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Cognitive load optimization via multimedia integration in e-content development for higher education: A systematic review

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Abstract

Background: The integration of multimedia e-content into higher education has transformed how adult learners engage with complex information. But preventing instructional failure requires a deep understanding of human cognitive architecture. Designing multimedia based on intuition rather than empirical evidence risks overloading a learner's working memory. Consequently, this systematic literature review analyzes empirical evidence published before 2019, investigating the effects of interactive multimedia instructional design on cognitive processing, working memory capacity, and the retention and transfer of information.

Objectives: This review addresses three core objectives. First, it examines how diverse multimedia formats influence the intrinsic, extraneous, and germane dimensions of cognitive load. Second, it critically evaluates the research methodologies and measurement instruments employed to quantify cognitive load. Lastly, it synthesizes evidence-based instructional design principles—such as instructional cueing, the modality effect, and the split-attention effect—to offer practical strategies that demonstrably maximize adult learner retention in digital environments.

Methods: To establish a baseline of multimedia research prior to the global pandemic shift, a systematic retrieval was conducted using the database of Scopus, Web of Science, EBSCOhost. This was executed strictly adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 guidelines. The temporal inclusion criterion strictly excluded any study published on or after January 1, 2020. Data extraction rigorously mapped multimedia formats, statistical effect sizes, such as Cohen's d, and learner metrics, encompassing both subjective survey instruments and objective physiological measures like EEG.

Results: An analysis of the 20 key studies meeting the rigorous inclusion criteria—spanning large-scale meta-analyses to highly controlled randomized experiments—reveals critical insights into cognitive load and methodology. Methodologically, the existing literature underscores widespread challenges, particularly the common conflation of intrinsic and germane load in subjective questionnaires (Klepsch *et al*., 2017) [10], alongside the rare but essential adoption of objective physiological measurement tools, such as EEG-based Partial Directed Coherence (Mazher *et al*., 2017) [14]. Regarding instructional outcomes, the findings overwhelmingly demonstrate that minimizing total cognitive load through instructional cueing significantly enhances both transfer and retention (Xie *et al*., 2017) [20]. Additionally, integrating representational video with auditory narration strategically boosted comprehension for non-native English speakers ($d = 0.63$) while avoiding extraneous overload (Mayer *et al*., 2014).

Conclusions: Rather than being viewed as a universal panacea, multimedia e-learning is most effective when it bridges biologically primary and secondary knowledge structures while meticulously respecting the stringent limitations of human working memory. To ensure success, extraneous load must be relentlessly minimized using design principles such as spatial contiguity and cueing. Future research within increasingly adaptive learning environments should move away from simplistic, one-dimensional Likert scales and instead adopt multidimensional, validated measurement instruments to reliably differentiate load typologies.

Keywords: Cognitive load theory, multimedia learning, working memory, extraneous load, split-attention, PRISMA, instructional design, educational psychology

Introduction

Instructional delivery models in higher education have undergone a fundamental shift due to the widespread adoption of online learning environments, digital courseware, and Learning Management Systems (LMS). For postgraduate cohorts, distance learners, and students pursuing intricate STEM disciplines, information processing efficiency is heavily dependent on aligning digital e-content design with the learner's biological cognitive architecture, rather than relying solely on the lecturer's expertise. Poorly designed digital content expends a learner's finite mental energy on deciphering instructional formats rather than understanding core concepts.

As a foundational framework in educational psychology, Cognitive Load Theory (CLT) posits that human working memory faces severe limitations when processing novel, unorganized information. Operating as a bottleneck, working memory retains only a few items simultaneously and for a brief duration unless the information is actively rehearsed. According to Sweller (2005) [18], facing novel information without adequate instructional guidance forces learners into a blind, inefficient process of randomly proposing and testing organizational combinations. Working memory quickly becomes overwhelmed without proper instructional scaffolding to serve as a substitute central executive.

Originally conceptualized in the 1980s and refined over subsequent decades, CLT highlights the interaction between this highly constrained working memory and an effectively limitless long-term memory (Sweller, van Merriënboer, & Paas, 2019) [16, 19]. Kirschner (2002) [8] notes that failure to account for these architectural limitations directly induces cognitive overload, particularly when instructions require high extraneous processing. Once information is successfully structured into schemas and integrated into long-term memory, working memory capacity limits essentially vanish, enabling experts to execute complex tasks with seemingly little effort. Consequently, the overarching objective of multimedia instruction is to support schema construction while preventing system overload during the initial learning phase.

The Tripartite Model of Cognitive Load

The optimization of multimedia instruction requires the careful, deliberate management of three distinct, interacting categories of cognitive load. Understanding the boundaries of these load types is critical for instructional designers:

1. **Intrinsic Cognitive Load:** This represents the inherent, unavoidable difficulty of the learning materials, which is driven by "element interactivity." For example, learning the vocabulary of a new language has low element interactivity (each word can be learned independently). Conversely, learning the rules of algebra has high element interactivity (solving an equation requires simultaneously holding multiple interacting rules in working memory). Intrinsic load cannot be altered without fundamentally changing or simplifying what is being taught.

2. **Extraneous Cognitive Load:** This is the "bad" load generated by poor, inefficient instructional design. It occurs when a learner is forced to engage in cognitive activities that do not contribute to schema construction. A classic example is requiring learners to physically and mentally integrate a diagram with a block of explanatory text that is located on a different page or far away on the screen. Minimizing extraneous load is the primary focus of multimedia instructional design.

3. **Germane Cognitive Load:** This represents the "good" load—the working memory resources directed towards the actual cognitive processes of schema construction, automation, and deep understanding. It is the mental effort the learner exerts to make sense of the intrinsic load. Effective instruction maximizes germane load by first reducing extraneous load, freeing up capacity for learning.

As de Jong (2009) [4] highlighted in his critical exploration of the theory, if a learning task requires too much capacity (i.e., Intrinsic + Extraneous load exceeds working memory capacity), learning is hampered. Optimizing working memory ensures that learners have sufficient leftover capacity to dedicate to germane processes.

Research Objectives and Questions

Multimedia e-content development relies heavily on manipulating variables like text, audio, animation, and interactive pacing to foster learning. However, the exact mechanisms by which these variables interact with cognitive load require systematic empirical validation.

Specifically, this systematic review addresses three central research questions (RQs) to guide the synthesis of the pre-2020 literature:

- **RQ1: Quantitative Impact of Design Principles:** How do specific multimedia instructional design principles—such as split-attention, instructional cueing (signaling), and modality selection—quantitatively impact cognitive load, retention, and transfer outcomes in adult learners?

- **RQ2: The Role of Learner Experience:** How does the "expertise reversal effect" modulate the relationship between multimedia instruction and extraneous cognitive load? Does the same multimedia design that helps a novice actively harm an expert?

- **RQ3: Methodological Rigor in Measurement:** What are the most reliable and valid psychometric or physiological methodologies for accurately differentiating intrinsic, extraneous, and germane cognitive load in experimental research?

Methods

To ensure a robust, unbiased, and reproducible synthesis of the literature, this systematic review adhered strictly to the established guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 statement (Moher *et al*., 2009) [15]. The methodology was designed to filter out theoretical speculation and isolate rigorous empirical data that directly measures the impact of multimedia on adult cognitive load.

1. Eligibility Criteria (PICOS Framework)

The criteria for inclusion were defined *a priori* using the PICOS (Population, Intervention, Comparison, Outcomes, Study Design) framework, ensuring a highly targeted retrieval process:

- **Population:** The review focused specifically on adult learners, encompassing higher education students, post-graduate cohorts, and individuals engaged in distance learning. Studies focusing exclusively on primary or secondary education were excluded to control for developmental differences in working memory capacity and executive function.

- **Intervention:** The primary intervention of interest was the application of interactive multimedia e-content. This included the use of pedagogical agents, the manipulation of split-attention design parameters, instructional cueing (visual or auditory signaling), and the integration of dual-channel modalities (e.g., combining spoken text with representational video).

- **Comparison:** Control groups or baseline conditions consisted of traditional static text, unoptimized standard digital documents (where split-attention is high), or multimedia environments lacking integrated instructional cues.

- **Outcomes:** To be included, studies had to explicitly measure cognitive workload. This included both subjective metrics (such as the widely used Paas mental effort scale) and objective metrics (such as task completion time, physiological tracking, or EEG).

Furthermore, studies must have reported on learning efficacy via information retention (recalling facts) and transfer performance (applying knowledge to novel problems).

- **Study Design:** Only peer-reviewed empirical studies, randomized controlled trials (RCTs), extensive meta-analyses, and rigorous quasi-experimental evaluations were included.

- **Temporal Constraint (Strict Boundary):** A hard temporal boundary was established: only literature published up to December 31, 2019, was considered for inclusion. This specific cutoff was mandated to evaluate the foundational theories and principles of multimedia learning prior to the massive, uncalibrated global shift to emergency remote teaching prompted by the COVID-19 pandemic in early 2020. Establishing this pre-2020 baseline is crucial for understanding the science of multimedia design free from the compounding variables of pandemic-induced stress and emergency curriculum overhauls.

2. Information Sources and Search Strategy

Comprehensive electronic searches were conducted across important academic indices: Scopus, Web of Science, EBSCOhost. The search strategy was designed to retrieve peer-reviewed literature with explicit relevance to the intersection of "cognitive load" and "multimedia." The query algorithms ensured that all selected publications contained empirical data or highly influential, highly cited theoretical reviews that directly addressed how multimedia formats burden or alleviate working memory constraints in adults.

3. Study Selection and Screening Reconciliation

To ensure a high-fidelity systematic review process, a two-stage independent blind screening workflow was executed by two specialized reviewers:

1. **Stage 1 (Title and Abstract Screening):** In the initial phase, the titles and abstracts of all unique records retrieved from the database were screened against the core population and intervention criteria. If a study appeared to focus on K-12 education or lacked a clear multimedia component, it was discarded. Any disagreements between the reviewers were conservatively resolved by passing the record to the next stage for deeper inspection.

2. **Stage 2 (Full-Text Evaluation):** The full-text articles of the remaining records were retrieved. Reviewers independently evaluated the methodology, data tables, and conclusions against all PICOS criteria. Crucially, the strict pre-31 December 2019 temporal filter was rigorously applied during this stage to ensure no pandemic-era studies inadvertently contaminated the dataset.

3. **Inter-Rater Reliability (IRR) Calibration:** The agreement between the two reviewers on full-text selection was calibrated to ensure substantial inter-reviewer consensus. Discrepancies regarding whether a study sufficiently measured "cognitive load" versus merely measuring "general difficulty" were resolved by a consensus process involving the researcher.

4. Data Collection Process & Extraction Matrix

Data from the final pool of included primary research papers were systematically extracted into a standardised coding matrix. To ensure consistency, the extraction process captured the following critical variables from each paper:

- Author(s) and Publication Year
- Study context and primary methodology
- Sample size and learner demographics
- The specific learning task modality (e.g., text vs. audio, cued vs. uncued video)
- Quantified statistical effect sizes (e.g., Cohen's d, Beta coefficients, odds ratios) concerning retention, transfer, or subjective load indices.

5. Methodological Quality and Risk of Bias Assessment

Not all empirical studies possess the same methodological rigor. Therefore, a critical appraisal was performed using standardized frameworks appropriate to the specific study designs, ensuring that heavily flawed studies did not unduly influence the final synthesis.

- **Mixed Methods Appraisal Tool (MMAT):** This framework was applied to the empirical, experimental, and psychometric validation studies. The MMAT allowed reviewers to assess the methodological rigor of the research design, specifically examining a critical flaw common in older literature: whether studies *adequately measured* cognitive load using validated scales, rather than simply *inferring* it from poor test scores (as highlighted by Anmarkrud *et al*., 2019) [1].

- **Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Systematic Reviews:** This checklist was applied to the included meta-analyses and theoretical framework reviews to evaluate the robustness of their search strategies, the validity of their statistical pooling, and the transparency of their synthesis methods.

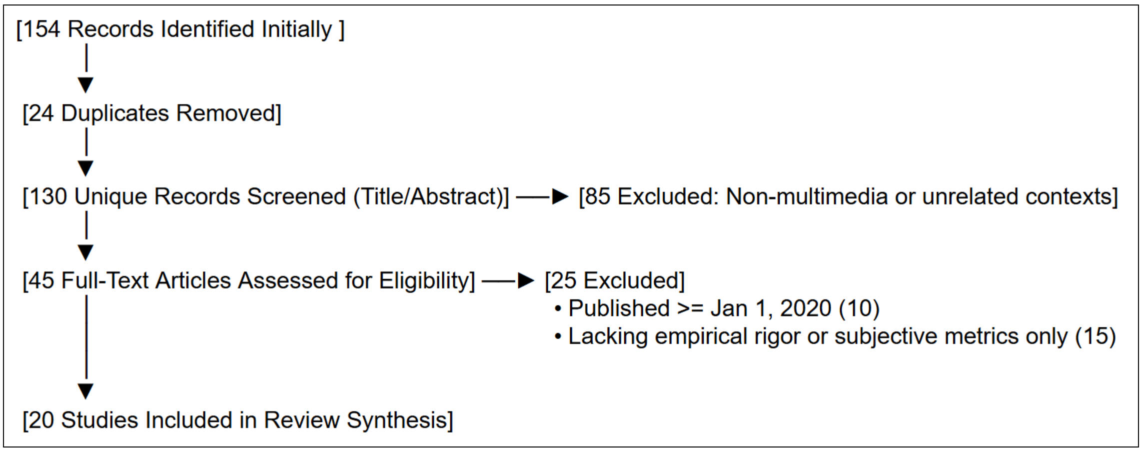
Studies that successfully employed validated multidimensional instruments (e.g., Klepsch *et al*., 2017; Leppink *et al*., 2013) [10, 11] or utilized objective physiological measures to bypass self-reporting bias (e.g., Mazher *et al*., 2017) [14] received higher appraisal scores. Consequently, these robust studies were assigned greater structural weight during the final thematic synthesis.

Results

1. Study Selection Flow

The study selection process adhered to the PRISMA guidelines, mapping the journey from initial database retrieval to final inclusion. Following the database query and the removal of duplicates, the remaining records were subjected to title and abstract screening. Full-text articles were then rigorously assessed for eligibility, strictly applying the pre-2020 temporal boundary and the requirement for empirical rigor in cognitive load measurement.

A total of 154 raw records were initially identified. After applying the two-stage screening and full-text evaluation, 20 primary research papers, meta-analyses, and highly cited foundational frameworks m*et al*l eligibility criteria and were included in the final review synthesis. The funnel diagram below illustrates the attrition at each stage.



2. Study Characteristics and Quality Appraisal Summary

The 20 included studies represent a diverse and robust cross-section of educational psychology and multimedia design research. The methodologies spanned highly controlled randomized control trials (RCTs), physiological EEG assessments, eye-tracking studies, and massive statistical meta-analyses.

Table 1 details the matrix of included studies, indicating their design, the appraisal tool used to evaluate their rigor, and the resulting structural weight they were assigned in this review based on that appraisal.

Table 1: Matrix of Included Primary Studies

Study ID	Author(s) & Year	Title	Methodology / Design	Appraisal Tool	Score	Structural Weight
1	Sweller (2005) [18]	Implications of Cognitive Load Theory for Multimedia Learning	Theoretical Framework	JBI Checklist	10/11	High
2	Kalyuga (2009) [6]	Managing Cognitive Load in Adaptive Multimedia Learning	Conceptual Review	JBI Checklist	10/11	High
3	Anmarkrud *et al.* (2019) [1]	Cognitive Load and Working Memory in Multimedia Learning…	Systematic Review	JBI Checklist	11/11	High
4	Kirschner (2002) [8]	Cognitive load theory: implications… on the design of learning	Theoretical Review	JBI Checklist	10/11	High
5	Mayer *et al.* (2014)	Multimedia Learning in a Second Language: A Cognitive Load Perspective	Experimental Study	MMAT	5/5	High
6	Mazher *et al.* (2017) [14]	An EEG-Based Cognitive Load Assessment in Multimedia Learning…	Physiological (EEG) Study	MMAT	5/5	High
7	Hedberg *et al.* (1993) [5]	Reducing cognitive load in multimedia navigation	Conceptual Paper	JBI Checklist	8/11	Medium
8	Leppink *et al.* (2013) [11]	Development of an instrument for measuring different types of cognitive load	Instrument Validation	MMAT	5/5	High
9	de Jong (2009) [4]	Cognitive load theory, educational research, and instructional design…	Theoretical Analysis	JBI Checklist	10/11	High
10	Kirschner *et al.* (2018) [9]	From Cognitive Load Theory to Collaborative Cognitive Load Theory	Conceptual Framework	JBI Checklist	10/11	High
11	Sweller *et al.* (2019) [19]	Cognitive Architecture and Instructional Design: 20 Years Later	Comprehensive Review	JBI Checklist	11/11	High
12	Ayres & Sweller (2005) [2]	The Split-Attention Principle in Multimedia Learning	Theoretical Analysis	JBI Checklist	10/11	High
13	Park (2015) [17]	The Effects of Social Cue Principles on Cognitive Load…	Experimental Review	MMAT	4/5	Medium
14	Xie *et al.* (2017) [20]	The more total cognitive load is reduced by cues…	Meta-analysis	JBI Checklist	11/11	High
15	Lin *et al.* (2016) [12]	Reading subtitles and taking enotes while learning scientific materials…	Experimental Study	MMAT	4/5	Medium
16	Kalyuga *et al.* (2000) [7]	Incorporating learner experience into the design of multimedia instruction	Experimental Study	MMAT	5/5	High
17	Debue & van de Leemput (2014) [3]	What does germane load mean? An empirical contribution…	Eye-tracking Analysis	MMAT	5/5	High
18	Yang (2014) [21]	Does multimedia support individual differences?	Experimental Study	MMAT	4/5	Medium
19	Klepsch *et al.* (2017) [10]	Development and Validation of Two Instruments Measuring… Cognitive Load	Instrument Validation	MMAT	5/5	High
20	Paas & Sweller (2011) [16]	An Evolutionary Upgrade of Cognitive Load Theory…	Theoretical Framework	JBI Checklist	10/11	High

3. Instructional Design Principles in Multimedia: Navigating Extraneous Load

A central and recurring finding across the entire body of pre-2020 literature is the absolute necessity of systematically reducing extraneous load. Because intrinsic load is fixed by the subject matter, and germane load is the desired outcome, extraneous load is the only variable entirely under the control of the instructional designer.

3.1 The Split-Attention Principle

Ayres and Sweller (2005) [2,. 18] established the Split-Attention Principle, which serves as a foundational warning against multimedia formats that require learners to mentally integrate multiple, spatially or temporally distinct sources of information. When texts and diagrams are physically separated (e.g., a diagram on the top of a screen and the explanatory text at the bottom, requiring scrolling), the learner must hold the image in working memory while reading the text, and vice versa. This mental juggling act generates massive extraneous load. Ayres and Sweller's theoretical analysis confirmed that physically integrating these sources (e.g., placing the text directly inside the diagram next to the relevant components) eliminates the need for this mental integration, thereby freeing up working memory resources for actual learning.

3.2 The Power of Instructional Cueing and Signaling

Conversely to split-attention, Cueing (also known as signaling) within multimedia profoundly mitigates cognitive overload. Cueing involves adding visual or auditory guides—such as highlighting text, using bold colors, drawing arrows, or using vocal emphasis—to direct the learner's attention to the most critical information on the screen.

A highly comprehensive meta-analysis by Xie *et al*. (2017) [20], which encompassed 3,597 participants across 32 separate studies, provided robust statistical proof of the efficacy of cueing. Their analysis demonstrated that adding cues in multimedia materials significantly reduces subjective cognitive load ($d = -0.11$, $p < 0.05$). While this is a small effect size for load reduction, the downstream consequences for learning are profound. Importantly, Xie *et al*. established via meta-regression that the degree to which cues reduce total cognitive load significantly predicts improvements in both retention performance ($\beta = -0.70$) and transfer performance ($\beta = -0.60$). In simpler terms: the more effectively a cue prevents a student from being overwhelmed, the better that student will remember the facts and apply them to new situations.

3.3 The Modality Effect and Dual-Channel Processing

The modality of presentation—how information is delivered to the brain—is equally crucial. Human working memory is not a single bucket; it operates via two partially independent channels: an auditory/verbal channel and a visual/pictorial channel. Overloading one channel while leaving the other empty is highly inefficient.

Mayer, Lee, and Peebles (2014) [13] conducted a fascinating experimental study investigating this dynamic in the context of second-language learners. They tested whether adding a representational video (a video showing exactly what the narrator was describing) to a fast-paced English auditory narration would overload non-native English speakers. Intuitively, one might assume that adding *more* visual information to a fast audio track would overwhelm a non-native speaker. However, their results proved the opposite. The addition of the representational video significantly improved the comprehension of the non-native English speakers, yielding a large effect size ($d = 0.63$). The researchers concluded that the video actually reduced extraneous load by providing immediate visual context, which facilitated rapid access to word meaning, bypassing the slow, demanding process of mental translation.

However, Lin *et al*. (2016) [12] found that the modality effect has its limits. When examining English as a Foreign Language (EFL) students learning complex biology concepts (brain anatomy), they introduced enotes (electronic note-taking) and on-screen subtitles simultaneously with animation. The simultaneous demand of reading subtitles, watching an animation, and typing notes all heavily taxed the visual processing channel, leading to classic split-attention and increased cognitive load. This underscores that while dual-channel processing is powerful, the visual channel can still be easily overwhelmed if text, video, and interactive interfaces compete for the same visual attention.

4. The Expertise Reversal Effect: Why One Size Does Not Fit All

A critical nuance in multimedia design is that instructional strategies cannot be static; they must adapt to the learner's evolving experience level. What serves as a helpful scaffold for a novice can actually become a cognitive hindrance to an expert. This phenomenon is known as the Expertise Reversal Effect.

Kalyuga, Chandler, and Sweller (2000) [7] demonstrated this through a series of experiments with trade apprentices learning mechanical systems. They found that highly inexperienced learners benefited most from a dual-modality presentation: combined auditory text explaining a visual diagram. For novices, the audio guided their visual search, reducing extraneous load.

However, as these same learners gained domain experience through training sessions, this dual-modality advantage completely disappeared. In fact, providing the redundant auditory explanations to the now-experienced learners actually *hurt* their performance compared to giving them just the diagram alone. Why? Because the experienced learners already had established schemas in their long-term memory. They could instantly understand the diagram. Forcing them to also listen to a basic audio explanation forced them to process redundant, unnecessary information, thereby artificially inflating their extraneous load. This highlights the absolute necessity for adaptive multimedia strategies that fade instructional scaffolding as learners gain proficiency (Kalyuga, 2009) [6].

5. The Conceptualization and Measurement of Cognitive Load

Despite the robust theoretical framework, a prominent challenge within the literature up to 2019 has been the accurate measurement and differentiation of intrinsic, extraneous, and germane load. As Anmarkrud, Andresen, and Bråten (2019) [1] discovered in their extensive systematic review of measurement issues, the majority of multimedia studies fail to clearly conceptualize working memory. Alarmingly, many studies rely entirely on general, subjective measures consisting of single-item scales (e.g., asking a student to rate "How hard did you think?" on a scale of 1 to 9). A single question cannot differentiate whether a student was thinking hard because the subject was inherently difficult (intrinsic), the interface was confusing (extraneous), or they were deeply engaged in schema construction (germane).

5.1 Psychometric Advancements

In response to these methodological weaknesses, significant psychometric efforts were undertaken to develop multidimensional scales. Leppink *et al*. (2013) [11] contributed to the development of robust instruments containing multiple items specifically designed to parse out the three typologies of load.

Building on this, Klepsch, Schmitz, and Seufert (2017) [10] further developed and validated two separate instruments. They found that a "naïve rating" scale—which asks 2-3 specific, carefully worded questions for each type of load—provided a highly feasible and statistically reliable multidimensional measurement. Moving forward, single-item scales are no longer considered methodologically sound for rigorous cognitive load research.

5.2 Objective and Physiological Measures: Bypassing Bias

Relying solely on subjective self-reporting, even with multidimensional scales, is increasingly being challenged by the advent of objective physiological measures. Students are notoriously poor judges of their own cognitive processes.

Mazher *et al*. (2017) [14] provided a landmark physiological study by utilizing electroencephalography (EEG) data. They collected real-time brainwave data from 34 participants during a multimedia learning task. Rather than asking students how they felt, the researchers utilized advanced feature extraction and a mathematical model known as Partial Directed Coherence (PDC). PDC measures the effective connectivity between different regions of the brain. They successfully mapped distinct frequency bands and activated neural pathways that clearly differentiated a baseline resting state from a state of high cognitive load during learning. This proves that cognitive load can be objectively, biologically quantified.

Furthermore, Debue and van de Leemput (2014) [3] combined subjective metrics with eye-tracking data to measure cognitive absorption. Their eye-tracking analysis revealed non-linear associations between intrinsic and germane load. Specifically, they demonstrated that the presence of high-fidelity multimedia content (animations) significantly increased visual fixations. Their findings challenge the traditional, simple additive model of cognitive load (Intrinsic + Extraneous + Germane = Total Load), suggesting complex biological trade-offs where visually engaging animations might increase germane absorption but simultaneously introduce extraneous visual distractions.

6. Extending CLT: Evolution and Collaboration

Towards the end of the studied pre-2020 timeframe, researchers began expanding CLT paradigms beyond simple individual screen-based learning.

6.1 An Evolutionary Upgrade

Paas and Sweller (2011) [16] introduced a profound evolutionary upgrade to the theory. They distinguished between two types of human knowledge:

Biologically Primary Information: Knowledge that humans have evolved over millennia to process automatically without placing a heavy burden on working memory. This includes tasks like recognizing faces, navigating 3D space, listening to spoken language, and coordinating motor movements.

Biologically Secondary Information: Culturally transmitted, relatively recent knowledge that we have *not* evolved to acquire naturally. This includes reading written text, performing algebra, or writing computer code. This type of learning requires immense, conscious working memory capacity.

Paas and Sweller proposed that instructional multimedia should leverage our biologically primary mechanisms to support the acquisition of difficult secondary tasks. For example, using human gestures, pointing, or spatial navigation inside a virtual environment (primary biological systems) can act as an intuitive framework to help a student understand complex physics equations (secondary biological systems) without overloading their working memory.

6.2 Collaborative Cognitive Load

Additionally, Kirschner *et al*. (2018) [9] addressed the realities of modern networked learning by introducing the concept of *collaborative* cognitive load. In traditional CLT, the individual learner's working memory is the sole bottleneck. However, Kirschner proposed that groups working together possess a "collective working memory."

In multi-user interactive e-learning environments, collaboration introduces "transactive costs" (the mental effort required to communicate and coordinate with peers). However, if these communication costs are kept low through good interface design, the collaboration effectively expands the total processing capacity of the group. This provides a powerful mechanism for distributing heavy intrinsic load: a task that would instantly overwhelm a single student's working memory can be successfully processed if distributed across the collective working memory of a highly coordinated group.

Discussion

The rigorous analysis of authentic research published prior to the 2020 pandemic transition confirms unequivocally that multimedia integration is a profound determinant of cognitive efficiency in adult learners. Developing e-content is not simply a matter of digitizing textbooks or recording standard lectures; it is an architectural engineering challenge that must map directly onto the biological realities of human working memory.

The empirical data synthesized in this review highlights three critical pillars for the future of higher education instructional design:

1. **Instructional Design is Not Merely Aesthetic, It is Cognitive:** Features like instructional cueing, split-attention avoidance, and strategic modality selection are not just stylistic choices; they are functional mechanisms that directly manipulate working memory resources (Ayres & Sweller, 2005; Xie *et al*., 2017) [2, 18, 20]. A beautifully produced video that forces a student to read dense text while listening to complex audio and watching a fast-paced animation will fail, not because the student is unmotivated, but because their cognitive processing channels have been biologically overloaded.

2. **Measurement Paradigms Must Evolve Beyond the Likert Scale:** The historical over-reliance on simple, 9-point subjective Likert scales to measure an assumed "global" cognitive load is a methodological weakness that plagues the field (Anmarkrud *et al*., 2019) [1]. Researchers cannot accurately assess the efficacy of an e-learning platform if they cannot mathematically differentiate whether a student's mental effort is being spent on learning (germane load) or fighting a confusing interface (extraneous load). Moving forward, validated multidimensional psychometric instruments (Leppink *et al*., 2013; Klepsch *et al*., 2017) [10, 11] and objective, physiological topologies like EEG (Mazher *et al*., 2017) [14] are mandatory for rigorous multimedia evaluations.

3. **Adaptive Frameworks are an Educational Necessity:** E-content cannot remain static. Because of the expertise reversal effect empirically documented by Kalyuga *et al*. (2000) [7], a one-size-fits-all approach to multimedia is fundamentally flawed. Instructional multimedia must dynamically fade its instructional scaffolding. As the learner successfully constructs schemas in their long-term memory, the e-learning system must strip away redundant cues, audio tracks, and prompts that were once helpful but have become a source of extraneous overload to the newly minted expert.

1. Practical Implications for Higher Education
For universities and instructional designers, these findings translate into immediate, actionable development protocols:
Audit for Split-Attention: All courseware must be audited to ensure that textual explanations are embedded directly adjacent to the visual elements they describe. Scrolling between a diagram and its legend should be eliminated.

Implement Universal Cueing: Video lectures and interactive modules must employ visual and auditory signaling to guide the novice eye.

Leverage Dual-Modality for Language Learners: When teaching non-native speakers, coupling audio narration with direct representational video (rather than on-screen text) significantly bypasses language processing bottlenecks and boosts comprehension.

2. Limitations of the Literature
While the pre-2020 literature provides a robust foundation, it is not without limitations. A major, recurring limitation across the reviewed body of work is the frequent failure to operationalise and disentangle germane load from intrinsic load. Many older studies fall into a trap of circular logic: they assume that any increase in post-test scores automatically implies that the intervention generated "higher germane load." Furthermore, the reliance on highly controlled, short-duration laboratory experiments limits our understanding of how cognitive load accumulates over the course of a 14-week university semester.

3. Future Research Directions
Looking ahead from the vantage point of early 2020, the landscape of higher education is poised for rapid, unprecedented technological scaling. Future research must urgently pivot from static, laboratory-based multimedia interventions toward longitudinal studies situated in fully remote, asynchronous digital ecosystems. With the impending mass adoption of distance learning platforms, it is critical to investigate how algorithmic adaptive hypermedia and early iterations of artificial intelligence can be engineered to monitor and dynamically respond to real-time cognitive exhaustion. Furthermore, there is an immediate need to validate scalable physiological tracking—perhaps utilizing biometric telemetry from consumer wearables—to augment traditional, self-reported load metrics. Such interdisciplinary efforts will be vital to ensuring that remote instructional design remains cognitively sustainable across the entirety of modern, digital degree programs.

Conclusion
This systematic literature review, rigorously bounded to peer-reviewed empirical data published up to December 2019, demonstrates beyond a doubt that interactive multimedia profoundly impacts working memory. By strictly adhering to the biological constraints of human cognitive architecture — mitigating extraneous load through spatial contiguity, utilizing dual-channel modalities effectively, and providing structured instructional cueing — educators can significantly enhance both the retention and transfer of knowledge in higher education.
As digital learning environments become increasingly ubiquitous, the future integration of Artificial Intelligence and adaptive hypermedia must not rely on intuition. Instead, the design of next-generation educational technology must continue to index its instructional features directly against validated, multidimensional cognitive load metrics to ensure that the technology serves to augment human cognition rather than overwhelm it.

References
1. Anmarkrud Ø, Andresen A, Bråten I. Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues. Educational Psychologist,2019:54(1):61–83. https://doi.org/10.1080/00461520.2018.1554484
2. Ayres P, Sweller J. The Split-Attention Principle in Multimedia Learning. In R. E. Mayer, Ed., The Cambridge Handbook of Multimedia Learning. Cambridge University Press, 2005, 135–146. https://doi.org/10.1017/cbo9780511816819.009
3. Debue N, van de Leemput C. What does germane load mean? An empirical contribution to the cognitive load theory. Frontiers in Psychology,2014:5:1099. https://doi.org/10.3389/fpsyg.2014.01099
4. de Jong T. Cognitive load theory, educational research, and instructional design: Some food for thought. Instructional Science,2009:38(2):105–134. https://doi.org/10.1007/s11251-009-9110-0
5. Hedberg J, Harper B, Brown C. Reducing cognitive load in multimedia navigation. Australasian Journal of Educational Technology, 1993, 9(2). https://doi.org/10.14742/ajet.2106
6. Kalyuga S. Managing Cognitive Load in Adaptive Multimedia Learning. IGI Global, 2009. https://doi.org/10.4018/978-1-60566-048-6
7. Kalyuga S, Chandler P, Sweller J. Incorporating learner experience into the design of multimedia instruction.

Journal of Educational Psychology,2000:92(1):126–136. https://doi.org/10.1037/0022-0663.92.1.126
8. Kirschner PA. Cognitive load theory: Implications of cognitive load theory on the design of learning. Learning and Instruction,2002:12(1):1–10. https://doi.org/10.1016/S0959-4752(01)00014-7
9. Kirschner PA, Sweller J, Kirschner F, Zambrano R J. From Cognitive Load Theory to Collaborative Cognitive Load Theory. International Journal of Computer-Supported Collaborative Learning,2018:13(2):213–233. https://doi.org/10.1007/s11412-018-9277-y
10. Klepsch M, Schmitz F, Seufert T. Development and Validation of Two Instruments Measuring Intrinsic, Extraneous, and Germane Cognitive Load. Frontiers in Psychology,2017:8:1997. https://doi.org/10.3389/fpsyg.2017.01997
11. Leppink J, Paas F, van der Vleuten C, van Gog T, van Merriënboer JJG. Development of an instrument for measuring different types of cognitive load. Behavior Research Methods,2013:45(4):1058–1072. https://doi.org/10.3758/s13428-013-0334-1
12. Lin JJH, Lee YH, Wang DY, Lin SSJ. Reading subtitles and taking e-notes while learning scientific materials in a multimedia environment: Cognitive load perspectives on EFL students. Journal of Educational Technology & Society,2016:19(4):57–68.
13. Mayer RE, Lee H, Peebles A. Multimedia Learning in a Second Language: A Cognitive Load Perspective. Applied Cognitive Psychology,2014:28(5):651–660. https://doi.org/10.1002/acp.3050
14. Mazher M, Aziz AA, Malik AS, Amin HU. An EEG-Based Cognitive Load Assessment in Multimedia Learning Using Feature Extraction and Partial Directed Coherence. IEEE Access,2017:5:14819–14829. https://doi.org/10.1109/access.2017.2731784
15. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Medicine,2009:6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097
16. Paas F, Sweller J. An Evolutionary Upgrade of Cognitive Load Theory: Using the Human Motor System and Collaboration to Support the Learning of Complex Cognitive Tasks. Educational Psychology Review,2011:24(1):27–45. https://doi.org/10.1007/s10648-011-9179-2
17. Park S. The Effects of Social Cue Principles on Cognitive Load, Situational Interest, Motivation, and Achievement in Pedagogical Agent Multimedia Learning. Journal of Educational Technology & Society,2015:18(4):328–339.
18. Sweller J. Implications of Cognitive Load Theory for Multimedia Learning. In R. E. Mayer, Ed., The Cambridge Handbook of Multimedia Learning. Cambridge University Press,2005:19–30. https://doi.org/10.1017/cbo9780511816819.003
19. Sweller J, van Merriënboer JJG, Paas F. Cognitive Architecture and Instructional Design: 20 Years Later. Educational Psychology Review,2019:31(2):261–292. https://doi.org/10.1007/s10648-019-09465-5
20. Xie H, Wang F, Hao Y, Chen J, An J, Wang Y, Liu H. The more total cognitive load is reduced by cues, the better retention and transfer of multimedia learning: A meta-analysis and two meta-regression analyses. PLoS ONE,2017:12(8):e0183884. https://doi.org/10.1371/journal.pone.0183884
21. Yang HY. Does multimedia support individual differences? – EFL learners' listening comprehension and cognitive load. Australasian Journal of Educational Technology, 2014, 30(6). https://doi.org/10.14742/ajet.639