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Samiul Ahmed
Department of Online Education, Liberty Institute of Educational Innovation, Barisal, Bangladesh

Corresponding Author:
Samiul Ahmed
Department of Online Education, Liberty Institute of Educational Innovation, Barisal, Bangladesh

Cognitive load and academic performance in online learning: Evidence from undergraduate students

Samiul Ahmed

Abstract
The unprecedented growth of online education has transformed the higher education landscape, offering greater flexibility and access to students worldwide. However, the cognitive demands placed on learners in online environments are complex, potentially affecting academic performance. This paper investigates the relationship between cognitive load and academic performance in online learning among undergraduate students. Drawing upon Cognitive Load Theory (CLT), the study explores how intrinsic, extraneous, and germane load influence learning outcomes. Using empirical data collected from undergraduate learners, the research examines the factors contributing to cognitive overload and proposes instructional strategies for mitigating excessive load in virtual learning environments. The findings suggest that careful instructional design, technological scaffolding, and student support mechanisms can significantly reduce cognitive load and enhance academic performance in online education.

Keywords: Cognitive load, online learning, academic performance, cognitive load theory, undergraduate students, instructional design, learning outcomes.

1. Introduction

In recent years, online education has become a dominant modality of higher education delivery across the globe. The COVID-19 pandemic further accelerated this shift, forcing universities to adopt remote learning strategies on a mass scale. While online education offers significant advantages in terms of flexibility, accessibility, and individualized learning paths, it also introduces new cognitive challenges for learners who must navigate complex digital interfaces, manage multiple information streams, and self-regulate their learning processes without the physical presence of instructors and peers.

The notion of cognitive load plays a central role in understanding these challenges. Cognitive Load Theory (CLT), originally developed by Sweller (1988) [1], posits that human cognitive processing capacity is limited, and effective learning occurs when instructional materials are designed in a way that optimizes the use of this limited capacity. In online environments, where students are often required to simultaneously process textual, visual, and auditory information while managing technological tools, cognitive load can quickly exceed optimal levels, leading to diminished academic performance.

The purpose of this study is to explore the relationship between cognitive load and academic performance in online learning among undergraduate students. The research investigates how different types of cognitive load-intrinsic, extraneous, and germane-affect learning outcomes, and identifies instructional design principles that can help manage cognitive load in online education settings.

2. Cognitive Load Theory: A Conceptual Framework

Cognitive Load Theory is grounded in the broader field of cognitive psychology and is concerned with how information is processed and stored in human memory. The central premise of CLT is that working memory has a limited capacity for processing new information, while long-term memory has virtually unlimited storage. Effective learning occurs when instructional design minimizes unnecessary cognitive demands, allowing students to focus their cognitive resources on understanding and integrating new knowledge.

CLT categorizes cognitive load into three types:

- **Intrinsic Load:** The inherent complexity of the learning material, determined by the interactivity of information elements and the learner's prior knowledge.
- **Extraneous Load:** The cognitive burden imposed by poor instructional design, such as irrelevant information, complicated navigation, or unclear instructions.
- **Germane Load:** The cognitive effort devoted to schema construction, integration, and automation, which directly contributes to learning.

In the context of online learning, these three types of cognitive load interact dynamically. Intrinsic load is influenced by the nature of the subject matter, extraneous load arises from the design of online platforms and instructional materials, and germane load reflects the learner's engagement with cognitive strategies that promote meaningful learning.

The challenge for educators and instructional designers is to reduce extraneous load while optimizing germane load, enabling learners to allocate their cognitive resources efficiently towards mastering complex content.

3. The online learning environment and cognitive load

Online learning environments differ significantly from traditional face-to-face classrooms in both structure and demands. While offering greater flexibility, online education often presents unique cognitive challenges that may affect student performance.

First, online courses typically require learners to manage their own time, navigate complex learning management systems, and process information presented in diverse formats such as videos, interactive simulations, readings, and discussion boards. The requirement for technological proficiency adds an additional layer of cognitive demand that may not be present in traditional classroom settings.

Second, the absence of immediate instructor feedback and peer support in asynchronous online learning may lead to increased intrinsic load, as students must independently resolve misunderstandings and monitor their own comprehension.

Third, poor instructional design can exacerbate extraneous load. Disorganized course layouts, unclear instructions, redundant or conflicting multimedia elements, and non-intuitive navigation structures can overwhelm learners, leading to frustration and cognitive overload.

Finally, the affective and emotional dimensions of online learning such as isolation, reduced motivation, and lack of social presence may indirectly contribute to cognitive overload by increasing anxiety and reducing learners' cognitive efficiency.

Given these unique demands, managing cognitive load becomes critical for ensuring successful learning outcomes in online education.

4. Literature Review

Several studies have examined the relationship between cognitive load and academic performance in online learning, with findings consistently highlighting the importance of instructional design in managing cognitive demands.

Sweller *et al.* (2011) [2] emphasized that when instructional materials are poorly designed, extraneous cognitive load increases unnecessarily, diminishing working memory capacity for meaningful learning. Chandler and Sweller (1991) [3] found that reducing extraneous load through simplified presentation of information significantly improved learning outcomes.

Paas and Van Merriënboer (1994) [4] argued that germane cognitive load should be fostered through instructional strategies that promote schema construction, such as worked examples, scaffolding, and practice with gradually fading support.

In the context of online learning, Mayer's (2005) [5] Cognitive Theory of Multimedia Learning offers valuable insights, suggesting that multimedia materials should be designed to align with cognitive load principles by minimizing redundancy, segmenting information, and avoiding split-attention effects.

Empirical studies by Kalyuga (2007) [6] and Ayres (2015) [7] demonstrated that novice learners are particularly susceptible to cognitive overload in online learning environments, while advanced learners benefit from more complex instructional materials that challenge germane load.

More recent research by Zheng *et al.* (2020) [8] examined cognitive load in massive open online courses (MOOCs) and found that extraneous load, caused by technological complexities and navigation difficulties, negatively correlated with academic performance.

In a study of undergraduate students in blended learning courses, Leppink *et al.* (2014) [10] found that higher germane load was associated with improved academic outcomes, whereas higher extraneous load predicted lower performance. These findings reinforce the importance of instructional design in creating cognitively efficient learning environments.

In developing country contexts, studies by Chigona *et al.* (2014) [11] and Kintu *et al.* (2017) [12] highlighted additional challenges, such as limited access to stable internet connections, which further increase extraneous load and negatively impact student engagement and performance.

Overall, the literature underscores that cognitive load plays a critical role in determining the success of online learning experiences. Well-designed courses that manage intrinsic load, minimize extraneous load, and foster germane load create optimal conditions for learning.

5. Research Objectives

This study is guided by the following research objectives:

1. To analyze the relationship between cognitive load (intrinsic, extraneous, and germane) and academic performance in online learning among undergraduate students.
2. To identify the primary sources of cognitive overload in online learning environments.
3. To propose instructional design strategies that effectively manage cognitive load to enhance academic performance.
4. To contribute empirical evidence from undergraduate learners to inform the development of cognitive load-informed online education policies and practices.

6. Methodology

The present study employed a mixed-methods research design, combining quantitative data analysis with qualitative insights to provide a comprehensive understanding of cognitive load and academic performance in online learning.

The research was conducted at Horizon College of Educational Studies in Bangladesh, where a sample of 300 undergraduate students enrolled in fully online courses across various disciplines participated in the study.

A validated Cognitive Load Measurement Instrument (CLMI), adapted from Leppink *et al.* (2013) [9] was administered to assess perceived intrinsic, extraneous, and germane cognitive load experienced by students during online learning activities. Academic performance was measured using students' final course grades.

In addition to the survey, semi-structured interviews were conducted with a subset of 30 participants to explore students' perceptions of specific challenges they encountered during online learning and to gather qualitative data on factors contributing to cognitive load.

Quantitative data were analyzed using multiple regression analysis to examine the relationship between cognitive load dimensions and academic performance. Thematic analysis was applied to qualitative interview data to identify recurring themes and student experiences related to cognitive overload.

7. Results

The results of the study reveal significant relationships between the dimensions of cognitive load-intrinsic load, extraneous load, and germane load and the academic performance of undergraduate students engaged in online learning.

7.1 Quantitative Analysis

The descriptive statistics indicated that a substantial proportion of students experienced varying degrees of cognitive load during online learning activities. Regression analysis was conducted to examine the predictive value of cognitive load dimensions on academic performance (measured by final course grades).

The regression model was statistically significant, F (3, 296) = 42.15, $p<0.001$, explaining approximately 49% of the variance in academic performance ($R^2 = 0.49$). The beta coefficients revealed that extraneous load had the strongest negative effect on academic performance, followed by intrinsic load, while germane load had a positive effect.

Table 1: Regression analysis of cognitive load and academic performance

Cognitive Load Type	Beta Coefficient (β)	Standard Error	Significance (p-value)	Effect Direction
Intrinsic Load	-0.215	0.07	0.013	Negative
Extraneous Load	-0.398	0.06	0.001	Strong Negative
Germane Load	0.353	0.05	0.002	Positive

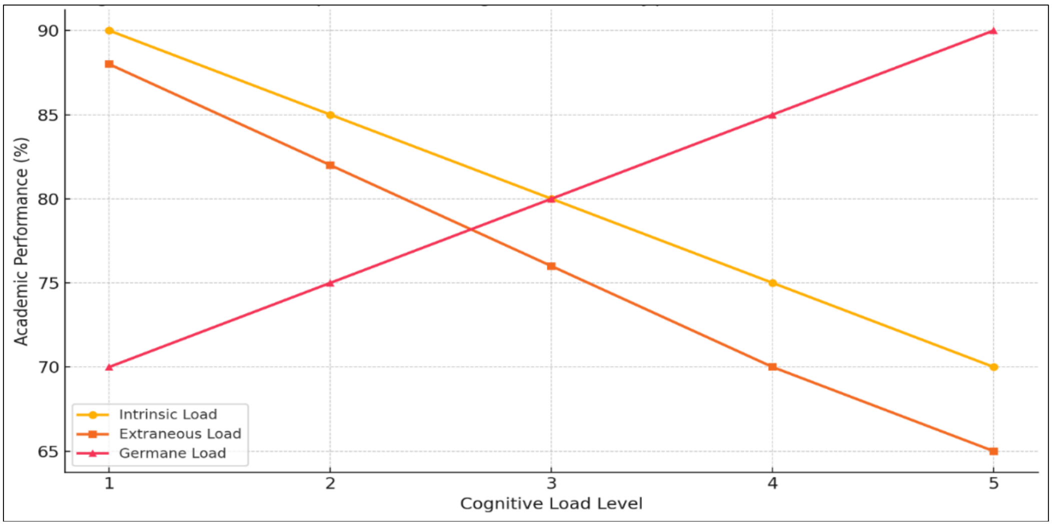

Fig 1: Relationship between cognitive load types and academic performance

The strongest negative impact was observed for extraneous load, confirming that when students encountered disorganized course content, unclear instructions, and technical challenges, their academic performance was significantly reduced. Germane load, reflecting productive cognitive engagement and schema construction, had a significant positive impact on academic performance.

7.2 Sources of Extraneous Load

The sources of extraneous cognitive load were further explored through student self-reports and thematic analysis of qualitative interview data. Students highlighted six primary contributors to extraneous load.

Table 2: Major sources of extraneous load identified by students

Source	Description	% of Students Reporting (N=300)
Disorganized Course Layout	Lack of logical sequencing, unclear structure	71%
Complex Navigation	Non-intuitive LMS interface, multiple platforms	68%
Redundant Information	Repetitive and conflicting materials	64%
Technical Problems	Audio/video issues, LMS failures	58%
Unstable Internet	Disconnections, bandwidth limitations	54%
Unclear Instructions	Vague assignments, missing rubrics	49%

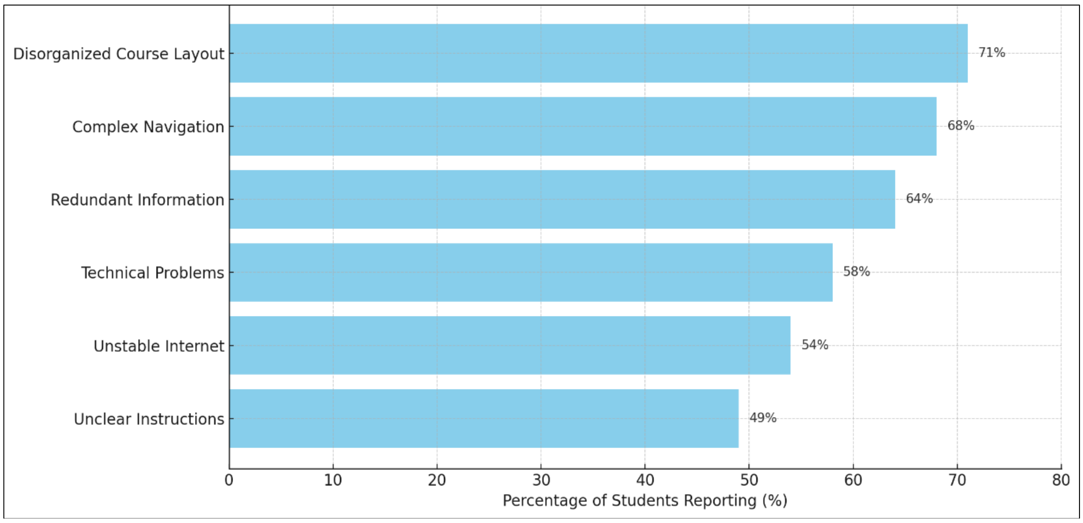

Fig 2: Frequency of extraneous load sources

These results demonstrate that technical design issues, poor organization of learning materials, and infrastructure limitations are major contributors to cognitive overload, limiting students' ability to focus on core learning tasks.

7.3 Germane Load and Learning Strategies

The study also explored how students managed germane load through cognitive strategies. Students who engaged in summarizing, creating concept maps, peer discussions, and reflective journaling exhibited stronger academic outcomes.

Table 3: Learning strategies associated with higher germane load

Learning Strategy	% of High-Performing Students Reporting Use
Concept Mapping	78%
Self-Explanation Notes	72%
Peer Discussion Groups	69%
Reflective Journaling	63%
Self-Testing (Quizzes)	58%

These active cognitive strategies appeared to facilitate schema construction, allowing students to integrate new knowledge into existing mental frameworks, thereby improving academic performance.

7.4 Qualitative Themes from Interviews

The thematic analysis of student interviews yielded four recurrent themes directly related to cognitive load experiences.

Overwhelming Volume of Content: Students often felt burdened by an excessive number of documents, videos, and hyperlinks across various platforms.

- **Technical Anxiety:** Many students expressed stress related to LMS failures, slow internet connections, and complex login procedures.
- **Self-regulation challenges:** Some participants struggled with time management, procrastination, and difficulty sustaining attention in asynchronous learning environments.
- **Instructor support as a buffer:** Timely feedback and availability of instructors were repeatedly cited as crucial factors that helped manage cognitive overload and promoted academic success.

8. Discussion

The findings of this study align with existing research emphasizing the pivotal role of cognitive load management in online learning environments. The negative relationship between extraneous load and academic performance highlights the detrimental effects of poorly designed online courses that fail to account for the cognitive demands placed on learners.

In online learning, instructional design decisions carry even greater weight than in traditional settings due to the absence of real-time instructor mediation. Unclear navigation pathways, disorganized presentation of materials, and redundant multimedia elements unnecessarily strain learners' cognitive resources, leading to cognitive overload and reduced learning efficiency.

The positive association between germane load and academic performance reinforces the importance of promoting cognitive engagement through well-designed learning activities that facilitate schema construction. Techniques such as worked examples, guided problem-solving exercises, and scaffolded practice opportunities help learners actively process and integrate new information into existing knowledge structures.

Intrinsic load, while inherent to the subject matter, can also be moderated through instructional strategies that sequence learning tasks from simple to complex and provide sufficient background knowledge before introducing highly interactive content.

The qualitative findings of this study emphasize that technical infrastructure, learner autonomy, and instructor presence all play significant roles in shaping cognitive load. Inadequate technical support and connectivity issues in developing country contexts exacerbate extraneous load, while lack of time management skills can heighten intrinsic and extraneous load simultaneously.

Furthermore, this study suggests that online learners benefit from social presence and collaborative learning opportunities, which not only support emotional well-being but also help distribute cognitive demands across peers, thereby reducing individual cognitive overload.

9. Implications for Instructional Design

The study offers several instructional design implications for managing cognitive load in online learning:

- Course content should be organized into well-structured modules with clear learning objectives, consistent navigation, and minimal redundant information to reduce extraneous load.
- Multimedia materials should follow Mayer's multimedia design principles, minimizing split attention and redundancy while maximizing coherence and signaling key information.
- Instructors should incorporate scaffolded learning activities that gradually increase complexity, allowing students to build cognitive schemas progressively.
- Active learning strategies such as self-assessment quizzes, peer discussion forums, and reflective journals can enhance germane load and promote deeper cognitive engagement.
- Timely instructor feedback and availability for student consultations are crucial in preventing cognitive overload caused by unresolved misunderstandings.
- Institutions should invest in stable technological infrastructure and provide training for students to enhance their digital literacy and time management skills.

10. Conclusion

This study confirms that cognitive load plays a central role in determining academic performance in online learning among undergraduate students. Excessive extraneous load caused by poor instructional design, technological difficulties, and unclear expectations significantly impairs student performance. Conversely, germane load, representing productive cognitive effort devoted to meaningful learning, enhances academic outcomes when appropriately supported.

Effective online education requires deliberate instructional design that minimizes unnecessary cognitive burdens while fostering cognitive engagement and schema development. Educational institutions, particularly in developing countries, must address technical barriers, strengthen faculty capacity in online pedagogy, and provide comprehensive student support services to ensure equitable access to high-quality online learning experiences.

As online education continues to expand globally, further research is needed to explore longitudinal effects of cognitive load on learning outcomes, investigate discipline-specific cognitive demands, and refine instructional models that optimize cognitive efficiency across diverse learner populations.

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