Journal of Inclusive Methodology and Technology in Learning and Teching
ISSN 2785-5104
Anno 6 n. 3 (2026)

EDIZIONI UNIVERSITARIE ROMANE
editoria scientifica dal 1952

Designing Digital Learning Environments Through Cognitive Load Theory and Universal Design for Learning: A Scoping Review[1]

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Abstract: Digital learning environments require pedagogical approaches that address students' cognitive demands and variability. This scoping review maps how Cognitive Load Theory (CLT) and Universal Design for Learning (UDL) inform the design of digital learning environments across educational contexts, examining design principles, implementation characteristics, research methods, and reported outcomes. Searches were conducted in Scopus, Web of Science, and ERIC. Eligibility criteria focused on empirical journal articles published in English that described, analysed, or evaluated digital environments designed using principles of CLT and/or UDL. Data were organised into a matrix covering study characteristics, theoretical frameworks, design elements, assessment instruments, and findings. The review included 34 studies: 17 were classified as CLT-oriented, 16 as UDL-oriented, and one explicitly combined both frameworks. The environments analysed included learning management systems, MOOCs, multimedia resources, mobile applications, immersive environments, and educational games. CLT-oriented designs emphasised segmentation, cueing, worked examples, and cognitive load management; in contrast, UDL-oriented designs highlighted accessible resources, flexible participation, and multiple means of engagement, representation, and action and expression. Reported outcomes included academic performance, cognitive load, engagement, motivation, accessibility, and usability. Heterogeneity in research designs and assessment measures limits conclusions regarding comparative effectiveness. The mapping identifies limited explicit integration of CLT and UDL and highlights the need for further research into their operational alignment in digital instructional design.

Keywords: Cognitive Load Theory; Universal Design for Learning; Digital Learning Environments.

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[1] This article is the result of the joint work of all authors. Specifically, Emilia Matera wrote the Introduction (Section 1); Laura D'Amico wrote the Materials and Methods (Section 2); Marika Lamacchia wrote the Results (Section 3); Marilena di Padova wrote the Discussion (Section 4); and Anna Dipace wrote the Conclusions (Section 5).

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1. Introduction

Digital learning environments offer opportunities for flexible, personalised education; however, they require students to process information and sustain attention, particularly when information complexity, multimedia richness, and interactive features are not adequately coordinated (Lodge & Harrison, 2019; Skulmowski & Xu, 2022). Cognitive Load Theory (CLT) interprets learning in light of the limited capacity of working memory and the organisation of knowledge in long-term memory, highlighting the importance of managing task complexity and reducing extraneous cognitive load (Sweller et al., 2019). Building on this perspective, the Cognitive Theory of Multimedia Learning (CTML) examines how students select, organise, and integrate verbal and visual information through distinct, limited-capacity channels (Mayer, 2005). Multimedia design principles such as signalling, segmentation, and coherence aim to guide attention, structure content, and minimise unnecessary processing. Universal Design for Learning (UDL) addresses student variability by promoting multiple means of engagement, representation, and action and expression to reduce barriers to access and participation (CAST, 2024). In digital environments, these principles are applied through accessible content formats, flexible learning pathways, alternative forms of participation, and opportunities to demonstrate learning, requiring careful structuring and support. These perspectives offer potential complementarities but require careful coordination: while multiple representations and flexible learning pathways can enhance accessibility, poor structuring risks introducing redundancy, split-attention effects, or additional decision-making demands (Bray et al., 2024; Sweller et al., 2019). Signalling, attention to prior knowledge, and scaffolded instructional support offer potential areas of convergence between cognitive efficiency and inclusive design (CAST, 2024; Mayer, 2005; Sweller et al., 2019). Previous reviews have explored different aspects of instructional design linked to CLT and UDL. Research on cognitive load and multimedia learning has focused on extraneous cognitive load, information organisation and presentation, and cognitive load assessment, highlighting the frequent use of subjective measures and providing empirical support for multimedia design principles (Mutlu-Bayraktar et al., 2019; Noetel et al., 2022). UDL reviews have examined its application across educational settings (Ewe & Galvin, 2023), the role of digital technologies (Bray et al., 2024), and challenges concerning the articulation and consistent application of principles and their alignment with theoretical foundations (Zhang et al., 2024). However, these syntheses do not specifically map how CLT and UDL are operationalised, individually or jointly, in designing digital learning environments. Consequently, this scoping review addresses the following research question: *How are CLT and/or UDL principles operationalised in the design of digital learning environments across educational contexts?*

2. Materials and Methods

This scoping review followed the methodological framework of Arksey and O'Malley (2005) and was reported in accordance with the PRISMA-ScR guidelines (Tricco et al., 2018). The review scope was defined using the Population–Concept–Context (PCC) framework, as summarised in **Table 1**.

Table 1. Population–Concept–Context (PCC) framework

Population (P)	Concept (C)	Context (C)
Learners and educators across educational levels and settings, without restrictions on age or educational stage.	Digital learning environments explicitly designed using principles of CLT and/or UDL.	Formal educational and professional training settings involving online, blended, or technology-enhanced learning.

It mapped CLT- and/or UDL-informed digital learning designs, contexts, populations, assessment methods, and outcomes. Searches were conducted in Scopus, Web of Science, and ERIC using the following search string, initially tested in Scopus and subsequently adapted to the other databases: ("online learning" OR "e-learning" OR "massive open online course" OR MOOC OR "learning management system" OR LMS OR "digital learning environment" OR "technology-enhanced learning") AND ("cognitive load theory" OR "cognitive load" OR CLT OR "universal design for learning" OR UDL) AND (design* OR develop* OR architectur* OR framework OR model OR "instructional design" OR "learning design") AND (education OR school OR "higher education" OR university OR "teacher education"). The last search was conducted on May 3, 2026. Eligible studies were English-language, open-access, peer-reviewed empirical journal articles published between 2015 and 2026, with retrievable full texts and an explicit link between digital learning environment design and CLT and/or UDL. Titles and abstracts were screened by the primary reviewer, while a second reviewer independently assessed a random sample of 80 records (20,2 % of the 397 identified) from a shared Zotero library, applying the same eligibility criteria. Inter-rater agreement was assessed using Cohen's kappa coefficient ($\varkappa$). Complete agreement was observed between reviewers (100%; $\varkappa = 1.00$). Full-text eligibility assessment and data extraction were conducted by the primary reviewer using a structured matrix covering study characteristics, theoretical foundations, research designs, assessment instruments, outcomes, and limitations. Descriptive counts and narrative synthesis were used to compare CLT-informed, UDL-informed, and combined approaches without pooling effect estimates. Studies were classified as CLT- or UDL-informed when the respective framework explicitly guided instructional design, rather than merely being mentioned or used to assess cognitive load. Studies were classified as combined when both frameworks informed the design. The protocol was not registered.

3. Results

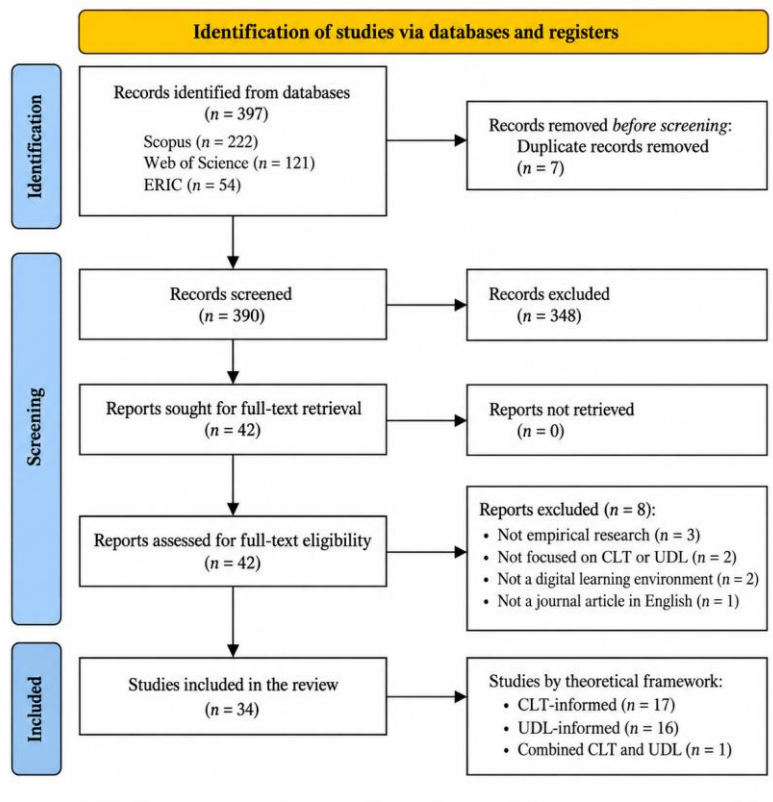
3.1. Study selection and characteristics of the included studies

Database searches yielded 397 records (Scopus: 222; Web of Science: 121; ERIC: 54). After removing seven duplicates, 390 records were examined; of these, 348 were excluded, while 42 underwent full-text assessment. Eight contributions were excluded, resulting in a total of 34 studies: 17 based on Cognitive Load Theory (CLT), 16 on Universal Design for Learning (UDL), and one integrating both theoretical frameworks. The studies covered various educational levels, ranging from primary school to postgraduate education, and included teacher training as

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well as professional training in fields such as healthcare and airport security (Toh & Tasir, 2024; Woolcott et al., 2019; Taddio et al., 2025; Wyssenbach et al., 2025). The disciplines involved span mathematics, science, medicine, information literacy, entrepreneurship, and technical education, as well as languages and digital literacy (Lechner et al., 2024; Squire, 2019; Triana-Vera & López-Vargas, 2026; Lazou & Tsinakos, 2025). Research designs included experimental, quasi-experimental, pre-post, qualitative, mixed-methods, action research, design-based, and usability evaluation studies (Albus et al., 2021; Ho et al., 2024; Zhu & Niyozov, 2024; Taddio et al., 2025). Digital environments included learning management systems (LMS), MOOCs, interactive videos, mobile applications, multimedia resources, immersive technologies, educational games, and AI-based recommendation systems. Design features encompassed segmentation, signalling, worked examples, scaffolding, multimodal representation, accessibility adaptations, learner choice, and formative feedback (Afify, 2020; Krüger & Bodemer, 2022; Mrayhi et al., 2026; Lazou & Tsinakos, 2025). **Figure 1** illustrates the study selection process, while Supplementary **Table S1** describes the characteristics of the all the studies included.

Figure 1. PRISMA flow diagram of the study selection



3.2. Theoretical orientations and their operationalisation

Seventeen studies (50.0%) were informed by CLT, 16 (47.1%) by UDL, and one (2.9%) combined both frameworks. Additional theoretical foundations included multimedia learning (Mayer, 2005; Afify, 2020; Albus et al., 2021), self-determination theory (Ryan & Deci, 2000; de Araujo Guerra Grangeia et al., 2016), Community of

Inquiry (Seymour, 2024), design thinking (Sriwisathiyakun, 2024), and constructive alignment (Abgaz, 2026). CLT-informed designs employed segmentation, pacing, signalling (Afify, 2020; Wyssenbach et al., 2025; Albus et al., 2021), worked examples, fading, and adaptation to prior knowledge (Woolcott et al., 2019; Lechner et al., 2024; Chiu & Mok, 2017). Other strategies addressed information integration, redundancy, distraction, and split attention (de Araujo Guerra Grangeia et al., 2016; Toh & Tasir, 2024). Applications included multimedia videos for technical education and career guidance (Grustan et al., 2025; Yüzen & Perkmen, 2022), medication calculation apps (McMullan, 2018), and online anatomy instruction (Sohrabi et al., 2023). UDL-informed designs incorporated alternative formats, captions, transcripts, flexible navigation, assessment options, collaboration, and instructor communication (Garrad & Nolan, 2023; Herrera Nieves et al., 2019; Seymour, 2024; Zhu & Niyozov, 2024; Evmenova, 2018; Lohmann & Boothe, 2025). Other applications addressed e-learning acceptance, accessibility, platform functionality, and personalised recommendations (Al-Azawei et al., 2017; Herrera Nieves et al., 2025; Mrayhi et al., 2026). Inclusive VR incorporated multimodal representation, participatory content creation, and attention to cognitive demands (Lazou & Tsinakos, 2025). The combined study integrated UDL, design thinking, and CLT-informed instructional decisions without comparing the approach with single-framework conditions (Sriwisathiyakun, 2024).

3.3. Assessment and reported outcomes

Studies based CLT have primarily evaluated learning performance and cognitive load, often through self-assessment measures, as well as motivation, attitudes, and the learning experience (Squire, 2019; Gökdeniz Tahiroğlu & Özcan, 2025). The outcomes analyzed have included video duration (Afify, 2020), worked examples and motivational support (scaffolding) (Lechner et al., 2024; Triana-Vera & López-Vargas, 2026), and the use of signaling in virtual reality (Albus et al., 2021). Variations in performance were not always accompanied by changes in cognitive load. In the context of airport security training, under the conditions examined, a continuous presentation led to better performance than a segmented presentation (Wyssenbach et al., 2025). Studies based on UDL framework have primarily examined perceptions, accessibility, participation, and the learning experience, utilizing questionnaires, interviews, focus groups, accessibility audits, and student work. The findings have addressed aspects such as accessibility, flexibility, organization, and instructional support (Herrera Nieves et al., 2019; Seymour, 2024; Taddio et al., 2025; Parra et al., 2018), as well as stress, the availability of choices regarding assessment methods, and social interaction (Lohmann & Boothe, 2025; Lohmann et al., 2018). Other studies have examined teachers' competencies and perceptions regarding UDL (Evmenova, 2018; Leif et al., 2023; Awajan, 2022), as well as resource utilization, technical accessibility, knowledge acquisition, course completion and pass rates, and critical reflection (Garrad & Nolan, 2023; Herrera Nieves et al., 2025; Abgaz, 2026; Zhu & Niyozov, 2024). Research has also investigated satisfaction, interaction, and the quality of the guidance provided (Mrayhi et al., 2026). Overall, research based on CLT has emphasized performance and cognitive load, whereas research based on UDL has focused more on accessibility, participation, and learning experience. Methodological heterogeneity has limited the possibility of making direct comparisons.

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4. Discussion

The distribution of studies based on CLT and UDL reflects differing evaluation priorities: while CLT research has primarily examined learning performance and cognitive load, UDL studies have focused more on accessibility, participation, and engagement. This suggests that the two research traditions have adopted different criteria for evaluating instructional design, thereby making a direct comparison of results difficult. The variability in findings observed regarding tasks, prior knowledge, and assessment measures (Albus et al., 2021; Lechner et al., 2024; Wyssenbach et al., 2025) aligns with CLT's emphasis on the relationship between learner competence and instructional support (Sweller et al., 2019), highlighting the importance of considering contextual and learner-related factors when interpreting the outcomes of individual interventions. The limited integration between CLT and UDL, which precludes a systematic evaluation of how their respective design principles interact in practice, may partly reflect the challenges of reconciling instructional flexibility with cognitive demands. Indeed, the use of multiple representations, alternative formats, and extensive student choice may increase processing demands when insufficiently structured (Bray et al., 2024; Sweller et al., 2019). Conversely, strategies such as signalling, adaptation to prior knowledge, and gradual scaffolding suggest potential areas of convergence between the two frameworks (CAST, 2024; Sweller et al., 2019). The only study combining both theoretical frameworks (Sriwisathiyakun, 2024) illustrates an integrated design approach but does not establish its added value compared to designs based on a single framework. Therefore, future studies should examine how to harmonise flexibility and accessibility with cognitive demands, drawing on the UDL 3.0 guidelines (CAST, 2024). Comparative research designs and evaluative approaches that incorporate both cognitive and inclusive dimensions could help clarify the implications of integrating these two frameworks. Furthermore, it must be noted that although some of the studies reviewed involved participants with disabilities, their mere presence does not demonstrate differentiated outcomes for the students involved (Evmenova, 2018; Sriwisathiyakun, 2024), thereby limiting the ability to draw conclusions regarding the effectiveness of interventions for diverse learner groups. The results should be interpreted with caution; primarily, the heterogeneity of research designs and outcome measures limits comparability and precludes a quantitative synthesis of intervention effects. Moreover, the review was restricted to three databases and to peer-reviewed, open-access articles in English published between 2015 and 2026, potentially resulting in the exclusion of relevant evidence. Finally, although a second reviewer independently examined 80 randomly selected records, the subsequent selection stages and full-text assessments were conducted by the lead reviewer, leaving a potential risk of selection errors. The methodological limitations outlined constrain the generalisability of the findings, a factor that cannot be overlooked when interpreting the identified patterns.

5. Conclusions

This scoping review highlights distinct assessment priorities in CLT- and UDL-informed digital learning environments, with limited evidence of their explicit integration. Across the 34 included studies, the findings reveal differences in the instructional approaches and evaluation measures associated with each framework, alongside substantial methodological heterogeneity. Future research should examine

the joint implementation of CLT and UDL through comparative study designs and assessment measures addressing both learning outcomes and accessibility, with greater attention to differences across learner populations.

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