

Integrating multimedia scaffolding in e-modules to enhance students' critical thinking: a systematic review

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Abstract

Integrating multimedia scaffolding in e-modules to enhance students' critical thinking: a systematic review. The accelerated growth of digital learning environments requires electronic instructional materials that develop higher-order cognitive skills. E-modules enriched with multimedia offer such potential; however, without structured guidance, multimedia richness may overload learners' cognition and fail to develop critical thinking. This study investigates how the synergistic integration of scaffolding and multimedia within e-modules enhances students' critical thinking skills in digital learning environments. A Systematic Literature Review (SLR) was conducted following PRISMA guidelines, searching ScienceDirect, ERIC, and ResearchGate databases for peer-reviewed articles published between 2020 and 2026. Based on strict inclusion criteria, 25 articles were included, predominantly from Scopus- and Sinta-indexed journals. The analysis demonstrates that multimedia components in e-modules minimize cognitive overload and promote deeper information processing. Scaffolding strategies—question prompts, metacognitive scaffolding, gradual hints, and adaptive feedback—effectively guide students to self-regulate learning and evaluate their thinking processes. Moreover, integrating multimedia and scaffolding within Problem-Based Learning (PBL), STEM, and inquiry-based approaches consistently enhances critical thinking aspects, including analysis, evaluation, inference, and argument construction. These findings imply that balancing multimedia richness with structured scaffolding is essential for creating learning environments that support 21st-century critical thinking skills.

Keywords: Critical Thinking; Digital Learning; E-Modules; Interactive Multimedia; Scaffolding

Introduction

The unprecedented evolution of information and communication technology, intertwined with multifaceted global demands, has ushered in the contemporary epoch widely recognized as the Fourth Industrial Revolution (Industry 4.0) (Salsabila & Rehnaningtyas, 2024; Sirait, 2022). Consequently, its impact is strongly felt in science education, which must therefore be grounded in future needs by leveraging technology (Fadillah, 2024; Sa'adah, 2024). Characterized as the knowledge era, the current century has witnessed an unprecedented surge in technological and informational advancements, triggering profound transformations across diverse sectors (Mardhiyah et al., 2021; Rahayu et al., 2022; Rosyid & Mubin, 2024).

To navigate this evolving landscape, learners require robust critical thinking capabilities, a cornerstone of modern education, enabling them to systematically dissect information, assess validity, and formulate logical solutions to complex issues (Halim, 2022; Humam & Hanif, 2025; Robbani, 2025). Despite this necessity, empirical evidence indicates a persistent deficit in students' higher-order reasoning abilities, underscoring the urgent need for targeted pedagogical interventions (Akhyar et al., 2024; Sholeh et al., 2024). To support the development of such skills, digital technology has profoundly influenced the way education is delivered worldwide. This shift affects not only the delivery of learning materials but also the ways of thinking, interacting, and managing learning processes across various educational levels (Fitriana & Nindia, 2025; Sinaga & Firmansyah, 2024). One manifestation of this technological utilization is the electronic module (e-module), which integrates text, images, videos, animations, and various interactive elements. E-modules enable access anytime and anywhere, thereby fostering more effective independent learning (Mutia et al., 2025; Pribowo et al., 2024).

Despite their advantages, relying solely on electronic modules is insufficient to automatically foster learners' higher-order cognitive abilities (Nabila et al., 2026). Therefore, instructional strategies that support gradual comprehension are required, one of which is scaffolding. Scaffolding is defined as a pedagogical strategy in which teachers provide structured, incremental support tailored to students' current capabilities, progressively withdrawing this assistance to cultivate autonomous mastery of the taught concepts (Kuncoro & Turahmat, 2025; Marlina & Rahayu, 2025). As a learning support, scaffolding is highly useful in helping students comprehend materials progressively, from simple to more complex concepts (Mustofa et al., 2021; Sari et al., 2025). It is imperative for educators to possess both theoretical comprehension and practical proficiency in scaffolding, enabling them to effectively integrate this strategy into classroom instruction (Putri et al., 2022).

Grounded in the Cognitive Theory of Multimedia Learning (Mayer) and Vygotsky's Zone of Proximal Development (ZPD), the integration of multimedia and scaffolding is theorized to optimize cognitive processing. Multimedia reduces extraneous cognitive load by presenting information through dual channels (visual and auditory), while scaffolding provides the necessary structural support within the ZPD. This synergy specifically targets higher-order dimensions of critical thinking, namely analysis, evaluation, inference, and argument construction, by guiding learners to actively process complex information rather than passively consuming it.

In actual classroom settings, educators frequently encounter significant obstacles when designing and implementing interactive digital resources, primarily stemming from inadequate technical proficiency and digital literacy (Anisah et al., 2025; Ruslan et al., 2025). This constraint hinders the creation of engaging learning experiences aligned with the digital world that students currently inhabit (Meliyani et al., 2022). Moreover, although numerous studies have examined the use of e-modules or scaffolding strategies separately, few have specifically integrated multimedia scaffolding within e-modules to enhance students' critical thinking competencies (Cahyono et al., 2025). In addition, there is a notable paucity of research that has undertaken a systematic synthesis and critical evaluation of these empirical findings. While previous systematic reviews and meta-analyses have separately examined the effects of multimedia learning (Abdulrahman et al., 2020), scaffolding in online environments (Thomann & Deutscher, 2025; Zuo et al., 2023), or PBL e-modules (Meirani et al., 2026), there remains a critical gap in understanding their synergistic integration. Specifically, it remains unexplored how the structured integration of multimedia scaffolding specifically within e-modules operates to enhance students' critical thinking competencies, necessitating a systematic synthesis of recent empirical evidence.

To address this identified gap, a comprehensive investigation is required to evaluate how integrating multimedia scaffolding into e-modules can enhance students' critical thinking competencies. Accordingly, this study undertakes a systematic review of relevant literature to examine the characteristics, effectiveness, and impact of multimedia scaffolding integration within e-modules on the development of critical thinking skills. The insights derived from this analysis are anticipated to provide both theoretical and practical foundations for the design of more innovative and accessible digital instructional materials.

Method

This research adopted a Systematic Literature Review (SLR) methodology, with the reporting process structured in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 framework. The literature search was conducted across three databases, namely ScienceDirect, ERIC, and ResearchGate (which collectively yielded articles indexed in Scopus and Sinta), limited to publications from 2020 to 2026, with the final search executed in September 2026. The search string was: ("multimedia scaffolding" OR "instructional scaffolding") AND ("e-module" OR "digital module") AND ("critical thinking" OR "higher order thinking").

The inclusion criteria encompassed primary empirical studies (quantitative, qualitative, or mixed-methods designs) published within the 2020–2026 timeframe, centered on themes related to multimedia, scaffolding, e-modules, and/or critical thinking skills, and accessible in full-text format. Conversely, records

were excluded if they represented duplicate entries across multiple databases, constituted opinion articles, editorials, or non-empirical publications, or fell outside the defined scope of the present study. To ensure the rigor of the review, the methodological quality of the included studies was appraised using the Mixed Methods Appraisal Tool (MMAT), which assesses studies across five domains: clarity of research questions, appropriateness of data collection, adequacy of sample representation, soundness of data analysis, and coherence of findings. All 25 final studies met the minimum threshold for methodological quality (scoring ≥ 3 out of 5 criteria). The evidence was then synthesized using a thematic narrative synthesis approach, in which findings were systematically coded and categorized based on three dimensions: (1) multimedia characteristics, (2) forms of scaffolding, and (3) their specific impacts on critical thinking indicators (analysis, evaluation, inference, and argument construction). Cross-study comparisons were conducted to identify patterns, inconsistencies, and contextual moderators across educational levels, subject areas, and research designs.

The selection procedure proceeded through four sequential phases aligned with the PRISMA 2020 framework. The initial search yielded 78 records from the three databases. After removing 22 duplicate records and 8 records excluded for other reasons, including inaccessible full-text or non-English publications, 48 records were screened based on titles and abstracts, leading to the exclusion of 15 records deemed irrelevant to the research focus. Subsequently, 33 full-text articles were assessed for eligibility. Of these, 8 were excluded because they did not meet the inclusion criteria, specifically lacking empirical data, focusing on non-critical thinking outcomes, or not integrating scaffolding within e-modules. This process culminated in a total of 25 articles that satisfied all criteria and were subsequently subjected to in-depth analysis.

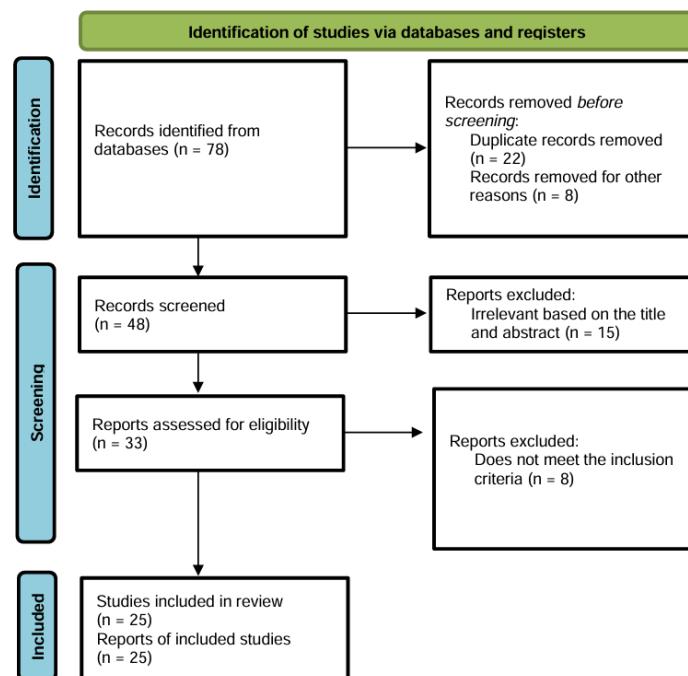


Figure 1. Article Selection Process Based on the PRISMA 2020 Guidelines

Results and Discussion

After an extensive search of the scientific literature, a total of 25 articles meeting the criteria were obtained for further analysis. Based on the synthesis of these articles, this study formulates a conceptual framework for the integration of multimedia and scaffolding in e-modules. This framework links three main elements: (1) the characteristics of interactive multimedia (text, videos, animations, and interactive features), (2) four forms of structured scaffolding (question prompts, metacognitive scaffolding, gradual hints, and adaptive feedback), and (3) learning approaches (PBL, STEM, or inquiry). The integration of these three elements is systematically designed to optimize the aspects of students' critical thinking, namely analysis, evaluation, inference, and argument construction. The details of this framework synthesis are elaborated in the following subsection.

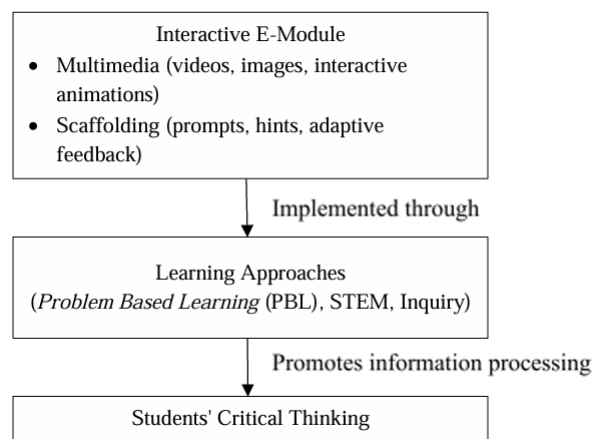


Figure 2. Conceptual Framework of Multimedia and Scaffolding Integration

As visualized in Figure 2, this framework demonstrates that multimedia in e-modules does not function merely as a passive presenter of information. When combined with active learning approaches, multimedia becomes a medium for embedding scaffolding strategies (such as question prompts and adaptive feedback). A systematic comparison of the 25 included studies reveals diverse educational contexts and methodological designs. The studies span various educational levels, including elementary (Dermawan et al., 2025; Listiyorini et al., 2025), junior high (Rohma et al., 2023), and senior high schools (Amalia et al., 2024; Megawati et al., 2026), primarily within science, biology, and chemistry domains. Methodologically, the majority employed quantitative or mixed-methods designs, utilizing interactive multimedia types such as Articulate Storyline, Book Creator, and Python-based simulations. The scaffolding strategies predominantly featured question prompts and adaptive feedback, integrated within Problem-Based Learning (PBL) and STEM frameworks to specifically target critical thinking indicators like analysis, evaluation, and inference.

Table 1. Articles Selected through the SLR Process

No.	Authors (Year)	Research Focus	Journal & Reputation	Key Findings on Critical Thinking & Scaffolding
1.	Abdulrahman et al. (2020)	Role of multimedia tools in enhancing teaching-learning processes	Heliyon	Structured audiovisual multimedia improves student engagement and conceptual understanding
2.	Nurhikmah et al. (2021)	Development of interactive e-modules for multimedia-based learning	Al-Ishlah: Journal of Education	Combining text, images, and video creates relevant learning experiences
3.	Sidiq et al. (2023)	Interactive e-modules based on animated videos	IJERSC	Animations and interactive evaluation boost active engagement in analyzing information
4.	Rohma et al. (2023)	Question-prompt scaffolding in electronic student worksheets (e-LKPD)	Journal Paedagogy	Structured prompts guide students in organizing information and drawing in-depth conclusions
5.	Rahmat et al. (2021)	Metacognitive scaffolding for academic writing in online learning	Int. Journal of Education	Improves planning, monitoring, and evaluation of online learning processes
6.	Zuo & Kong (2023)	Meta-analytic review of scaffolding effects in online learning	Education Sciences	Gradual hints and adaptive feedback significantly adjust the assistance to match students' needs

No.	Authors (Year)	Research Focus	Journal & Reputation	Key Findings on Critical Thinking & Scaffolding
7.	Thomann & Deutscher (2025)	Meta-analysis of prompt-based scaffolding in digital learning environments	Education Research Review	Digital prompts yield strong positive effects when designed with clear structure and context
8.	Janeczko et al. (2026)	Developing preservice teachers' professional vision in virtual learning	Education, Technology, R&D	Interactive videos with embedded analytical prompts improve reflective thinking
9.	Kaldaras et al. (2024)	Technology-enhanced feedback and scaffolding in science	International Journal of STEM	Simulations with technology-driven feedback promote deep conceptual understanding in science
10.	Alkan et al. (2024)	Simulation-based training with multi-feedback scaffolding systems	Education & Information Technology	Multiple feedback systems offer effective scaffolding for real-time error correction
11.	Amalia et al. (2024)	Socio-scientific issue-based e-modules for critical thinking enhancement	Unnes Science Education Journal	Enhances critical thinking (inference and integration) with N-gain > 0.70
12.	Dermawan et al. (2025)	Interactive e-modules for fostering critical thinking in elementary education	OJCMT	Yields class-level mastery and significantly improves average critical thinking scores
13.	Zahra & Purwantoyo (2024)	Interactive e-modules for differentiated learning	Journal of Biology Education	Achieved an N-gain of 0.85 for the analysis and evaluation of learning materials
14.	Sajidan et al. (2025)	Hypothetical inquiry-based e-modules	JEMIN	Assists students in drawing logical conclusions and constructing strong arguments under challenging conditions
15.	Fathurohman et al. (2021)	STEM integrated PBL physics modules for higher order thinking skills	Journal Physics: Conference Series	Effectively promotes higher-order thinking skills (HOTS) in high school students
16.	Luciana et al. (2025)	Interactive simulation of Python-based STEM E-LKPD	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education] Jurnal Pendidikan Fisika dan Teknologi [Journal of Physics and Technology Education]	Yields positive outcomes in understanding contextual science issues and sustainability awareness
17.	Lusiana et al. (2025)	Contextual physics e-modules based on wetland environments	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education]	Significantly enhances the conceptual understanding of physics in high school students
18.	Amelia & Khairuna (2025)	STEM-based e-modules integrated with ethnoscience	Unnes Science Education Journal	Integrating ethnoscience and STEM into e-modules improves creative and critical thinking skills
19.	Tartiyoso (2025)	STEM-based e-modules for science literacy and process skills	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education]	Improves scientific literacy and science process skills via structured multimedia

No.	Authors (Year)	Research Focus	Journal & Reputation	Key Findings on Critical Thinking & Scaffolding
20.	Saralee et al. (2024)	Articulate-assisted PBL e-modules for IPA critical thinking	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education]	The PBL e-module assisted by Articulate effectively facilitates analysis and evaluation abilities
21.	Megawati et al. (2026)	PBL e-modules on circulatory system for critical and collaborative thinking	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education]	Simultaneously improves 11th-grade students' critical thinking and collaboration skills
22.	Qoshirotutth orfi et al. (2024)	Problem solving oriented e-modules for acid base critical thinking	International Journal of Current Science Research	Problem-solving oriented and effective in enhancing inference and evaluation on the acid-base topic
23.	Daulay & Sugiharti (2025)	PBL e-modules for enhancing acid-base critical thinking skills	Jurnal Inovasi Pembelajaran Kimia [Journal of Chemistry Learning Innovation]	Consistently enhances students' critical thinking scores through the PBL approach in e-modules
24.	Listiyorini et al. (2025)	Book creator assisted e-modules with critical thinking activities	Jurnal Penelitian Pendidikan IPA [Journal of Research in Science Education]	Combining Multimedia Book Creator with critical thinking activities proves effective for junior high school students
25.	Meirani et al. (2026)	Systematic review of PBL e-modules for 21st-century skill development	Jurnal Pemberdayaan Masyarakat [Journal of Community Empowerment]	Systematic reviews confirm PBL e-modules as a key catalyst for 21st-century skills

Multimedia Characteristics in E-Modules

The characteristics of multimedia in e-modules are evident through the integration of various digital media formats, encompassing textual, visual, auditory, and dynamic media elements, alongside animations and interactive features. Abdulrahman et al. (2020) demonstrated that multimedia serves not merely as a visual enhancement but actively increases student engagement and conceptual understanding. Building on this perspective, Nurhikmah et al. (2021) highlighted that the synthesis of textual, visual, and dynamic video elements within interactive e-modules substantially elevates the holistic quality of the educational experience. Furthermore, Saralee et al. (2024) engineered PBL-oriented e-modules tailored for integrated science and social studies (IPAS) through the Articulate platform. The empirical evidence demonstrated that leveraging interactive multimedia tools, particularly Articulate Storyline, substantially bolsters students' critical thinking competencies. This conclusion receives additional empirical support from Listiyorini et al. (2025), who developed e-modules using Book Creator for junior high school science education. Their investigation demonstrated that the strategic fusion of multimedia elements with cognitively demanding tasks yielded substantial gains in students' capacity for critical analysis and evidence-based evaluation.

Forms of Scaffolding in Digital Learning

Scaffolding in digital learning encompasses various forms, including question prompts, metacognitive scaffolding, gradual hints, and adaptive feedback. Rohma et al. (2023) demonstrated that question prompt scaffolding enhances critical thinking, as structured questions help students organize information effectively. Rahmat et al. (2021) demonstrated that metacognitive scaffolding substantially strengthens students' capacity to plan, monitor, and critically assess their own learning trajectories in online environments. In their meta-analysis, Zuo et al. (2023) showed that gradual hints and adaptive feedback effectively improve learning outcomes. Furthermore, Thomann & Deutscher (2025) affirmed that prompt-based scaffolding in digital

learning environments produces markedly positive learning outcomes, particularly when the prompts are contextualized with clarity and specificity.

Integrating Multimedia and Scaffolding

The integration of multimedia and scaffolding is implemented by incorporating guiding questions or prompts within digital environments. Thomann & Deutscher (2025) stated that prompt-based scaffolding approaches significantly enhance learning outcomes. Janeczko et al. (2026) found that video modeling with embedded analytical prompts improves professional vision. Furthermore, Kaldaras et al. (2024) demonstrated that computer-based simulations with technology-driven feedback enable students to directly comprehend scientific concepts. Finally, Alkan et al. (2024) reported that multi-feedback systems within simulation environments provide effective scaffolding for real-time error correction.

The Impact of Multimedia and Scaffolding on Critical Thinking

Experimental studies demonstrate that e-modules utilizing socio-scientific issues and problem-based approaches can enhance students' critical thinking skills. Amalia et al. (2024) found that SSI-based e-modules improve critical thinking with a high N-gain score (> 0.70). Dermawan et al. (2025) showed that interactive e-modules increase the mean critical thinking scores in elementary schools. Zahra & Purwantoyo (2024) reported that differentiated e-modules yield an N-gain of 0.85 in the analysis and evaluation aspects. Furthermore, Sajidan et al. (2025) demonstrated that hypothetical inquiry-based e-modules effectively facilitate students' capacity to derive sound conclusions and build well-structured argumentation. This evidence converges with contemporary scholarship on the design and development of digital instructional materials. Fathurohman et al. (2021) established that STEM-based Problem-Based Learning physics modules effectively foster advanced cognitive abilities. Luciana et al. (2025) demonstrated that interactive STEM simulation-based e-modules yield positive outcomes regarding contextual science issues. Additionally, Lusiana et al. (2025) found that wetland-contextualized e-modules significantly improve the physics concept mastery of high school students.

Eight recent articles added to this review corroborate these findings. Amelia & Khairuna (2025) constructed a STEM-oriented e-module enriched with ethnoscience perspectives on biotechnology, demonstrating substantial efficacy in cultivating the creative thinking competencies of tenth-grade learners. Tartiyoso (2025) demonstrated that STEM-integrated electronic modules substantially enhance both scientific literacy and inquiry-based process competencies within chemistry instruction. Saralee et al. (2024) developed Articulate-assisted PBL e-modules for natural and social sciences (IPAS) that enhanced students' critical thinking. Megawati et al. (2026) demonstrated that PBL-integrated e-modules focusing on the circulatory system substantially foster both critical thinking and collaborative competencies among eleventh-grade learners. Qoshirotutthorfi et al. (2024) constructed a problem-solving-driven e-module centered on acid-base chemistry, demonstrating significant improvements in the critical thinking competencies of eleventh-grade students. Daulay & Sugiharti (2025) provided empirical evidence that PBL-driven e-modules centered on acid-base chemistry consistently strengthen students' critical thinking proficiencies. Listiyorini et al. (2025) leveraged the Book Creator platform to design e-modules that effectively strengthened junior high school students' critical reasoning competencies. Finally, in their systematic literature review, Meirani et al. (2026) concluded that PBL-based e-modules consistently enhance students' essential modern competencies, encompassing analytical reasoning, cooperative engagement, and complex problem resolution.

Overall, the use of interactive and structured multimedia content in e-modules, enriched with various forms of scaffolding and problem-based learning approaches, assists students in analyzing concepts in depth, evaluating evidence, drawing logical conclusions, and constructing strong arguments. This comprehensive integration serves as a crucial hallmark of the critical thinking skills required in 21st-century learning.

Despite the generally positive findings, a critical examination of the reviewed studies highlights notable inconsistencies and methodological limitations. The effectiveness of multimedia scaffolding appears to be moderated by contextual factors, such as the students' prior knowledge and self-regulated learning capabilities. For instance, while interactive simulations with adaptive feedback showed high efficacy in senior high school chemistry (Qoshirotutthorfi et al., 2024), similar approaches in elementary settings required more intensive teacher facilitation (Dermawan et al., 2025). Furthermore, the heterogeneity in research designs, sample sizes, and the specific operationalization of critical thinking indicators across studies suggests that the reported

enhancements, while positive, are not universally uniform. These variations indicate that the mere presence of multimedia and scaffolding is insufficient; the alignment of the scaffolding strategy with the specific cognitive demands of the multimedia content and the learners' developmental stage is a crucial moderator of success.

Conclusion

Drawing upon a comprehensive synthesis of 25 empirical studies, this review concludes that embedding structured scaffolding mechanisms, namely question prompts and adaptive feedback, within interactive multimedia e-modules demonstrates a positive contribution to the enhancement of students' critical thinking competencies. The principal novelty of this review lies in demonstrating that such integration transforms multimedia from a mere presenter of information into an active catalyst that fosters analysis, evaluation, and problem-solving, particularly within Problem-Based Learning (PBL) and STEM approaches. Consequently, future e-module development should prioritize a balanced combination of multimedia richness and well-designed scaffolding strategies to satisfy the rigorous requirements of modern educational competencies.

However, the strength of these claims must be interpreted with caution, as the review is based on a relatively small and heterogeneous set of studies with varying methodological designs and educational contexts. A primary limitation of this review is the reliance on secondary data synthesis without direct empirical testing of the proposed conceptual framework. Therefore, future research should prioritize rigorous empirical studies, such as quasi-experimental designs, that directly test integrated multimedia-scaffolding designs across diverse educational levels to validate these findings and isolate the specific mechanisms driving critical thinking development.

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