

# Instructional Strategies for Managing Cognitive Load in Science Learning: A Systematic Literature Review

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## Abstract

This study aims to identify and analyze instructional strategies for managing students' cognitive load in science learning within the Cognitive Load Theory (CLT) framework. A systematic literature review was conducted following PRISMA 2020 guidelines, searching the Google Scholar and Scopus databases via Publish or Perish software, with the last search conducted on June 12, 2026, covering publications from 2016 to 2026. Included articles were empirical studies in peer-reviewed journals indexed in Scopus, Sinta, DOAJ, or equivalent local peer-reviewed outlets, focusing on the application of instructional strategies to manage cognitive load among primary and secondary school students. A total of 21 articles were selected from an initial pool of 95, through a four-stage screening process involving deduplication, title and abstract screening, and full-text eligibility assessment. Data were synthesized through descriptive, content, and critical analysis to identify trends across studies. The analysis focused on the types of instructional strategies employed and their implications for managing intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL). The findings revealed three main trends. First, technology and digital media were widely adopted to reduce ECL by presenting information in a more structured, multimodal format. Second, active learning models, such as problem-based learning and generative approaches, enhanced GCL by fostering deeper cognitive engagement. Third, instructional designs that explicitly integrate CLT principles, such as chunking, pacing, and the 4C/ID model, demonstrated the most comprehensive potential for managing students' cognitive load. These findings affirm the importance of instructional design aligned with students' working memory capacity to enhance the effectiveness of science learning. However, the absence of a formal risk-of-bias assessment represents a methodological limitation that should be considered when interpreting these findings.

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## INTRODUCTION

The characteristics of science subject matter, laden with abstract concepts, technical terminology, and phenomena that cannot be directly observed, render science learning a cognitively complex endeavor (Mutanaffisah et al., 2021; Putri et al., 2025). Students are required not only to understand concepts but also to integrate multiple knowledge representations, including symbolic, visual, mathematical, and verbal forms. This process demands the ability to construct conceptual relationships, interpret scientific models, and transform information representations within a relatively short timeframe. Consequently, success in science learning is determined not solely by the completeness of the material delivered but also by the extent to which the instructional process facilitates efficient information processing within students' cognitive systems. Without proper

management, the conceptual complexity inherent in science subjects risks creating cognitive barriers that diminish the effectiveness of learning.

From an information-processing perspective, the limited capacity of working memory is a critical factor influencing learning success. When informational demands exceed this capacity, individuals tend to experience cognitive overload, which impedes the formation of knowledge schemas. This phenomenon is explained by Cognitive Load Theory (CLT), developed by John Sweller, which emphasizes that instructional design must account for the limitations of working memory to ensure optimal retention of information in long-term memory (Reski & Fadilah, 2024). Within this framework, cognitive load comprises intrinsic cognitive load (ICL), related to the complexity of the material; extraneous cognitive load (ECL), arising from inefficient instructional design; and germane cognitive load (GCL), representing the allocation of cognitive resources toward the formation and reinforcement of knowledge schemas. The interaction among these three components determines the quality of the learning experience, making instructional design management a critical factor in ensuring that students' cognitive resources are productively utilized throughout the learning process.

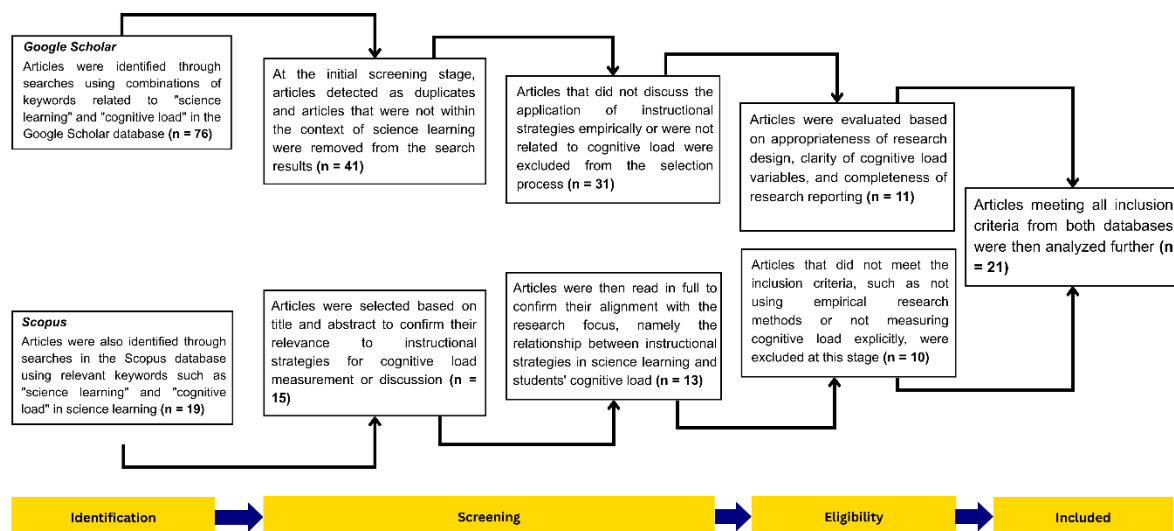
Various instructional strategies have been developed to help teachers manage the complexity of subject matter and minimize students' cognitive load in science learning. The literature reports a wide range of strategies, including visual media, interactive multimedia integration, multimodal approaches, and learning-strategy training, designed to enhance information-processing efficiency (Chen et al., 2023; Hsieh et al., 2016; Nugraha, 2021). From a CLT perspective, appropriate instructional design can reduce extraneous cognitive load, optimize intrinsic cognitive load in accordance with material complexity, and enhance germane cognitive load to support the formation of more stable knowledge structures (Utomo et al., 2025). A number of studies have also demonstrated that multimedia designed in accordance with information processing principles can improve conceptual understanding and learning efficiency in abstract science topics (Shermeh & Hashemi, 2020; Tazesh & Kadivar, 2016). However, the evidence is not without contradiction: while technology-enhanced strategies such as augmented reality and interactive simulations consistently report reductions in ECL, studies applying active learning models such as problem-based learning reveal a more complex picture, where increased task demands may simultaneously elevate ICL while promoting GCL (Agbidye et al., 2019; Hong et al., 2017). This tension between cognitive efficiency and cognitive engagement has yet to be systematically reconciled in the existing literature.

Despite the growing body of research, three specific gaps remain unaddressed in the existing literature. First, prior reviews have predominantly examined single instructional interventions in isolation, without synthesizing how different categories of strategies target ICL, ECL, and GCL in distinct ways within a unified analytical framework. Second, existing systematic and scoping reviews in science education have not explicitly compared the relative effectiveness of technology-based, active-learning, and CLT-specific design strategies, leaving practitioners without evidence-based guidance for strategy selection. Third, the geographical concentration of studies in Western and East Asian contexts means that findings may not adequately reflect the instructional realities of Southeast Asian science classrooms, where resource constraints and curriculum structures differ substantially (Li et al., 2023). To address these gaps, this study contributes theoretically by synthesizing cross-study evidence to clarify the differential effects of instructional strategy categories on ICL, ECL, and GCL; methodologically by employing a PRISMA-guided systematic review to ensure transparent and replicable synthesis; and practically by providing evidence-based recommendations for science teachers and curriculum designers on strategy selection aligned with cognitive load management principles. The study is directed at answering two primary questions: (1) what instructional strategies

are reported to be effective in managing cognitive load in science learning, and (2) how do these strategies influence the components of intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL). The remainder of this article is organized as follows: the Methods section describes the systematic search and selection procedures; the Results section presents the general characteristics of the included studies and synthesizes findings by instructional strategy category; and the Discussion section interprets the cross-study patterns and their implications for science education research and practice.

## RESEARCH METHODS

This study employs a Systematic Literature Review (SLR) to identify and synthesize empirical research on instructional strategies and cognitive load in science learning. This method enables the integration of findings from various primary studies through a structured, transparent, and replicable procedure, in which the search, selection, and analysis of the literature are carried out systematically and according to clear criteria (Kraus et al., 2024). The review procedure follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure that the identification and selection of the literature are conducted systematically and transparently (Sarkis-Onofre et al., 2021). The article selection stages include identification, screening, eligibility, and inclusion, beginning with a search of academic databases, followed by title and abstract screening, full-text evaluation to assess alignment with the research criteria, and, finally, the determination of which articles to include in the data synthesis. The article selection flow is presented in a PRISMA diagram as shown in Figure 1.



**Figure 1.** Article Selection Flow Diagram Based on PRISMA

Data sources were obtained through searches of scientific articles in the Google Scholar and Scopus databases using the Publish or Perish (PoP) software, which efficiently exports, manages, and screens search results from both databases. The search was last conducted on June 12, 2026. The search focused on articles published between 2016 and 2026 to capture the latest research on cognitive load management in science learning. The search strategy employed combinations of keywords using Boolean operators AND and OR to improve the precision and coverage of search results, such as "cognitive load" AND "instructional strategy" AND "science learning" for English-language articles, and "beban kognitif" AND "strategi pembelajaran" AND "pembelajaran IPA" for Indonesian-language articles, with the addition of terms such as "biology education," "physics education," and "chemistry education" to broaden coverage within the context of science education. The initial search

identified 95 articles, comprising 76 from Google Scholar and 19 from Scopus. Subsequently, article selection was conducted using inclusion and exclusion criteria covering publication period, publication type, language, research topic, subject characteristics, study focus, full-text availability, and research design. Included articles are empirical studies published in peer-reviewed journals that discuss the application of instructional strategies in science learning, focusing on measuring or managing cognitive load among primary and secondary school students. Articles irrelevant to the science learning context, lacking instructional intervention, or consisting of conceptual reviews without empirical data were excluded from analysis. The inclusion and exclusion criteria are presented in Table 1.

**Table 1.** Inclusion and Exclusion Criteria

| Aspect             | Inclusion Criteria                                                                                                                                 | Exclusion Criteria                                                                 |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Publication Period | Published between 2016 and 2026.                                                                                                                   | Published outside 2016–2026.                                                       |
| Publication Type   | Empirical research articles in peer-reviewed journals, including those indexed in Scopus, Sinta, DOAJ, or equivalent local peer-reviewed journals. | Literature reviews, editorials, opinion pieces, or non-peer-reviewed publications. |
| Language           | Indonesian or English.                                                                                                                             | Languages other than Indonesian or English.                                        |
| Topic              | Instructional strategies and cognitive load in formal science learning.                                                                            | Outside the context of science learning, or not addressing cognitive load.         |
| Subject            | Students in formal education (primary and secondary level).                                                                                        | University students or subjects outside primary and secondary education.           |
| Focus of Study     | Involves applying instructional strategies to manage cognitive load.                                                                               | Only measures cognitive load without any instructional intervention.               |
| Availability       | Full text available.                                                                                                                               | Abstract only or full text not available.                                          |
| Research Design    | Empirical research (quantitative/qualitative/experimental/mixed methods).                                                                          | Conceptual studies without empirical data.                                         |

Following the completion of the selection process, articles meeting the inclusion criteria were analyzed through data extraction using a systematically constructed sheet to record key information from each study, including author and year of publication, educational level or research context, type of instructional strategy, cognitive load components (ICL, ECL, GCL), and main research findings. The collected data were organized into an extraction matrix to facilitate cross-article comparisons and identify variations in instructional strategies reported in the literature, with a summary of the results presented in Table 2. The selection process resulted in the progressive reduction of articles across four stages: of the 95 articles initially identified, 39 were removed at the identification stage due to duplication or irrelevance to the science learning context; 12 were excluded during title and abstract screening for not addressing instructional strategies or cognitive load; 20 were excluded following full-text evaluation for not aligning with the research focus; and a further 3 were excluded for failing to meet the inclusion criteria, specifically for not employing empirical research methods or not measuring cognitive load explicitly, yielding a final corpus of 21 articles for analysis.

The data were then analyzed through a combination of three analytical approaches: (1) descriptive analysis, in which the frequency and distribution of cognitive load components (ICL, ECL, GCL) across articles were calculated and tabulated to identify prevailing trends; (2) content analysis, in which findings from each article were inductively coded and categorized into thematic patterns

based on the type of instructional strategy and its reported effect on cognitive load components; and (3) critical analysis, in which results across studies were systematically compared to interpret the broader implications of the findings and identify consistencies or contradictions in the literature, thereby producing a comprehensive synthesis of trends in instructional strategies for managing cognitive load in science learning. Regarding risk-of-bias assessment, this review did not conduct a formal quality appraisal of the included studies. This decision was made on methodological grounds: given that the primary aim of this review is to map and synthesize trends in instructional strategy use across diverse study designs, rather than to estimate effect sizes or make causal claims, a formal risk-of-bias procedure was considered beyond the scope of the current analysis. Furthermore, the inclusion criteria were designed to function as a proxy quality filter by restricting the corpus to empirical studies published in peer-reviewed journals. Nevertheless, the authors acknowledge this as a methodological limitation: conclusions drawn in this review should be interpreted with the understanding that the methodological quality of individual studies was not formally assessed, and findings from studies with weaker designs may carry the same weight as those from more rigorous ones. This limitation is addressed further in the concluding section. All referenced sources were cited in accordance with applicable academic integrity standards, and no conflicts of interest are declared in the conduct of this review.

**Table 2.** Article Data Extraction Matrix

| Author (Year)                 | Instructional Strategy                                         | Main Findings                                                                                           |
|-------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Lai et al. (2019)             | Augmented Reality (AR)                                         | AR reduced ECL and improved learning outcomes compared to conventional instruction.                     |
| Shermeh & Hashemi (2020)      | CLT, Multimedia, Speech (method comparison)                    | The multimedia method was most effective in reducing CL and improving learning outcomes.                |
| Du et al. (2025)              | Educational animation with textual cues                        | Appropriate textual cues reduced ECL and enhanced GCL.                                                  |
| Chen & Chang (2024)           | AI-assisted game-based learning in science                     | AI-based games reduced ECL and improved motivation and learning outcomes.                               |
| Weng et al. (2018)            | Interactive e-textbook in science learning                     | Optimal interactivity in e-textbooks reduced CL and improved learning outcomes.                         |
| Yilmaz (2023)                 | Instructional animation with a cueing technique                | Cueing in animation reduced ECL and improved focus.                                                     |
| Pramudiyan & Fadhillah (2024) | PBL, PjBL, Discovery Learning                                  | High learning interest was positively associated with greater resilience toward high CL.                |
| Sabilla et al. (2019)         | Conventional instruction (lecture with minimal evaluation)     | High CL was significantly and negatively correlated with students' conceptual understanding.            |
| Agbidye et al. (2019)         | Problem-Based Learning (PBL)                                   | PBL significantly reduced CL and improved conceptual understanding in science.                          |
| Tazesh & Kadivar (2016)       | Multimedia learning with seductive details                     | Seductive details increased ECL and reduced performance; clean design proved more optimal.              |
| Fadl & Youssef (2020)         | Augmented Reality (AR)                                         | AR reduced CL and improved positive attitudes; effectiveness depended on CLT-based design.              |
| Nurwanda et al. (2020)        | Dominant lecture method, worksheets, exercises, questionnaires | Lecture-dominant method and external factors in pesantren settings increased CL.                        |
| Hsieh et al. (2016)           | Gesture-based concept map teaching system                      | The gesture-based concept map system reduced ECL and improved learning outcomes.                        |
| Oh & Kim (2016)               | Generative concept map                                         | Generative concept mapping enhanced GCL and academic achievement compared to conventional concept maps. |

| Author (Year)           | Instructional Strategy                        | Main Findings                                                                                     |
|-------------------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------|
| Hong et al. (2017)      | Inquiry-based learning (POE) with iPad        | Inquiry via iPad reduced cognitive anxiety and CL; CL was negatively correlated with interest.    |
| Moshizi et al. (2020)   | 4C/ID model (Van Merriënboer) and multimedia  | The 4C/ID design significantly reduced CL and improved learning outcomes and academic motivation. |
| Angga et al. (2022)     | Chunk learning media                          | Dividing material into small chunks effectively prevented cognitive overload.                     |
| Putri et al. (2021)     | Chunking technique                            | Chunking successfully managed the ICL in the reproductive system content.                         |
| Nugraha (2021)          | Talking Toys media                            | The concrete-audiovisual Talking Toys media effectively reduced CL.                               |
| Santoso (2023)          | Pacing and Dual Processing (audio-visual)     | Pacing and dual processing led to lower total CL and improved comprehension.                      |
| Kpiranyam et al. (2024) | Experiential Learning vs. Discussion Strategy | Experiential learning reduced CL and enhanced self-efficacy (accounting for 11% of CL variance).  |

Table 2 presents the data extraction matrix summarizing the key characteristics and main findings of the 21 included studies. Among the technology-based studies, Lai et al. (2019) and Fadl & Youssef (2020) both reported that Augmented Reality effectively reduced ECL and improved learning outcomes, though Fadl & Youssef (2020) emphasized that effectiveness was contingent on CLT-aligned design. Similarly, Chen & Chang (2024) found that AI-assisted game-based learning reduced ECL while improving motivation, and Weng et al. (2018) demonstrated that optimal interactivity in e-textbooks reduced overall CL. Animation-based strategies were also prominent: Yilmaz (2023) showed that cueing in instructional animations reduced ECL and improved focus, while Du et al (2025) found that appropriate textual cues in educational animations reduced ECL and simultaneously enhanced GCL. Hsieh et al. (2016) reported that a gesture-based concept map system reduced ECL and improved learning outcomes, and Nugraha (2021) found that concrete-audiovisual Talking Toys media effectively reduced CL in elementary science learning.

Among active learning model-based studies, Agbidiye et al. (2019) demonstrated that Problem-Based Learning significantly reduced CL and improved conceptual understanding compared to conventional instruction, while Hong et al. (2017) found that inquiry-based learning via iPad reduced cognitive anxiety and CL, with CL negatively correlated with student interest. Oh & Kim (2016) showed that generative concept mapping enhanced GCL and academic achievement, and Kpiranyam et al. (2024) reported that experiential learning reduced CL and enhanced self-efficacy, accounting for 11% of the variance in CL. Correlational studies added nuance: Sabilla et al. (2019) found a significant negative relationship between CL and conceptual understanding, Pramudiyan & Fadhilah (2024) reported that high learning interest was positively associated with resilience toward high CL, and Nurwanda et al. (2020) identified that lecture-dominant methods and external pesantren factors increased CL.

Among CLT-specific instructional design studies, Shermeh & Hashemi (2020) found that multimedia methods were most effective in reducing CL compared to CLT and speech methods. Tazesh & Kadivar (2016) demonstrated that seductive details increased ECL and reduced performance, affirming that clean instructional design is more optimal. Chunking-based studies by Putri et al. (2021) and Angga et al. (2022) showed that dividing material into smaller units effectively managed ICL and prevented cognitive overload. Santoso (2023) reported that pacing and dual processing strategies resulted in lower total CL and improved comprehension, while Moshizi et al. (2020) found that the 4C/ID model significantly reduced CL and improved both learning outcomes and academic motivation. Taken together, these findings reveal a consistent pattern whereby strategies that reduce ECL or enhance GCL through structured, CLT-aligned design tend to yield

more favorable learning outcomes, forming the analytical basis for the thematic synthesis presented in the Results and Discussion section.

## RESULTS AND DISCUSSION

### General Characteristics of the Studies

A total of 21 articles that met the inclusion criteria were analyzed in this study, encompassing both national and international publications between 2016 and 2026. The distribution of articles by publication year is presented in Figure 2. The visualization shows a clear increase in the number of studies, particularly during the 2019–2024 period, indicating growing academic attention to the application of CLT in science learning. This trend suggests that cognitive load management is increasingly being positioned as a critical component of effective science learning design, particularly as content complexity demands instructional strategies that optimize learners' information-processing capacity. This upward trend is consistent with the findings of Reski & Fadilah (2024), who reported growth in CLT-related research publications in science education in recent years.

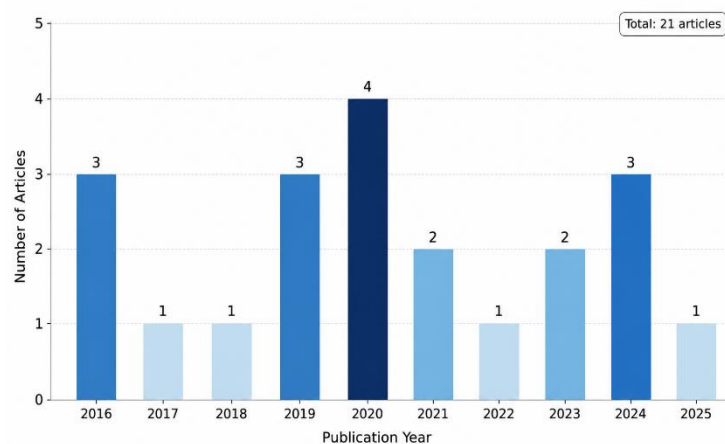


Figure 2. Distribution of Articles by Publication Year

To further strengthen the bibliometric mapping of the research landscape, a keyword co-occurrence analysis was conducted using VOSviewer. This approach is commonly employed in systematic studies to visualize the intellectual structure and thematic interconnections among studies (Donthu et al., 2021). The network visualization results revealed three dominant thematic clusters: the first cluster centered on cognitive load and science as the highest-frequency nodes; the second cluster linked science learning, student, effect, and test, reflecting a focus on measuring the effects of interventions on learning outcomes; the third cluster comprised learning performance, learning achievement, and cognitive load theory, indicating attention to the theoretical dimensions and learning attainment. The nodes teaching and exploration appeared at the periphery, suggesting that pedagogical aspects and conceptual exploration remain underrepresented, thereby opening opportunities for further research.

Analysis by educational level showed dominance at the senior secondary school level (SMA), followed by junior secondary (SMP) and primary school (SD). The percentage distribution is presented in Figure 4. The dominance of research at the secondary school level is understandable, as scientific concepts become increasingly complex at this stage, making the management of ICL, ECL, and GCL more crucial in supporting students' conceptual understanding (Shi et al., 2024). Conversely, research representation at the primary school level is relatively limited, likely due to the lower complexity of the subject matter at that stage as well as the limited availability of instruments for measuring cognitive load in young learners. This condition points to further research opportunities

at the primary education level to broaden the validity of implementing cognitive load theory-based strategies across various stages of students' cognitive development.

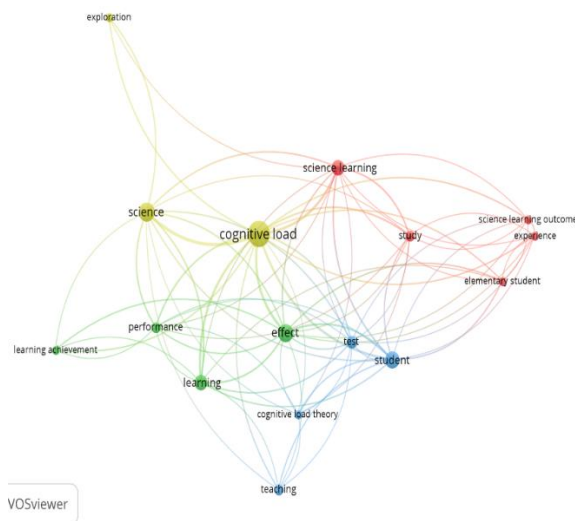


Figure 3. Keyword Co-occurrence Network Map Based on VOSviewer

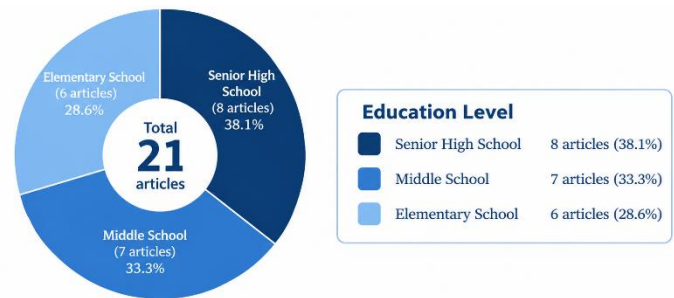


Figure 4. Percentage Distribution of Studies by Educational Level

Analysis of research methods revealed a predominance of quantitative approaches, particularly quasi-experimental designs, over other methods. The complete distribution of research methods employed across the analyzed studies is presented in Table 3. This dominance of quantitative approaches indicates that most studies have focused on empirically testing the effectiveness of instructional strategies in managing cognitive load and their impact on learning outcomes. This pattern is consistent with the findings of Nugroho et al. (2023), who reported a tendency toward a dominance of quantitative research in science education studies in Indonesia. Accordingly, experimental approaches remain the primary methodological strategy for examining the implementation of cognitive load theory in science learning contexts, although reinforcement through qualitative and mixed-methods designs remains necessary to more comprehensively understand cognitive processes and learning dynamics.

Table 3. Distribution of Studies by Research Method

| Model                | Research Design          | n  | Percentage (%) |
|----------------------|--------------------------|----|----------------|
| <b>Quantitative</b>  | Quasi Experimental       | 13 | 61.9           |
|                      | True Experimental        | 2  | 9.5            |
|                      | Correlation              | 2  | 9.5            |
|                      | Survey                   | 1  | 4.8            |
|                      | Descriptive Quantitative | 1  | 4.8            |
| <b>Qualitative</b>   | CAR/PTK                  | 1  | 4.8            |
| <b>Mixed/R&amp;D</b> | R&D / Media Development  | 1  | 4.8            |

The analyzed studies originated from diverse geographical contexts. Indonesia dominated with 7 articles (33.3%), followed by Taiwan with 5 articles (23.8%), Iran with 3 articles (14.3%), Nigeria with 2 articles (9.5%), and China, Korea, Egypt, and Turkey with 1 article each (4.8%). This distribution indicates that research on the application of cognitive load theory-based instructional strategies is not confined to any single region but has developed across a variety of science education contexts. Nevertheless, the dominance of certain countries may affect the breadth and generalizability of the findings, given differences in educational systems, learning cultures, and levels of technology integration in learning across contexts (Li et al., 2023). Therefore, interpretations of instructional

strategy effectiveness must take implementation conditions into account to avoid oversimplifying or overgeneralizing findings across differing educational systems.

Within this context of diverse settings, the instructional strategies employed to manage cognitive load across the reviewed studies can be classified into three main categories: (1) technology- and digital media-based strategies, (2) active learning model-based strategies, and (3) instructional design strategies that explicitly draw on CLT principles. This classification was developed based on shared characteristics of the interventions applied in the primary studies and their orientation toward managing ICL, ECL, and GCL. The frequency distribution of each category is presented in Table 4, which shows that technology- and digital media-based strategies represent the most dominant approach in the analyzed research corpus.

**Table 4.** Classification and Frequency of Cognitive Load Management Instructional Strategies

| Strategy Category                             | Number of Articles | Percentage (%) |
|-----------------------------------------------|--------------------|----------------|
| Technology and Digital Media-Based Strategies | 8                  | 38.1           |
| Active Learning Model-Based Strategies        | 7                  | 33.3           |
| CLT-Specific Instructional Design Strategies  | 6                  | 28.6           |

### Technology- and Digital Media-Based Strategies

Technology and digital media-based strategies represent the most dominant category among the analyzed studies. This approach encompasses a wide range of educational technology applications, including Augmented Reality (AR) in the studies of Lai et al. (2019) and Fadl & Youssef (2020); interactive e-textbooks by Weng et al. (2018); AI-assisted game-based learning in Chen & Chang (2024); animation with cueing in Yilmaz (2023) and Du et al. (2025); a gesture-based concept map system in Hsieh et al. (2016); and Talking Toys media examined by Nugraha (2021). This variation reflects the growing integration of digital media into science learning, particularly for visualizing abstract concepts and presenting inter-concept relationships in clearer, more structured ways.

From a CLT perspective, technology in these studies generally reduced ECL by presenting information in a more integrated, easier-to-process format. AR enables abstract concepts to be visualized as interactive three-dimensional objects, thereby reducing the need for additional mental processing arising from symbolic abstraction (Fadl & Youssef, 2020). Similarly, cue-based animation helps direct students' attention to key elements of the material, minimizing distractions. The effectiveness of this approach aligns with the multimedia design principles of the Cognitive Theory of Multimedia Learning, which emphasizes signaling, coherence, redundancy reduction, and spatial contiguity to optimize information processing in working memory (Mishra, 2025).

Nevertheless, the use of technology does not automatically guarantee learning effectiveness. The study by Tazesh & Kadivar (2016) demonstrated that the presence of seductive details, visually or aurally appealing elements that are nonetheless irrelevant, can actually increase ECL and impair conceptual understanding. This finding affirms that the success of technology-based strategies is determined more by the quality of instructional design and pedagogical appropriateness than by media sophistication alone. Accordingly, the integration of technology into science learning must be designed selectively to genuinely support cognitive load management and enhance conceptual understanding.

### Active Learning Model-Based Strategies

Beyond technology-based strategies, several studies have applied active learning models to manage cognitive load in science learning. This approach encompasses Problem-Based Learning (PBL) in the study of Agbidye et al. (2019), inquiry-based learning using the Predict–Observe–Explain

(POE) model in Hong et al. (2017), experiential learning in Kpiranyam et al. (2024), the use of generative concept mapping by Oh & Kim (2016), as well as examinations of students' cognitive load within active classroom learning contexts, including its relationship with conceptual understanding (Sabilla et al., 2019), learning interest (Pramudiyan & Fadhilah, 2024), and learning conditions in pesantren environments (Nurwanda et al., 2020). In general, active learning strategies place students at the center of the learning process through activities that involve exploration, discussion, problem-solving, and knowledge construction, so that learning is not merely about presenting information but also about cognitive engagement in understanding scientific concepts.

From a CLT perspective, learning activities that demand deep cognitive engagement can increase GCL, that is, the cognitive load allocated to the formation and strengthening of knowledge schemas (Syagif, 2024). For instance, PBL and experiential learning encourage students to integrate prior knowledge with new information through contextual problem-solving processes (Kpiranyam et al., 2024). Other strategies, such as generative concept mapping, help students explicitly organize inter-concept relationships, thereby making knowledge structures more systematic (Oh & Kim, 2016). Through these mechanisms, active learning strategies not only facilitate conceptual understanding but also strengthen the construction of more meaningful knowledge.

On the other hand, implementing active learning strategies can increase ICL, particularly when task complexity is high or when students lack sufficient prior knowledge. Overly open-ended exploratory activities can make it difficult for students to integrate new information, placing an excessive burden on working memory capacity (Syagif, 2024). Therefore, the effectiveness of these strategies depends heavily on instructional design that provides adequate scaffolding, such as guided inquiry steps, task simplification, or visual representations that support information processing. Such support is necessary to ensure that increases in germane cognitive load genuinely reflect meaningful cognitive schema formation and reinforcement (Krieglstein et al., 2023; Syagif, 2024).

### **CLT-Specific Instructional Design Strategies**

Beyond technology-based strategies and active learning models, several studies explicitly designed instructional approaches grounded in CLT principles. This category encompasses the application of the 4C/ID model (Moshizi et al., 2020), chunking techniques (Angga et al., 2022; Putri et al., 2021), pacing and dual processing strategies (Santoso, 2023), CLT-based multimedia design (Shermeh & Hashemi, 2020), and the application of coherence principles through the manipulation of seductive details in multimedia environments (Tazesh & Kadivar, 2016). Unlike strategies that emphasize learning methods or media, this approach focuses on regulating the structure, sequence, and representation of content to align with students' working memory capacity. Accordingly, cognitive load management is not solely dependent on learning activities but primarily on how content is designed to make information processing more efficient (Moshizi et al., 2020).

Most strategies in this category focus on managing content complexity to maintain a balanced ICL. The chunking technique, for instance, breaks complex information into smaller conceptual units that are more readily processed by working memory. The studies of Putri et al. (2021) and Angga et al. (2022) demonstrated that this approach helps students build understanding incrementally while reducing the risk of cognitive overload. A similar principle is evident in pacing and dual-processing strategies, which present content progressively through a combination of visual and auditory representations, thereby reducing split-attention effects and improving information-processing efficiency (Santoso, 2023). Additionally, CLT-based multimedia design emphasizes presenting concise, relevant material to minimize ECL (Shermeh & Hashemi, 2020).

Among these various approaches, the 4C/ID model may be regarded as the most comprehensive design framework for integrating the management of ICL, ECL, and GCL. This model combines learning tasks, supportive information, procedural information, and part-task practice to facilitate the gradual mastery of complex skills. Its systematic learning structure enables the progressive formation of knowledge schemas without placing excessive demands on working memory capacity (Moshizi et al., 2020). Nevertheless, analysis of the included studies indicates that most research continues to emphasize reducing ECL through improvements in instructional design rather than explicitly managing ICL, consistent with the view that ECL is the most controllable component of cognitive load through instructional design (Reski & Fadilah, 2024).

The three identified strategy categories demonstrate distinct management orientations: technology-based strategies predominantly reduce ECL, active learning models predominantly enhance GCL, and CLT-based instructional design integrates all three components simultaneously. Across studies, the relationship between instructional strategies, cognitive load, and learning outcomes reveals a relatively consistent pattern. Strategies that successfully reduced ECL were generally followed by improvements in student learning outcomes. The use of instructional technology designed in accordance with CLT principles, such as AR or interactive digital media, has been shown to effectively reduce irrelevant cognitive load, thereby enabling more effective conceptual understanding (Chen & Chang, 2024; Lai et al., 2019). Similar findings were reported by Agbidiye et al. (2019), who demonstrated that PBL can reduce students' cognitive load while simultaneously improving conceptual understanding in science compared to conventional instruction. This pattern indicates that the effectiveness of instructional strategies is closely associated with their ability to regulate ECL during learning.

On the other hand, several strategies not only reduced ECL but also enhanced GCL by deepening information processing. Approaches such as generative concept mapping and 4C/ID model-based instructional design suggest that strategies promoting active cognitive engagement can strengthen the formation of knowledge schemas (Moshizi et al., 2020; Oh & Kim, 2016). However, correlational research also indicates that excessively high cognitive load is associated with lower conceptual understanding among students. Sabilla et al. (2019) found a significant negative relationship between the two, suggesting that cognitive overload can impede the formation of knowledge schemas. Additional findings indicate that affective factors, such as interest and self-confidence, can moderate this relationship, with students who exhibit high learning interest tending to demonstrate greater capacity to manage complex cognitive demands (Hong et al., 2017; Pramudiyan & Fadhilah, 2024).

Although the various strategies demonstrate potential in managing cognitive load, this analysis also identifies several research gaps. Studies at the primary school level remain relatively limited compared with research at the junior and senior secondary levels, despite the critical role of this phase in establishing foundational conceptual understanding of science. Furthermore, the management of ICL has rarely been an explicit focus compared to efforts to reduce ECL, leaving the dynamics of content complexity in science learning underexplored. The dominance of short-term research designs also limits understanding of the long-term impact of instructional strategies on students' cognitive development. Accordingly, future research should more equitably integrate the management of ICL, ECL, and GCL and explore their implementation across a broader range of educational contexts.

## CONCLUSION

This systematic review affirms that the effectiveness of instructional strategies in science learning is strongly influenced by how effectively the learning design manages students' cognitive load. Cross-study findings indicate that strategies aligned with CLT principles tend to produce more efficient learning processes by reducing irrelevant ECL and facilitating information processing that supports the formation of knowledge schemas. Accordingly, the primary contribution of CLT-based approaches lies not in the use of any particular method or technology, but rather in instructional design's capacity to balance the cognitive demands of the content with students' working memory capacity. This perspective affirms the importance of positioning CLT as an operational learning design framework for developing instructional strategies in science education. Nevertheless, this review also reveals that research on cognitive load management in science learning remains largely partial. Most studies focus on reducing ECL, while the dynamics of ICL and the role of GCL in knowledge schema formation remain underexplored. Furthermore, the limited range of research contexts and the dominance of short-term designs constrain understanding of the sustained impact of instructional strategies on students' cognitive development. It is further acknowledged that this review did not conduct a formal risk-of-bias assessment of the included studies; future reviews on this topic are encouraged to incorporate systematic quality appraisal procedures, such as the Mixed Methods Appraisal Tool (MMAT), to enable more nuanced interpretation of findings in relation to study quality. Future research should therefore develop more integrative approaches to examine interactions among ICL, ECL, and GCL, broaden the implementation context across various educational levels, and employ longitudinal designs to understand the long-term impact of CLT-based instructional strategies on students' conceptual understanding.

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