

Cognitive Load Theory: Emerging Trends and Innovations

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1. Introduction

Cognitive load theory (Sweller et al., 1998, 2019) has been a cornerstone of educational research for nearly four decades, integrating principles from cognitive psychology and instructional design to enhance learning, performance, and training outcomes. Supported by extensive research (for meta-analyses, see, Barbieri et al., 2023; Ginns, 2005, 2006; Schroeder & Ceneci, 2018; Sundararajan & Adesope, 2020), cognitive load theory (CLT) provides insights into how the constraints and capacities of the human information processing system can be used to optimize instructional methods and learning environments. Its focus on aligning educational practices with cognitive limitations and strengths has significantly informed approaches to effective teaching and learning.

However, the context of learning has changed significantly since the beginnings of CLT, as introduced by Sweller (1988). Rapid technological developments have transformed learning into a lifelong continuously evolving journey rather than a static school-based concept (Fidalgo & Thormann, 2024). This shift presents both advantages and challenges for learners and instructional designers. On the downside, the increasing flow of stimuli can make it difficult for learners to filter information and focus on what is most relevant. On the upside, understanding human cognitive architecture, including its limitations (such as working memory capacity (Baddeley, 1992, 2020) and strengths (such as its capacity for embodied learning (Barsalou, 2008, 2020) combined with insights into individual learner characteristics, enables instructional designers to create optimized learning environments (Zou et al., 2025). Additionally, exploring the supportive role of modern technology offers promising solutions for enhancing learning efficiency. This Special Issue, based on contributions to the 15th International Cognitive Load Theory Conference hosted by the Epsilon Lab at the University of Montpellier Paul-Valéry, France, brings together 15 articles showcasing emerging trends and innovations in cognitive load theory research.

2. Presenting and Handling Learning Materials

Two articles in this Special Issue address the split-attention effect, a phenomenon that typically results in increased cognitive load and impaired learning when essential information is spread across multiple, separate sources—such as text and images—rather than presented in an integrated format (Chandler & Sweller, 1991; Pouw et al., 2019). In the first contribution to this Special Issue, Guzmán and Zambrano (2024) investigate the split-attention effect by comparing individual versus collaborative learning approaches. They also examine element interactivity, a measure of material difficulty based on the



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number of informational elements that must be integrated for effective learning. Their results suggest that individual learning is more effective for high element interactivity materials presented in an integrated format, while collaborative learning in dyads is more beneficial when information is presented in a dispersed format. The second contribution, by [De Koning \(2024\)](#), explores strategies to mitigate the split-attention effect by comparing a physical approach (annotation) with a mental approach (imagery and drag-and-drop) in university students. It was found that combining physical and mental strategies significantly reduced the cognitive load, offering practical insights for designing materials with dispersed information by supporting a dual-strategy approach.

While a fragmented presentation of information affects learning due to split attention, redundancy (when the same information is presented in multiple ways or instances) can affect learning too ([Kalyuga & Sweller, 2014](#)). In the third contribution, [Trypke et al. \(2024\)](#) investigated modal and codal redundancy and their effect on learning and cognitive load. Modal redundancy referred to stimuli that were presented in two ways in the same modality, in this case the visual modality (images and text). In the codal redundancy condition, the information was presented in two different modalities but used the same linguistic code (spoken and written text). It seemed that modal redundancy facilitated learning and led to lower cognitive load, while codal redundancy elicited a classic (aversive) redundancy effect.

Another key approach in handling learning materials is the distinction between blocked and mixed practice. In the fourth contribution, [Chen et al. \(2023\)](#) studied middle-school students and found that studying multiple domains (e.g., mathematics and language) within a single session was more efficient than studying each domain separately in blocked sessions. However, this effect was only found for materials that looked similar on the surface and not for materials that required completely different approaches. Their findings suggest that alternating between subjects within a study session enhances learning efficiency, supporting a mixed approach for homework across different domains.

In the fifth contribution, [Mugisha and Arguel \(2025\)](#) explored the use of mixed reality in learning knot tying as a technical skill needed for surgical procedures. They tested the principle of spatial contiguity and aimed to measure its impact on cognitive load and procedural learning performance. Their main finding, that an integrated- compared to a non-integrated learning format was specifically beneficial for intrinsic load, has implications for instructional design recommendations for procedural learning tasks.

3. Monitoring

The rise of data-driven and automated education has introduced both opportunities and challenges, with standardized assessments contributing to a high-stakes testing culture that may reduce learners to data points focused on scores, potentially impacting emotional wellbeing ([French et al., 2024](#)). Internal factors such as self-regulation ([Schunk & Zimmerman, 2008](#); [Yang et al., 2024](#)) offer resilience, as highlighted by the integrative review by [Brockbank and Feldon \(2024\)](#) in the sixth contribution. These researchers propose cognitive reappraisal as a self-monitoring strategy to manage negative emotions in learning. More specifically, they propose that cognitive reappraisal, which involves reframing or reassessing the beliefs underlying an emotional response to better align with goals ([Gross, 2015](#)), may reduce the impact of negative emotions on cognitive load.

In the seventh contribution, [Graham et al. \(2024\)](#) investigated self-monitoring via “thinking aloud” in university students solving biology problems to assess its effects on learning and cognitive load. Although thinking aloud did not facilitate learning directly, it led to longer task engagement, with lower monitoring accuracy than the control group.

These findings underscore the importance of careful implementation of monitoring strategies in learning contexts. In the eighth contribution, [Gorbunova et al. \(2024\)](#) investigated graduate law students' prior knowledge and self-regulated learning skills when studying the civil code in an online session. They found that both these factors led to increased germane load and performance. These authors stress the need to carefully consider and select learner-control options in asynchronous online environments.

4. Working Memory Recovery

In today's information-saturated era, stress and mental fatigue due to information overload is a growing concern ([Arnold et al., 2023](#)), highlighting the need for interventions to help replenish cognitive energy. [Consalvi et al. \(2024\)](#) explored one such intervention in the ninth contribution by examining the effects of nature exposure on working memory recovery. While previous behavioral research suggests that natural environments can help replenish cognitive resources ([Mason et al., 2022](#); [Van Oordt et al., 2023](#)), [Consalvi et al. \(2024\)](#) used psychophysiological measures in addition to behavioral measures to assess whether exposure to nature imagery could restore working memory after a demanding task. Although no significant effects were observed, the study offers a rigorous method for continuous cognitive load assessment, which may inform future interventions. Future research should explore alternative strategies for replenishing cognitive capacity beyond nature exposure, such as structured rest breaks or mindfulness interventions.

5. Individual Learner Characteristics

The trend toward personalized learning underscores the importance of individual factors, such as topic interest and cognitive capacities, in shaping learning outcomes and cognitive load ([Bernacki et al., 2021](#)). This was addressed in the tenth contribution by [Schuessler et al. \(2024\)](#), who examined how topic interest moderates the relationship between task complexity and mental effort in chemistry assignments for middle-school students, finding that low-interest tasks required more cognitive effort for simple assignments but not for more complex ones. In the eleventh contribution, [Lee and Ayres \(2024\)](#) demonstrated that using worked examples in mathematics improved retention and reduced cognitive load compared to problem-solving strategies, particularly for students with a strong mastery approach orientation. In the twelfth contribution, [Altmeyer et al. \(2024\)](#) investigated the effects of augmented reality (AR) on learning about electricity, focusing on individual differences such as spatial abilities and verbal working memory. Results suggest that tablet-based AR benefitted students with low spatial ability, while AR glasses better supported those with low verbal working memory—though these effects were not observed in primary school children, likely due to developmental factors.

6. Embodied Learning

Cognitive load theory also considers the affordances of human cognitive architecture, including the role of embodied learning. Grounded in embodied cognition ([Barsalou, 2008, 2020](#)) and evolutionary educational psychology ([Geary, 2012, 2024](#)), embodied learning emphasizes that humans understand the world through bodily interactions. In the thirteenth contribution, [Mian et al. \(2024\)](#) compared real and imitative practice in learning piano pieces and paper folding. The findings suggest that imitation enhanced learning efficiency in piano, while real practice was more effective for paper folding, in the female participants specifically indicating that the level of embodiment may need to be tailored to specific tasks and gender. Embodiment in learning was studied in the domain of geometry by [Kenneally and Bentley \(2024\)](#) in the fourteenth contribution to investigate the use of AR in teaching molecular geometry and determined that allowing students to explore 3D

molecular structures through physical interaction reduced the cognitive load and improved understanding compared to mental rotation alone.

7. Reflections on CLT in Modern Research

Given rapid technological advancements, it is crucial to continually evaluate whether the guiding theories in educational research, including CLT, remain relevant. In the fifteenth contribution, Martella et al. (2024) reviewed recent CLT research (2020–2023), noting a decrease in experimental studies and a shift toward intervention research, which may impact study replicability. They emphasized the need for ongoing experimental validation to support robust and reliable CLT research outcomes.

8. Conclusions

Overall, this Special Issue reaffirms the ongoing relevance of cognitive load theory in modern learning contexts. The studies presented underscore the importance of leveraging technology and instructional design to address cognitive limitations in learners, offering promising interventions to manage cognitive load in our rapidly evolving society. Together, these findings suggest that CLT will continue to be a valuable framework for future educational research and practice, emphasizing the need for adaptable and experimentally validated approaches in instructional design.

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References

- Altmeyer, K., Brünken, R., Kuhn, J., & Malone, S. (2024). The role of cognitive learner prerequisites for cognitive load and learning outcomes in AR-supported lab work. *Educational Sciences*, 14(11), 1161. [CrossRef]
- Arnold, M., Goldschmitt, M., & Rigotti, T. (2023). Dealing with information overload: A comprehensive review. *Frontiers in Psychology*, 14, 1122200. [CrossRef]
- Baddeley, A. (1992). Working memory. *Science*, 255(5044), 556–559. [CrossRef]
- Baddeley, A. (2020). Working memory. In A. Baddeley, M. W. Eysenck, & M. C. Anderson (Eds.), *Memory* (3rd ed., pp. 71–111). Routledge. [CrossRef]
- Barbieri, C. A., Miller-Cotto, D., Clerjuste, S. N., & Chawla, K. (2023). A meta-analysis of the worked examples effect on mathematics performance. *Educational Psychology Review*, 35(1), 11. [CrossRef]
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59(1), 617–645. [CrossRef] [PubMed]
- Barsalou, L. W. (2020). Challenges and opportunities for grounding cognition. *Journal of Cognition*, 3(1), 31. [CrossRef]
- Bernacki, M. L., Greene, M. J., & Lobczowski, N. G. (2021). A systematic review of research on personalized learning: Personalized by whom, to what, how, and for what purpose(s)? *Educational Psychology Review*, 33, 1675–1715. [CrossRef]
- Brockbank, R. B., & Feldon, D. F. (2024). Cognitive reappraisal: The bridge between cognitive load and emotion. *Educational Sciences*, 14(8), 870. [CrossRef]
- Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, 8(4), 293–332. Available online: <http://www.jstor.org/stable/3233596> (accessed on 14 March 2025).
- Chen, O., Retnowati, E., Castro-Alonso, J. C., Paas, F., & Sweller, J. (2023). The relationship between interleaving and variability effects: A cognitive load theory perspective. *Educational Sciences*, 13(11), 1138. [CrossRef]

- Consalvi, L., Ouwehand, K., & Paas, F. (2024). Effects of observing urban and natural scenes on working memory depletion and restoration: An EEG study. *Educational Sciences*, 14(11), 1204. [CrossRef]
- De Koning, B. B. (2024). Best of both worlds? Combining physical and mental self-management strategies to support learning from split-attention examples. *Educational Sciences*, 14(3), 284. [CrossRef]
- Fidalgo, P., & Thormann, J. (2024). The future of lifelong learning: The role of artificial intelligence and distance education. In F. G. Paloma (Ed.), *Lifelong learning: Education for the future world* (1st ed., pp. 1–17). IntechOpen. [CrossRef]
- French, S., Dickerson, A., & Mulder, R. A. (2024). A review of the benefits and drawbacks of high-stakes final examinations in higher education. *Higher Education*, 88, 893–918. [CrossRef]
- Geary, D. C. (2012). Evolutionary educational psychology. In K. R. Harris, S. Graham, T. Urdan, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *APA educational psychology handbook, Vol. 1. Theories, constructs, and critical issues* (pp. 597–621). American Psychological Association. [CrossRef]
- Geary, D. C. (2024). *The evolved mind and modern education: Status of evolutionary educational psychology*. Cambridge University Press.
- Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction*, 15(4), 313–331. [CrossRef]
- Ginns, P. (2006). Integrating information: A meta-analysis of the spatial contiguity and temporal contiguity effects. *Learning and Instruction*, 16(6), 511–525. [CrossRef]
- Gorbunova, A., Lange, C., Savelyev, A., Adamovich, K., & Costley, J. (2024). The interplay of self-regulated learning, cognitive load, and performance in learner-controlled environments. *Educational Sciences*, 14(8), 860. [CrossRef]
- Graham, M., Ilic, M., Baars, M., Ouwehand, K., & Paas, F. (2024). The effect of self-monitoring on mental effort and problem-solving performance: A mixed-methods study. *Educational Sciences*, 14(11), 1167. [CrossRef]
- Gross, J. J. (2015). Emotion regulation: Current status and future prospects. *Psychological Inquiry*, 26(1), 1–26. [CrossRef]
- Guzmán, J., & Zambrano, R. (2024). Effects of split-attention and task complexity on individual and collaborative learning. *Educational Sciences*, 14(9), 1035. [CrossRef]
- Kalyuga, S., & Sweller, J. (2014). The redundancy principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 247–262). Cambridge University Press. [CrossRef]
- Kenneally, C. D., & Bentley, B. (2024). A cognitive load approach to molecular geometries: Augmented reality technology and visuospatial abilities in chemistry. *Education Sciences*, 14(9), 1036. Available online: <https://www.proquest.com/scholarly-journals/cognitive-load-approach-molecular-geometries/docview/3110442754/se-2> (accessed on 14 March 2025).
- Lee, H. M., & Ayres, P. (2024). The worked-example effect and a mastery approach goal orientation. *Educational Sciences*, 14(6), 597. [CrossRef]
- Martella, A. M., Lawson, A. P., & Robinson, D. H. (2024). How scientific is cognitive load theory research compared to the rest of educational psychology? *Education Sciences*, 14(8), 920. [CrossRef]
- Mason, L., Ronconi, A., Scrimin, S., & Pazzaglia, F. (2022). Short-term exposure to nature and benefits for students' cognitive performance: A review. *Educational Psychology Review*, 34, 609–647. [CrossRef]
- Mian, M. N., Beder, H., Marcus, N., & Ayres, P. (2024). Comparing real and imitative practice with no practice during observational learning of hand motor skills from animations. *Educational Sciences*, 14(9), 949. [CrossRef]
- Mugisha, G., & Arguel, A. (2025). Procedural learning in mixed reality: Assessing cognitive load and performance. *Education Sciences*, 15(3), 339. [CrossRef]
- Pouw, W., Rop, G., de Koning, B., & Paas, F. (2019). The cognitive basis for the split-attention effect. *Journal of Experimental Psychology: General*, 148(11), 2058–2075. [CrossRef]
- Schroeder, N. L., & Cenkci, A. T. (2018). Spatial contiguity and spatial split-attention effects in multimedia learning environments: A meta-analysis. *Educational Psychology Review*, 30, 679–701. [CrossRef]
- Schuessler, K., Fischer, V., Walpuski, M., & Leutner, D. (2024). The moderating role of interest in the relationship between perceived task difficulty and invested mental effort. *Educational Sciences*, 14(10), 1044. [CrossRef]
- Schunk, D. H., & Zimmerman, B. J. (Eds.). (2008). *Motivation and self-regulated learning: Theory, research, and applications*. Routledge.
- Sundararajan, N., & Adesope, O. (2020). Keep it coherent: A meta-analysis of the seductive details effect. *Educational Psychology Review*, 32(3), 707–734. [CrossRef]
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285. [CrossRef]
- Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, 10, 251–296. [CrossRef]
- Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31, 261–292. [CrossRef]
- Trypke, M., Stebner, F., & Wirth, J. (2024). The more, the better? Exploring the effects of modal and codal redundancy on learning and cognitive load: An experimental study. *Educational Sciences*, 14(8), 872. [CrossRef]
- Van Oordt, M., Ouwehand, K., & Paas, F. (2023). Restorative effects of observing natural and urban scenery after working memory depletion. *International Journal of Environmental Research and Public Health*, 20(1), 188. [CrossRef]

- Yang, Y., Zheng, Z., Wang, J., & Sun, D. (2024). The relationships of motivation and self-regulation to students' cognitive presence and empowerment in online learning environment. *Educational Information Technologies*, 29, 23391–23414. [[CrossRef](#)]
- Zou, L., Zhang, Z., Mavilidi, M., Chen, Y., Herold, F., Ouwehand, K., & Paas, F. (2025). The synergy of embodied cognition and cognitive load theory for optimized learning. *Nature Human Behaviour*, 1–9. [[CrossRef](#)]

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