Cognitive Load Theory and the Design of Effective Educational Materials

1. Introduction

Cognitive Load Theory (CLT) is a foundational framework in educational psychology that informs the design of instructional materials by considering the limitations of human cognitive architecture—specifically, the restricted capacity of working memory and the virtually unlimited capacity of long-term memory (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Sweller et al., 1998; Sweller et al., 2019). CLT distinguishes between intrinsic, extraneous, and germane cognitive load, and provides evidence-based principles to optimize learning by reducing unnecessary mental effort and focusing cognitive resources on schema acquisition and automation (Van Merriënboer & Sweller, 2010; Young et al., 2014; Paas et al., 2003; Sweller et al., 1998; Sweller, 1994; Sweller et al., 2019). Over the past three decades, CLT has generated a wide array of instructional design strategies, such as worked examples, split-attention reduction, modality integration, signaling, and segmenting, which have been empirically validated across diverse educational contexts, including digital, multimedia, and health professions education (Castro-Alonso et al., 2021; Van Merriënboer & Sweller, 2010; Young et al., 2014; Noetel et al., 2021; Sweller et al., 1998; Hadie et al., 2021; Castro-Alonso et al., 2019; Chandler & Sweller, 1991). The theory continues to evolve, integrating insights from neuroscience, technology, and collaborative learning, and remains central to the development of effective, learner-centered educational materials (Hanham et al., 2023; Skulmowski & Xu, 2021; Ginns & Leppink, 2019; Gkintoni et al., 2025; Sweller et al., 2019).

2. Methods

A comprehensive Deep Search was conducted across over 170 million research papers in Consensus, including Semantic Scholar, PubMed, and other databases. The search targeted cognitive load theory, instructional design, and educational material optimization. Out of 1,024 identified papers, 506 were screened, 428 met eligibility criteria, and the 50 most relevant papers were included in this review.

Search Strategy

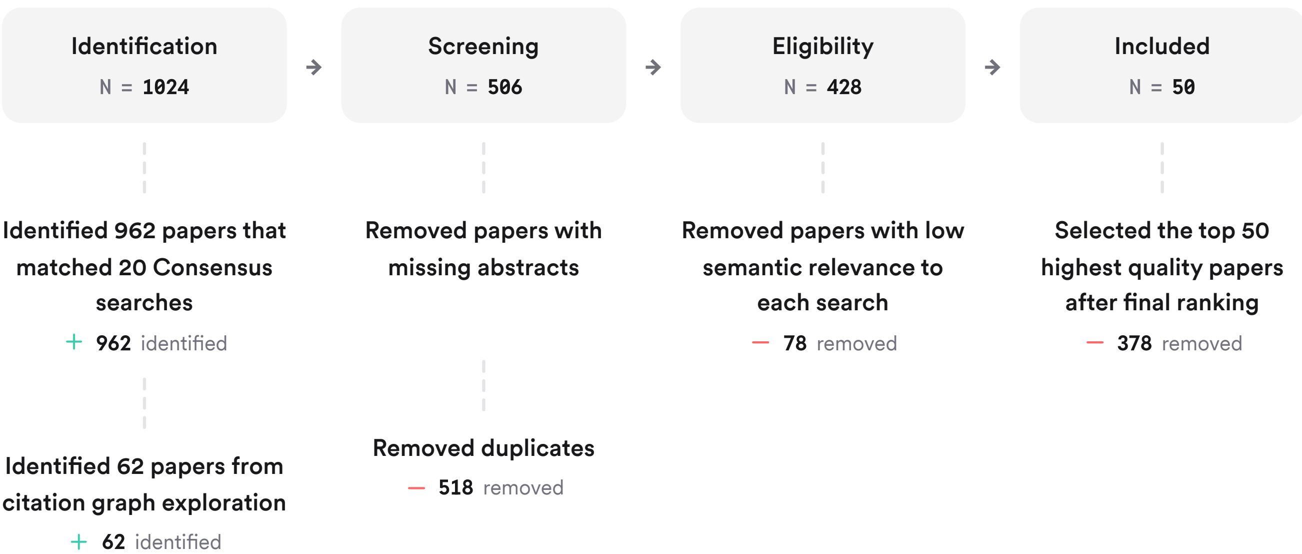

FIGURE 1 Flow diagram of search and selection process.

Twenty unique search strategies were used, focusing on foundational theory, instructional design applications, digital learning, measurement, and interdisciplinary perspectives.

3. Results

3.1 Core Principles of Cognitive Load Theory

CLT is grounded in the understanding that working memory is limited in both capacity and duration, while long-term memory can store complex schemas indefinitely (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Sweller et al., 1998; Sweller et al., 2019). The theory distinguishes:

- **Intrinsic load**: The inherent complexity of the material, determined by element interactivity and learner expertise (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Chen et al., 2023; Sweller, 1994).
- **Extraneous load**: Cognitive effort imposed by poor instructional design, which does not contribute to learning (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Skulmowski & Xu, 2021; Sweller et al., 1998; Chandler & Sweller, 1991).
- **Germane load**: Cognitive resources devoted to schema construction and automation, which should be maximized (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Sweller et al., 1998; Sweller, 1994).

3.2 Instructional Design Strategies Informed by CLT

Empirical research has led to the development of several evidence-based instructional design principles:

- **Worked examples**: Providing step-by-step solutions to problems reduces extraneous load and supports schema acquisition, especially for novices (Van Merriënboer & Sweller, 2010; Young et al., 2014; Paas et al., 2003; Sweller et al., 1998; Chandler & Sweller, 1991).
- **Split-attention and spatial contiguity**: Integrating text and visuals spatially and temporally prevents unnecessary mental integration and reduces extraneous load (Castro-Alonso et al., 2021; Klepsch & Seufert, 2020; Castro-Alonso et al., 2019; Chandler & Sweller, 1991).
- **Redundancy and coherence**: Removing nonessential or repetitive information prevents overload and focuses attention on key concepts (Castro-Alonso et al., 2021; Noetel et al., 2021; Castro-Alonso et al., 2019).
- **Signaling (cueing)**: Highlighting essential information guides attention and improves learning efficiency (Castro-Alonso et al., 2021; Noetel et al., 2021; Castro-Alonso et al., 2019).
- **Segmenting and pacing**: Breaking complex information into manageable segments allows learners to process material at their own pace, reducing overload (Castro-Alonso et al., 2021; Noetel et al., 2021; Castro-Alonso et al., 2019).
- **Modality effect**: Presenting information using both visual and auditory channels can optimize working memory use (Castro-Alonso et al., 2021; Castro-Alonso et al., 2019).

3.3 Applications in Digital and Multimedia Learning

CLT principles are especially relevant in digital and multimedia environments, where the risk of cognitive overload is high due to complex, interactive, or multimedia content (Castro-Alonso et al., 2021; Skulmowski & Xu, 2021; Noetel et al., 2021; Surbakti et al., 2024; Castro-Alonso et al., 2019). Studies show that applying CLT-based design (e.g., segmenting, signaling, reducing redundancy) in online and technology-enhanced learning environments improves comprehension, engagement, and retention (Castro-Alonso et al., 2021; Skulmowski & Xu, 2021; Noetel et al., 2021; Surbakti et al., 2024; Hadie et al., 2021; Castro-Alonso et al., 2019; Chandler & Sweller, 1991).

3.4 Adaptation to Learner Expertise and Context

The **expertise reversal effect** highlights that instructional techniques effective for novices may become less effective or even detrimental for advanced learners, necessitating adaptive instructional design (Castro-Alonso et al., 2021; Young et al., 2014; Paas et al., 2003; Leppink & Van Den Heuvel, 2015; Kalyuga & Singh, 2016). CLT also informs collaborative and simulation-based learning, emphasizing the need to manage collective cognitive load and support schema construction in complex, real-world tasks (Kirschner et al., 2018; Fraser et al., 2015; Wasfy et al., 2021).

Key Papers

Paper	Methodology	Focus/Context	Key Results
(Van Merriënboer & Sweller, 2010)	Review	Health professional education	CLT principles guide design by managing intrinsic, extraneous, and germane load
(Castro-Alonso et al., 2021)	Review	Multimedia learning	Five key strategies: multimedia, split-attention, redundancy, signaling, segmenting
(Sweller et al., 1998)	Seminal review	Instructional design	CLT provides guidelines for reducing working memory load and encouraging schema construction
(Sweller et al., 2019)	Review	20 years of CLT	Summarizes advances and instructional procedures based on cognitive architecture
(Chandler & Sweller, 1991)	Experimental	Split-attention effect	Integrated instructions reduce cognitive load and improve learning outcomes

FIGURE 2 Comparison of key studies on cognitive load theory and instructional design.

Top Contributors

Type	Name	Papers
Author	J. Sweller	(Sweller, 2019; Van Merriënboer & Sweller, 2010; Paas et al., 2003; Abkemeier, 2020; Sweller, 2021; Sweller et al., 1998; Chen et al., 2023; Sweller, 1994; Sweller, 2016; Sweller et al., 2019; Castro-Alonso et al., 2019; Chandler & Sweller, 1991)
Author	J. V. van Merriënboer	(Van Merriënboer & Sweller, 2010; Young et al., 2014; Merriënboer & Ayres, 2005; Sweller et al., 1998; Chen et al., 2023; Leppink & Van Den Heuvel, 2015; Sweller et al., 2019)
Author	F. Paas	(Castro-Alonso et al., 2021; Paas et al., 2003; Paas & Van Merriënboer, 2020; Sweller et al., 1998; Chen et al., 2023; Chen et al., 2018; Sweller et al., 2019; Castro-Alonso et al., 2019; Paas et al., 2004)
Journal	*Educational Psychology Review*	(Castro-Alonso et al., 2021; Sweller, 2021; Sweller et al., 1998; Chen et al., 2023; Sweller, 1994; Chen et al., 2018; Kalyuga & Singh, 2016; Sweller et al., 2019; Schnotz & Kürschner, 2007; Paas et al., 2004)
Journal	*Instructional Science*	(Klepsch & Seufert, 2020; Jong, 2010; Paas et al., 2004)
Journal	*Medical Education*	(Van Merriënboer & Sweller, 2010; Young et al., 2014)

FIGURE 3 Authors & journals that appeared most frequently in the included papers.

4. Discussion

Cognitive Load Theory has profoundly shaped the design of effective educational materials by providing a scientific basis for instructional decisions that align with human cognitive architecture (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Sweller et al., 1998; Sweller et al., 2019). The theory's distinction between intrinsic, extraneous, and germane load enables designers to systematically analyze and optimize learning tasks, reducing unnecessary mental effort and maximizing schema acquisition (Van Merriënboer & Sweller, 2010; Paas et al., 2003; Sweller et al., 1998; Sweller, 1994). Empirical evidence supports the effectiveness of CLT-based strategies—such as worked examples, split-attention reduction, signaling, and segmenting—across a wide range of domains and delivery formats (Castro-Alonso et al., 2021; Van Merriënboer & Sweller, 2010; Young et al., 2014; Noetel et al., 2021; Sweller et al., 1998; Hadie et al., 2021; Castro-Alonso et al., 2019; Chandler & Sweller, 1991).

However, CLT is not without limitations. Some critics argue that the theory can be overly prescriptive or reductionist, and that reducing cognitive load is not always beneficial—some productive struggle may enhance learning in certain contexts (Jong, 2010; Kalyuga & Singh, 2016; Schnotz & Kürschner, 2007). The theory continues to evolve, incorporating insights from neuroscience, adaptive learning, and collaborative contexts, and ongoing research seeks to refine measurement tools and address challenges such as the expertise reversal effect and the integration of affective and motivational factors (Hanham et al., 2023; Skulmowski & Xu, 2021; Ginns & Leppink, 2019; Gkintoni et al., 2025; Sweller et al., 2019; Firdaus et al., 2025).

Claims and Evidence Table

Claim	Evidence Strength	Reasoning	Papers
CLT provides effective instructional design principles that improve learning	Strong	Supported by decades of empirical research and meta-analyses	(Castro-Alonso et al., 2021; Van Merriënboer & Sweller, 2010; Young et al., 2014; Paas et al., 2003; Sweller et al., 1998; Sweller et al., 2019; Castro-Alonso et al., 2019; Chandler & Sweller, 1991; Paas et al., 2004)
Reducing extraneous cognitive load enhances learning outcomes	Strong	Consistent findings across domains and delivery formats	(Castro-Alonso et al., 2021; Van Merriënboer & Sweller, 2010; Young et al., 2014; Paas et al., 2003; Sweller et al., 1998; Hadie et al., 2021; Castro-Alonso et al., 2019; Chandler & Sweller, 1991)
Instructional strategies must be adapted to learner expertise (expertise reversal effect)	Strong	Evidence that novices and experts benefit from different approaches	(Castro-Alonso et al., 2021; Young et al., 2014; Paas et al., 2003; Leppink & Van Den Heuvel, 2015; Kalyuga & Singh, 2016)
CLT-based design is especially important in digital/multimedia environments	Strong	Digital content increases risk of overload; CLT strategies mitigate this	(Castro-Alonso et al., 2021; Skulmowski & Xu, 2021; Noetel et al., 2021; Surbakti et al., 2024; Hadie et al., 2021; Castro-Alonso et al., 2019; Chandler & Sweller, 1991)
Some productive cognitive struggle can be beneficial	Moderate	Emerging research suggests not all cognitive load is detrimental	(Jong, 2010; Kalyuga & Singh, 2016; Schnotz & Kürschner, 2007)

FIGURE Key claims and support evidence identified in these papers.

5. Conclusion

Cognitive Load Theory offers a robust, evidence-based framework for designing effective educational materials by aligning instructional strategies with the realities of human cognitive architecture. Its principles have been widely validated and are especially critical in complex, digital, and multimedia learning environments.

5.1 Research Gaps

Despite its strengths, further research is needed to refine CLT's application in adaptive, collaborative, and affective learning contexts, and to develop more nuanced measurement tools for cognitive load in diverse educational settings.

Research Gaps Matrix

Topic/Outcome	Digital Learning	Health Professions	Novice Learners	Adaptive/AI Systems	Collaborative Learning
CLT-based Design Principles	18	10	14	7	8
Expertise Reversal Effect	7	5	8	4	6
Measurement/Assessment	9	6	7	3	5

FIGURE Matrix of research topics and study attributes, highlighting areas with limited research.

5.2 Open Research Questions

Future research should explore how CLT can be integrated with adaptive technologies, collaborative learning, and affective factors to further enhance instructional design.

Question	Why
How can CLT principles be dynamically adapted in real-time by AI-driven educational systems?	Adaptive systems could personalize cognitive load management for individual learners.
What are the best strategies for applying CLT in collaborative and group-based learning environments?	Collaboration introduces new cognitive demands that may require tailored design principles.
How can cognitive load measurement be improved to capture affective and motivational factors in learning?	Integrating emotion and motivation could lead to more holistic and effective instructional design.

FIGURE Open research questions for future investigation on cognitive load theory and instructional design.

In summary, cognitive load theory remains a cornerstone for designing effective educational materials, with ongoing research expanding its reach and refining its application for diverse and evolving learning environments.

These papers were sourced and synthesized using Consensus, an AI-powered search engine for research. Try it at https://consensus.app

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