, extraneous, and germane load (Falah et al., 2022; Paas & Renkl, 2003; Wang et al., 2022). Intrinsic cognitive load is associated with material complexity and the interaction among elements that must be processed simultaneously. In mathematics learning, such complexity may arise when learners need to understand relationships among multiple concepts or procedures to solve a problem. Although intrinsic load cannot be completely eliminated, it can be managed by sequencing instructional materials from simpler concepts to more complex ones (Falah et al., 2022; I Made Tegeh et al., 2025; Sunawan et al., 2017).

In contrast, extraneous cognitive load results from the way instructional information or tasks are designed and presented. In digital mathematics learning, sources of extraneous load may include spatially separated text and diagrams, irrelevant information, excessive explanations, or representations that require learners to repeatedly shift their attention. When mathematics content already imposes high intrinsic complexity, inefficient instructional design may place additional demands on learners' limited working-memory capacity (Haryati et al., 2023; Murtianto et al., 2025; Wang et al., 2022). Reducing unnecessary extraneous processing is therefore an important consideration in the design of digital mathematics instruction.

Germane cognitive load, meanwhile, concerns cognitive resources devoted to constructing, organizing, and automating knowledge schemas. In mathematics learning, these processes may be supported through *worked examples*, comparisons of alternative problem-solving strategies, and reflection on solution procedures (Hariati, 2022; Haryati et al., 2023; Skulmowski & Xu, 2022). Cognitive load management should therefore not be understood as reducing all cognitive demands, but rather as minimizing unnecessary processing so that cognitive resources can be allocated to activities that support knowledge construction.

Within this framework, *split attention* is primarily associated with extraneous cognitive load that arises when learners must process two or more interdependent sources of information that are presented separately. In mathematics learning, this may occur when explanatory text is positioned far from a corresponding diagram, symbols are not clearly connected to their representations, or solution steps must be mentally matched with other parts of the instructional material. Learners must then shift their attention and mentally integrate these sources, consuming working-memory resources that could otherwise be devoted to understanding the mathematical content (Skulmowski & Xu, 2022; Wang et al., 2022; Zhang et al., 2023). This mechanism explains why spatial and temporal integration represents an important characteristic of instructional designs intended to reduce *split attention*.

The *modality effect*, by contrast, concerns the distribution of information across visual and auditory processing channels. Theoretically, complex visual information may be supported by auditory narration so that all information does not need to be processed simultaneously through the visual channel (Castro-Alonso & Sweller, 2020; F. F. Sari et al., 2025; Suek, 2018). Several studies have also indicated that combinations of visual and auditory representations may support comprehension in digital learning environments (Hariati, 2022; Wahyuniar et al., 2021). However, the present synthesis indicates that such benefits should not be treated as universal effects. The effectiveness of modality depends on how visual and auditory information are combined as well as on the characteristics of the material, learners, and learning environment.

Overall, the defining characteristics of *split attention* and the *modality effect* in mathematics learning concern how they regulate the distribution of information-processing demands. *Split attention* involves reducing unnecessary mental integration by bringing interdependent information together, whereas the *modality effect* concerns the potential distribution of information across visual and auditory channels when instructional conditions support such distribution. The findings for RQ1 also highlight the limitations of the available evidence. The predominance of developmental studies and the inconsistent direct measurement of cognitive load indicate that support for these principles in digital mathematics learning currently rests more strongly on instructional design rationale and learning outcomes than on direct experimental evidence of changes in cognitive load.

2. Effects of *Split Attention* on Students' Cognitive Load

The synthesis indicates that *split attention* may increase cognitive load when learners are required to process and integrate interdependent sources of information that are presented separately. Under such conditions, learners must not only process the subject matter itself but also allocate cognitive resources to locating, matching, and connecting information across different locations or representations. This additional mental integration may increase *extraneous cognitive load* and reduce the working-memory capacity available for understanding the learning material (Adinda et al., 2025; Wang et al., 2022; Zhang et al., 2023).

This mechanism is particularly relevant to mathematics learning because understanding often depends on the integration of multiple interrelated representations, including text, symbols, equations, diagrams, and solution steps. When these elements are presented separately, learners must repeatedly shift their attention to establish relationships among them. These demands may become more substantial when the material has high intrinsic complexity because working-memory resources are already required to process interactions among mathematical elements (Falah et al., 2022; Murtianto et al., 2025; Wang et al., 2022). Consequently, the design of information presentation becomes increasingly important as the complexity of the learning material increases (I Made Tegeh et al., 2025; Puspitasari et al., 2024; Sunawan et al., 2017).

In the context of digital mathematics learning, the findings of Adinda et al. (2025) provide an indication that integrating representations according to the *split-attention* principle may support learning outcomes. However, as identified in RQ2, the study did not directly measure cognitive load using mental effort scales, response time, or physiological indicators. Therefore, the reported improvement in learning outcomes cannot automatically be interpreted as evidence of reduced cognitive load. Rather, the findings provide support for the feasibility of instructional designs that reduce spatially separated information, rather than direct causal evidence of changes in cognitive load.

An important instructional implication is that interdependent text, symbols, diagrams, and solution steps should be spatially integrated and presented at relevant times to reduce unnecessary mental integration (Skulmowski & Xu, 2022; Wang et al., 2022; Zhang et al., 2023). This principle does not imply that all information should always be combined. Rather, information that is interdependent and cannot be adequately understood in isolation should be integrated to minimize processing demands that do not directly contribute to learning.

Overall, the review supports the theoretical mechanism through which *split attention* may increase *extraneous cognitive load* by requiring learners to mentally integrate separated sources of information. However, direct empirical evidence in digital mathematics learning remains limited, particularly because few studies have compared integrated and separated presentation conditions while directly measuring cognitive load. Thus, rather than concluding that *split attention* has been consistently demonstrated to increase cognitive load in mathematics learning, the available evidence indicates that the mechanism is theoretically well supported and accompanied by empirical indications, while the magnitude of its effects in digital mathematics learning requires more rigorous experimental investigation.

3. Effects of the Modality Effect on Students' Cognitive Load

The synthesis indicates that the *modality effect* may theoretically reduce cognitive load by distributing information processing across visual and auditory channels. When complex visual materials, such as diagrams, symbols, or animations, are accompanied by relevant audio narration, some information can be processed through the auditory channel rather than placing the entire processing demand on the visual channel (Castro-Alonso & Sweller, 2020; S. Sari et al., 2025; Suek, 2018). From a CLT perspective, such distribution may reduce unnecessary extraneous processing and allow working-memory capacity to be used more efficiently for understanding instructional content (Haryati et al., 2023; Wang et al., 2022).

Although this mechanism has a strong theoretical basis, the present review indicates that the benefits of the *modality effect* in digital mathematics learning cannot yet be generalized. The available evidence does not include experimental comparisons that specifically isolate visual-text and visual-audio presentations while controlling for content, presentation pace, and learner control. Murtianto et al. (2025), for example, found that *audio persuasion prompts* in the second experiment were associated with higher learning achievement, lower cognitive load, and greater self-efficacy. However, because audio was combined with the type of prompt and *worked-example* design, the observed effects cannot be attributed exclusively to auditory modality.

The findings of Azisah et al. (2025) further indicate that multimedia does not necessarily produce cognitive benefits. Interactive multimedia did not significantly moderate the relationship between motivation and cognitive load. This finding is important because the simultaneous use of multiple forms of media or processing channels does not, by itself, constitute evidence of a *modality effect*. Similarly, improvements in comprehension, motivation, participation, or learning outcomes associated with multimedia (Hariati, 2022; Ilma et al., 2026; Wahyuniar et al., 2021) cannot automatically be interpreted as evidence of reduced cognitive load when cognitive load has not been directly measured.

The effectiveness of modality should also be understood in relation to the conditions under which it is applied. Combining visual information with audio may be beneficial when visual information is sufficiently complex, narration is relevant and synchronized with visual representations, and learners have control over pausing or replaying the material. Conversely, these benefits may diminish when narration is excessively fast, auditory information is transient, or audio merely duplicates text already presented visually. Under such conditions, additional audio may create redundancy or impose unnecessary processing demands. Learners' prior knowledge, material complexity, and device characteristics should therefore also be considered when determining whether dual-modality presentation is likely to support learning.

In digital mathematics learning, the modality principle should therefore be applied selectively rather than as a rule that every visual representation should be accompanied by audio. Videos, animations, dynamic diagrams, and audio narration may facilitate the explanation of complex or abstract mathematical concepts when each representation serves a clear and complementary informational function (Castro-Alonso & Sweller, 2020; Clarke et al., 2005; F. F. Sari et al., 2025; Setiawi et al., 2024). In contrast, adding a modality that provides no complementary information may introduce redundancy and does not necessarily improve processing efficiency.

Overall, the review indicates that the *modality effect* provides a theoretically relevant mechanism for managing the distribution of processing demands in digital mathematics learning; however, direct empirical evidence demonstrating reductions in cognitive load remains limited. The *modality effect* should therefore not be treated as a universal principle whereby visual-audio presentations are always more effective than visual-only presentations. Instead, the findings support a conditional interpretation of the modality effect, with its benefits depending on material complexity, information synchronization, narration pace, redundancy, learner control, prior knowledge, and characteristics of the learning environment.

4. Application of *Split-Attention* and *Modality Effect* Principles in Online Mathematics Learning Design to Reduce Cognitive Load

The synthesis indicates that the application of *split-attention* and *modality effect* principles in online mathematics learning should be understood as a conditional design strategy rather than a universally applicable rule. Instructional design informed by *Cognitive Load Theory* (CLT) is fundamentally intended to reduce unnecessary processing so that working-memory resources can be allocated to information relevant to knowledge construction (Adhikari, 2025; Murtianto et al., 2025; Skulmowski & Xu, 2022). This consideration is particularly important in digital mathematics learning because learners frequently encounter multiple interrelated representations, including text, symbols, equations, diagrams, animations, and solution steps (Asmara et al., 2024).

Based on the synthesis with a moderate level of confidence, one of the primary strategies for reducing potential *split attention* is the spatial and temporal integration of interdependent information. Explanatory text, symbols, diagrams, and solution steps should be positioned close to the representations to which they refer and presented when the information is needed (Hariati, 2022; Haryati et al., 2023; Zhang et al., 2023). Such integration may reduce the need for learners to shift their attention and mentally match information across separate sources (Falah et al., 2022; Sunawan et al., 2017; Wang et al., 2022). *Signaling* may also help clarify relationships among elements and direct attention toward relevant information. However, integration is particularly important for interdependent sources of information; information that can be understood independently does not necessarily need to be combined.

In addition to information integration, segmentation and learner control are important considerations in digital mathematics design. Complex worked examples, procedures, or animations can be divided into more manageable segments, while pause, replay, and speed-control functions allow learners to regulate information processing according to their needs. These strategies are particularly relevant to reducing *transient information* problems, in which information disappears before learners have sufficient time to process and integrate it. Cognitive load management therefore depends not only on the form of representation but also on presentation timing and the degree of control provided to learners.

The application of the *modality effect* requires greater caution because the confidence level associated with recommendations for audio use is low to moderate. Audio narration may accompany diagrams, animations, or complex visual representations when the visual channel is densely loaded with information (Castro-Alonso & Sweller, 2020; F. F. Sari et al., 2025; Suek, 2018). However, audio should provide complementary information rather than simply repeat identical on-screen text. Redundancy between visual text and audio narration may impose additional processing demands, particularly when narration is rapid or learners cannot pause and replay the material. Audio use should therefore be adapted to material complexity, learner characteristics, and the devices through which instruction is delivered.

Learners' prior knowledge is another important consideration in determining the appropriate level of instructional support. Learners with limited prior knowledge may require more explicit explanations, signaling, and integrated representations to establish relationships among concepts. In contrast, the same support may become redundant for more knowledgeable learners and potentially contribute to an *expertise reversal effect*. Digital mathematics instruction should therefore consider not only media characteristics but also the extent and form of support required by learners with different levels of prior knowledge.

These findings also provide a more proportionate interpretation of the use of videos, animations, and interactive multimedia. Such media can provide representations that support the understanding of abstract mathematical concepts (Adinda et al., 2025; Azisah et al., 2025; Ilma et al., 2026; Wahyuniar et al., 2021), but multimedia use itself does not guarantee reduced cognitive load. Its effectiveness depends on how text, images, symbols, audio, animations, and interactive controls are organized. Consequently, media validity, positive learner responses, motivation, or improved learning outcomes alone are insufficient to conclude that an instructional design has reduced cognitive load when cognitive load has not been directly measured.

Overall, the findings for RQ4 indicate that online mathematics learning designed to manage cognitive load should incorporate the integration of interdependent information, segmentation, learner control, selective use of modality, and adaptation of instructional support to prior knowledge. These principles do not constitute a single design format applicable to all learning conditions; rather, they represent a set of design decisions that should be adapted to the characteristics of the material, learners, media, and learning environment. This conditional perspective provides the foundation for the Conditional SAM-Math Model, which positions design decisions, boundary conditions, cognitive load measurement, and learning outcomes as interconnected components.

IV. CONCLUSION

Based on the *Systematic Literature Review* of 11 primary studies, *split-attention* and *modality effect* principles are relevant to cognitive load management in digital mathematics learning, although the strength of the available empirical evidence remains uneven. *Split attention* may increase *extraneous cognitive load* when learners are required to mentally integrate interdependent text, symbols, diagrams, or solution steps presented separately. Accordingly, spatial-temporal integration, signaling, segmentation, and learner control represent design strategies that receive relatively consistent support. In contrast, the *modality effect* should not be regarded as a universal principle whereby combining visual and auditory information always reduces cognitive load. The benefits of audio are conditional and depend on material complexity, information synchronization, narration pace, redundancy, learner control, prior knowledge, and the characteristics of the device and learning environment. The review further indicates that improvements in learning outcomes, motivation, positive learner responses, or media feasibility cannot be treated as direct evidence of reduced cognitive load unless cognitive load is explicitly measured. Based on the synthesis, the Conditional SAM-Math Model positions design decisions, boundary conditions, cognitive load measurement, and learning outcomes as interconnected components. Future research should empirically test this model through experimental designs that directly compare *split-attention* and modality conditions, employ explicit measures of cognitive load, and account for learner and learning-environment characteristics to provide stronger evidence of the relationships among multimedia design, cognitive load, and mathematics learning outcomes.

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