International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 2, Mar-Apr 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Online vs. Offline Learning: A Quantitative Analysis of Student Preferences and the Access-Cognition Trade-off Model

Mrs. Nompi Raj, Manaswi Suviditha S, Neha Sara Rajan
School of Commerce, Jain (Deemed-to-be University), India
nompi.raj@jainuniversity.ac.in, smanaswi65@gmail.com, nehasara20004@gmail.com

--************************----------------------------------

Abstract:

The rapid transition from traditional face-to-face educational systems to digital learning environments, heavily catalyzed by the COVID-19 pandemic, has fundamentally disrupted established pedagogical paradigms. While emergency remote teaching demonstrated the viability of digital infrastructure and preserved educational continuity, the subsequent stabilization of academic delivery has revealed a complex and often contradictory landscape of learner preferences and performance outcomes. This research presents a quantitative analysis of student preferences regarding online, offline, and hybrid learning modalities. Utilizing primary survey data collected from fifty-one (n=51) students across varying educational tiers, the study investigates these environments across critical dimensions: cognitive understanding, behavioral engagement, academic performance, social interaction, and socio-technical barriers. The findings reveal a distinct "Preference Paradox": although online learning is lauded for its flexibility and logistical convenience, a significant majority of students report better performance, greater discipline, and a strong preference for offline learning. To contextualize these findings, this paper introduces a novel theoretical framework—the Access-Cognition Trade-off Model (ACTM)—proposed as a conceptual and interpretive lens positing that digital environments optimize for informational access at the expense of cognitive processing efficacy, whereas physical classrooms restrict spatial-temporal access while highly optimizing the cognitive execution environment. Given the exploratory nature of the study, findings should be interpreted as indicative trends. By synthesizing empirical results with Cognitive Load Theory, Social Presence Theory, Transactional Distance Theory, Self-Determination Theory, and Media Richness Theory, this paper provides evidence-informed guidelines for the design of future hybrid educational systems.

Keywords — online learning, offline learning, hybrid learning, cognitive load theory, access-cognition trade-off model, student preferences, educational technology, social presence theory.

--************************----------------------------------

I. INTRODUCTION

A. Background and Motivation

The educational sector has witnessed a historic and paradigm-altering shift over the past decade, a transformation heavily accelerated by the COVID-19 pandemic [1]. Traditional classroom instruction, historically the undisputed backbone of academic pedagogy, was abruptly supplanted by digital learning systems to maintain public health and safety [2]. This forced transition functioned as an unprecedented natural experiment, compelling educators and learners to immerse themselves in virtual environments regardless of their prior technological proficiency [3].

As the acute phase of the pandemic receded and institutions began offering a return to physical classrooms or formalized hybrid alternatives, a critical opportunity emerged to evaluate how these distinctly different environments shape human cognition, engagement, and long-term academic performance [4]. The ongoing debate between online and offline learning transcends a simple logistical comparison of delivery mechanisms; it addresses fundamental questions regarding the socio-technical nature of education [6]. Offline learning, characterized by physical co-presence, synchronous communication, and rigid schedules, provides an environment rich in immediate feedback and robust social cues [7]. Online learning, conversely, offers asynchronous flexibility, spatial independence, and the digitization of vast academic resources [9].

Empirical observations and emerging literature increasingly suggest that the convenience of digital access does not automatically equate to effective knowledge acquisition or sustained learner engagement [10]. Students navigating online platforms frequently report feelings of isolation, diminished motivation, and heightened susceptibility to distraction, highlighting a persistent disconnect between technological capability and pedagogical efficacy [4].

B. Research Objectives

This divergence between the logistical ease of online education and the cognitive efficacy of offline instruction forms the central inquiry of this research. The overarching objective is to dissect the multifaceted nature of student preferences, moving beyond superficial utilization metrics to understand the deep psychological, cognitive, and practical factors driving these choices. Specifically, this study seeks to articulate what students prefer—independent of institutional assumptions—and to theoretically ground these preferences in established cognitive science. The analysis aims to transition academic discourse from a binary competition between modalities toward the deliberate, evidence-based design of hybrid systems that strategically leverage the inherent strengths of both environments [12].

II. LITERATURE REVIEW

To comprehensively interpret the dynamics of modern educational environments, it is imperative to anchor empirical data within established psychological and pedagogical frameworks. The following theoretical paradigms provide the necessary foundation for evaluating the efficacy of online versus offline learning.

A. Cognitive Load Theory (CLT)

Cognitive Load Theory (CLT), originally developed by John Sweller, postulates that human working memory is highly limited in both capacity and duration [13]. Learning is conceptualized as the active process of transferring information from working memory into long-term memory via the construction of cognitive schemas [14]. CLT identifies three distinct types of cognitive load: intrinsic load (inherent difficulty of subject material), extraneous load (generated by instructional design mechanics), and germane load (cognitive resources dedicated to schema construction) [15].

In technology-based learning environments, extraneous cognitive load is frequently amplified [9]. Navigating complex learning management systems, troubleshooting unstable connectivity, and processing asynchronous multimedia materials can exhaust working memory resources that should be allocated to germane processing [16]. Educational Neuroscience tools such as EEG and fNIRS demonstrate that poorly designed digital interfaces lead to measurable cognitive overload, directly degrading learning outcomes [18]. Offline environments tend to minimize extraneous load through the physical presence of an instructor who dynamically regulates information flow, directs attention, and provides real-time scaffolding [10].

B. Social Presence Theory (SPT)

Social Presence Theory (SPT) emphasizes the degree to which a person is perceived as a "real" individual in mediated communication [7]. Within the Community of Inquiry (CoI) framework developed by Garrison, Anderson, and Archer, social presence operates alongside cognitive presence and teaching presence as a fundamental pillar of meaningful educational experiences [7]. Offline learning inherently possesses exceptionally high social presence. The richness of face-to-face interactions—encompassing eye contact, body language, vocal inflection, and spontaneous peer dialogue—fosters a profound sense of belonging and academic community [23].

In contrast, online learning strips away critical non-verbal cues, leading to a sterile environment where students feel disconnected from peers and instructors [4]. The literature consistently demonstrates that diminished social presence in online settings correlates strongly with reduced student engagement, lower affective learning, and higher attrition rates [25].

C. Transactional Distance Theory (TDT)

Michael Moore's Transactional Distance Theory (TDT) defines "distance" not merely in geographical terms, but as a psychological and communicational gap between instructors and learners [28]. TDT identifies three interacting variables: dialogue (extent of teacher-learner interaction), structure (rigidity of course design), and learner autonomy (self-direction in goal setting and evaluation) [30]. In highly structured, low-dialogue online courses, transactional distance is maximized, placing an often unsustainable burden on learner self-regulation [31]. Offline classrooms natively minimize transactional distance through high dialogue and dynamic, responsive structures [32].

D. Self-Determination Theory (SDT)

Self-Determination Theory (SDT) posits that optimal human motivation requires the continuous fulfillment of three innate psychological needs: autonomy (self-regulation), competence (effectiveness mastery), and relatedness (meaningful social connection) [33]. The transition to online learning fundamentally alters the mechanisms through which these needs are satisfied. While asynchronous online learning ostensibly increases autonomy [35], it often compromises competence due to technical challenges and a lack of immediate instructional support, as well as relatedness due to physical isolation [36]. Face-to-face environments naturally satisfy relatedness through peer integration and collaborative tasks, while simultaneously satisfying competence through immediate instructor validation [4].

E. Media Richness Theory (MRT)

Media Richness Theory (MRT), introduced by Daft and Lengel, suggests that communication effectiveness relies on a medium's capacity to reproduce information without loss or ambiguity [39]. Media are classified on a continuum of richness based on their ability to handle multiple cues simultaneously and facilitate rapid feedback [40]. Physical classrooms represent the pinnacle of media richness, transmitting complex concepts through immediate, multi-channel communication [41]. For highly equivocal tasks—such as mastering mathematical proofs, engaging in philosophical debates, or executing scientific experiments—lean digital media result in cognitive frustration and diminished learning outcomes [42].

III. THEORETICAL FRAMEWORK: THE ACTM

The Access-Cognition Trade-off Model (ACTM) is proposed as a conceptual and interpretive framework rather than a fully empirically validated model. While the existing theories of CLT, SPT, TDT, SDT, and MRT explain specific psychological and communicative deficiencies within online learning, they often fail to capture the systemic duality and architectural compromises inherent in modern educational technology. The ACTM is introduced to address this gap.

Drawing upon an analogy from computer science and distributed computing, the ACTM posits that educational modalities force a fundamental compromise between informational availability (Access) and processing efficacy (Cognition). Recent research in cognitive psychology and artificial intelligence is consistent with a similar trade-off between behavioral flexibility (in-context learning) and long-term retention (in-weight learning), suggesting that systems optimizing for immediate access may sacrifice deep structural encoding [43]. This trade-off parallels emerging findings in artificial intelligence, where systems optimizing for in-context retrieval exhibit reduced internalization compared to systems trained for parameterized knowledge retention [43].

A. The Access Layer (Online Learning)

Online learning optimizes almost exclusively for the "Access Layer." It maximizes the bandwidth of information delivery, rendering geographical boundaries and temporal constraints obsolete. Students can access vast repositories of recorded lectures, digital texts, and global expertise instantaneously, achieving a state of hyper-availability. However, this hyper-availability operates on a lean cognitive infrastructure. The digital environment provides raw data but delegates the entire "computational" burden—maintaining focus, enforcing discipline, and achieving schema integration—to the isolated student's internal cognitive resources. This leads to cognitive offloading, where reliance on digital access diminishes internal memory processing and long-term retention [45].

B. The Cognition Layer (Offline Learning)

Offline learning optimizes for the "Cognition Layer." It is inherently restrictive at the access level, requiring strict synchronization of time, location, and physical presence. However, this physical environment serves as a highly optimized execution environment. The physical classroom offloads executive functioning from the individual learner to the environmental structure: the instructor commands attention, the institutional schedule enforces discipline, and physical peer presence triggers social accountability. The offline setting provides high-powered cognitive scaffolding, including immediate feedback loops and structured pedagogical pacing, which drastically reduces extraneous cognitive load.

C. The Mechanism of the Trade-off

The ACTM suggests that an unmediated increase in spatial-temporal access—such as moving a curriculum fully online—may trigger a degradation in cognitive processing efficiency for the median learner. Students may select online options for their unparalleled convenience, explicitly prioritizing Access, yet their cognitive architecture may require the structured, interactive environment of the physical classroom to synthesize complex novel information. This trade-off provides a conceptual explanation for the "Preference Paradox": students demand the logistical ease of online platforms but recognize the superior learning outcomes generated by physical classrooms.

As illustrated in Fig. 1, the ACTM positions each modality along an Access-Cognition continuum. Hybrid learning models should not be viewed merely as scheduling compromises, but as deliberate architectural attempts to resolve the Access-Cognition Trade-off by separating high-volume data-acquisition tasks (suited for online) from heavy cognitive-processing tasks (suited for offline).

Figure 1

Conceptual Framework of the Study

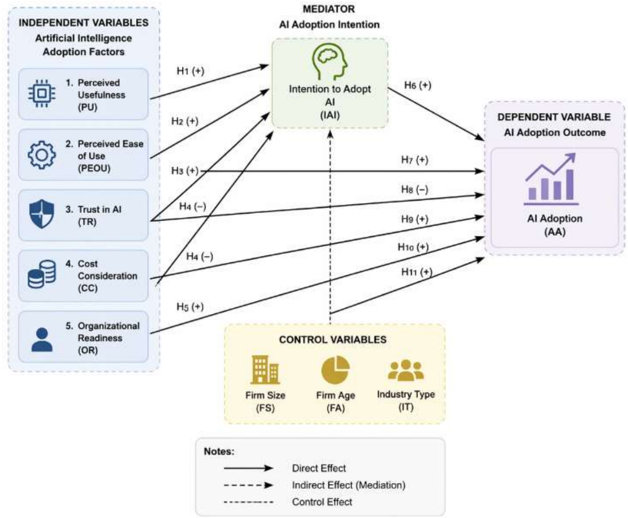

Fig. 1. The Access-Cognition Trade-off Model. Online learning maximizes informational access but minimizes cognitive scaffolding; offline learning restricts access but maximizes the cognitive execution environment; hybrid occupies the middle zone.

IV. METHODOLOGY

A. Research Design

This study employed a descriptive and comparative quantitative research design to systematically evaluate student experiences across online, offline, and hybrid learning modalities [4]. The primary objectives were: (1) to evaluate students' explicit preferences based on dimensions of flexibility, interaction, and accessibility; (2) to compare the perceived effectiveness of each modality regarding cognitive understanding, academic performance, and behavioral engagement; (3) to identify and quantify critical challenges, particularly technological barriers and motivational deficits in digital environments; and (4) to analyze the role of social interaction, time management, and discipline in shaping long-term educational preferences.

B. Sampling Strategy and Demographics

The study utilized a simple random sampling method to ensure broad, unbiased representation and to mitigate selection bias. The sample comprised fifty-one participants (n=51) drawn from high school, undergraduate, and postgraduate educational tiers [4]. The inclusion of diverse academic backgrounds ensured that data reflected generalized student experiences across the educational spectrum rather than cohort-specific anomalies. Participants were selected based on their sustained exposure to both fully online environments—primarily driven by pandemic lockdowns—and traditional offline learning paradigms, enabling informed comparative assessments based on lived experience rather than theoretical assumptions [4].

Given the exploratory nature and limited sample size (n=51), the analysis is restricted to descriptive statistics. Inferential statistical testing (e.g., hypothesis testing, regression modeling) was not performed, and therefore findings should be interpreted as indicative trends rather than statistically generalizable conclusions. The sample size of fifty-one is appropriate for foundational cognitive and design studies that prioritize depth of process data and internal validity over broad scope [47].

C. Data Collection Instrument

Primary data was collected using a structured questionnaire administered via Google Forms [4]. The instrument encompassed close-ended questions including multiple-choice selections and binary categorical responses, ensuring quantitative rigor and ease of comparison. The survey evaluated parameters across several domains: primary mode preference (Online, Offline, and Hybrid); perceived conceptual understanding and academic performance; engagement and intrinsic motivation levels; social connectivity versus feelings of isolation; discipline and time management capabilities; and the prevalence of technological impediments.

D. Methodological Limitations

Several methodological constraints inherent in this study must be explicitly acknowledged. First, self-reported academic performance may not accurately reflect objective outcomes, as students may conflate satisfaction with actual performance. Second, the sample is geographically and demographically constrained, limiting the generalizability of findings to broader populations. Third, the study employs no longitudinal tracking of learning retention, meaning that long-term cognitive outcomes remain unverified. Fourth, the cross-sectional design precludes causal inference between learning modality and performance outcomes. These limitations underscore the exploratory nature of this work.

V. RESULTS

A. Preferred Mode of Learning

When participants selected their preferred mode of education, the data indicated a strong aversion to exclusively digital platforms. As shown in Table I, a mere 9.8% of students preferred fully online learning, highlighting an overwhelming demand for physical presence. The slight preference for hybrid learning (47.1%) over fully offline environments (43.1%) suggests a desire to blend the structural richness of the classroom with the logistical flexibility of digital access [4].

TABLE I
STUDENT PREFERENCE BY LEARNING MODALITY (N=51)

Modality	Preference (%)
Hybrid Learning	47.1%
Offline (Face-to-Face)	43.1%
Online Learning	9.8%

B. Cognitive and Performance Metrics

Table II presents a comparative breakdown across key cognitive and behavioral dimensions, demonstrating a consistent pattern in which offline learning is associated with superior reported outcomes.

TABLE II
COMPARATIVE PERFORMANCE AND COGNITIVE METRICS (N=51)

Dimension	Offline (%)	Online (%)
Conceptual Understanding	72.5	27.5
Academic Performance	76.5	23.5
Student Engagement	66.7	33.3
Discipline & Time Mgmt.	78.0	22.0
Practical / Hands-on	84.3	15.7

The data is consistent with the predictions of Cognitive Load Theory: the physical presence of an instructor is associated with a reduction in extraneous cognitive load through dynamic pacing and the elimination of digital interface friction [14]. Similarly, 76.5% of students perceived their academic performance to be higher in offline settings, underscoring the role of structured environments in facilitating deep knowledge retention. Behaviorally, 78.0% of participants reported greater discipline in an offline setting—the institutional schedule of the physical classroom effectively offloads executive regulation from the student to the environment.

C. Social Connectivity and Isolation

The social dimension revealed a stark contrast between modalities. When asked about feelings of connectivity, 86.3% of students reported feeling more connected in offline environments, while 74.5% reported experiencing isolation during online learning. This dataset provides strong support for Social Presence Theory [7].

TABLE III
SOCIAL CONNECTIVITY AND MOTIVATIONAL METRICS (N=51)

Metric	Offline (%)	Online (%)
Feel Connected	86.3	13.7
Feel Isolated	25.5	74.5
Motivation Drop (Online)	—	88.0
Technical Issues (Online)	—	84.3

D. Motivation and Technological Barriers

A striking 88.0% of students reported a decline in motivation when operating in exclusively online environments. This motivational erosion is consistent with the tenets of Self-Determination Theory, particularly the compromise of relatedness and competence needs in digital spaces [33]. The technological barrier dimension further undermines online learning's claim to superior pedagogical efficacy. A total of 84.3% of students encountered technical issues during online learning, including erratic internet connectivity, software malfunctions, and device limitations [4]. These barriers do not merely disrupt learning temporally; they generate severe extraneous cognitive load that impedes knowledge transfer and breaks cognitive flow [48].

E. Future Learning Preferences

When asked to project their ideal educational framework, 51.0% of students expressed a desire to return to exclusive offline instruction, while 37.3% sought a hybrid compromise. The fully online model was preferred by only 11.8% of the cohort for long-term engagement. When students preferring offline learning were asked to identify the primary drivers, better interaction with teachers and classmates was cited by 62.0%, better focus and motivation by 14.0%, and fewer distractions and structured environment each by 12.0%, explicitly demonstrating that the primary value of the physical classroom lies in rich, synchronous human communication [4].

VI. DISCUSSION

A. Deconstructing the "Preference Paradox"

The most striking insight generated by the data is the explicit manifestation of the "Preference Paradox" [4]. This paradox highlights a critical dissonance between what students value for lifestyle convenience versus what they psychologically require for cognitive success. Online learning offers unparalleled logistical advantages: 29.8% of respondents praised flexible scheduling, and 23.4% valued the time and cost savings associated with remote learning [4]. However, despite acknowledging these benefits, a mere 9.8% chose online learning as their preferred mode.

The answer lies in the brain's requirement for environmental structure and social accountability. Students recognize that the autonomy granted by online learning is a pedagogical double-edged sword. Without the external regulation provided by a physical classroom, the burden of maintaining discipline and focus shifts entirely to the student's internal executive functions. As the data suggests, 78% of students lack the requisite sustained self-discipline in a home environment rich with digital distractions. The Preference Paradox implies that learners are willing to sacrifice significant personal convenience in exchange for the psychological scaffolding, peer accountability, and cognitive assurance that the offline environment provides [4].

B. Preliminary Support for the Access-Cognition Trade-off Model (ACTM)

The empirical findings provide preliminary support for the proposed ACTM. Online learning is consistent with successfully addressing the "Access" problem by making materials available on demand. However, the data suggests a pattern of underperformance at the "Cognition" layer: 72.5% of students reported better conceptual understanding offline, and 76.5% reported superior academic performance offline [4]. These patterns are consistent with the central proposition of the ACTM—that hyper-availability of data without a structured execution environment may degrade cognitive processing efficiency for typical learners. In the physical classroom, the instructor acts as a dynamic manager of cognitive load, reading micro-expressions of confusion and adjusting pedagogy in real-time to prevent overload. In the online model, the student faces an asynchronous data stream, a challenge exacerbated by the technical friction reported by 84.3% of participants [9].

C. Social Presence and Motivation Crisis

The dataset provides findings consistent with Social Presence Theory (SPT) and Self-Determination Theory (SDT). The most dominant reason students prefer offline learning is better interaction with teachers and classmates (62%). The reality that 86.3% feel more connected offline while 74.5% feel isolated online directly corresponds to the 88% who reported a drop in motivation in digital spaces [4]. According to SDT, intrinsic motivation is fueled by the psychological needs for relatedness and competence [34]. The digital environment, inherently mediated by screens and subject to the "Transactional Distance" described by Moore, strips away the affective and spontaneous dimensions of learning [29]. Students are not merely information-processing units; they are social entities whose cognitive engagement is profoundly intertwined with interpersonal accountability and peer validation [7]. When reduced to video boxes on a screen, the social contract of learning is weakened, leading to the motivational decline observed in the data.

D. Media Richness and the Limitations of Current Digital Tools

Strictly applying Media Richness Theory to the dataset exposes a critical limitation of current digital education tools [39]. While synchronous video conferencing is richer than asynchronous text, it remains significantly leaner than physical presence [40]. It lacks spatial audio, disrupts natural eye contact, limits peripheral vision, and introduces latencies that affect organic conversational flow. For complex, highly equivocal tasks—such as practical lab work (84.3% of students stated these require offline environments)—the digital medium is fundamentally too lean to support the necessary rapid feedback and nuance of deep knowledge transfer [42]. Furthermore, since 84.3% of students experience recurring technical issues, the digital medium routinely severs the pedagogical connection entirely, introducing devastating extraneous cognitive load.

VII. CONCLUSION

This quantitative analysis suggests that the digitalization of education, while a significant logistical and administrative achievement, presents substantial challenges for cognitive and pedagogical development. The empirical data indicates that offline learning is associated with superior outcomes in deep knowledge acquisition, academic performance, behavioral discipline, and social integration for the student sample studied.

Through the lens of the newly proposed Access-Cognition Trade-off Model (ACTM), used alongside established paradigms such as Cognitive Load Theory, Social Presence Theory, and Media Richness Theory, the "Preference Paradox" is coherently explained. Students appear to recognize that while online platforms optimize for the seamless delivery of information, the structured, interactive, and socially vibrant environment of the physical classroom is better suited to transforming that raw information into lasting understanding.

The findings of isolation, diminished motivation, and technological fatigue reported in digital settings suggest a need for strategic recalibration of modern education. The future does not lie in a regression to rigid traditionalism, nor in an uncritical abandonment to fully virtual environments. Instead, the evidence points toward the intelligent deployment of hybrid learning architectures that leverage digital networks for foundational materials and asynchronous tasks, while preserving physical classrooms for rigorous cognitive processing and deep human connection.

Future research should focus on controlled experimental designs comparing learning outcomes across modalities, incorporating objective performance metrics, longitudinal retention analysis, and neurocognitive measurements to further refine and empirically validate the ACTM framework. Larger, more demographically diverse samples will be essential for establishing the generalizability of these preliminary findings.

Limitations Summary: (1) Self-reported academic performance may not reflect objective outcomes. (2) Sample is geographically and demographically constrained. (3) No longitudinal tracking of learning retention was performed. These constraints limit causal inference and generalizability.

REFERENCES

[1] K. A. Bates et al., "Online learning during COVID-19: Meta-analysis," *Int. J. Environ. Res. Public Health*, vol. 19, no. 19, 2022.
[2] R. S. Gupta et al., "Impact of online education on student engagement," *Front. Psychol.*, 2025.
[3] A. J. Copeland and D. Hwang, "Remote vs. in-person learning," *Front. Educ.*, vol. 7, 2022.
[4] Primary Survey Data (n=51), 2024–2025.
[5] M. Means et al., "Online vs. in-person learning," *Online Learn. J.*, vol. 28, no. 2, 2024.
[6] J. Kellam and B. Cooke, "Socio-technical design in education," *Front. Educ.*, vol. 8, 2023.
[7] P. Gorsky and A. Blau, "Social presence in online learning," *Educ. Technol. Soc.*, 2015.
[8] L. Makri, "Social VR in higher education," *Front. Educ.*, 2023.
[9] F. Lopez-Caudana et al., "Hybrid teaching post-COVID," *Front. Educ.*, 2024.
[10] E. Olofsson and H. Lindberg, "Online vs face-to-face learning," *Cogent Educ.*, 2025.
[11] A. Adedoyin and E. Soykan, "Online learning readiness," *PLoS ONE*, 2021.
[12] M. Johnson, "Distance learning framework," *Soc. Sci.*, 2027.
[13] P. K. Pham, "Cognitive load in online learning," *J. Educ. Health Soc. Sci.*, 2023.
[14] J. Sweller et al., "Cognitive load theory," *Educ. Technol. Res. Dev.*, 2011.
[15] G. Risko and B. Duffy, "Social presence & cognitive load," *Interact. Technol. Smart Educ.*, 2019.
[16] N. Kumar, "Cognitive load in digital classrooms," 2025.
[17] T. Martin, "Cognitive load in mobile learning," *Front. Psychol.*, 2020.
[18] M. Ozan-Leiva and T. Chen, "Neuroscience & AI in learning," *Brain Sci.*, 2025.
[23] S. Brennan and L. Phelan, "Student engagement post-pandemic," *Innov. Educ. Teach. Int.*, 2026.
[25] Y. Li and Z. Wang, "Online interaction & engagement," *Front. Psychol.*, 2022.
[28] A. A. Alsofyani, "Transactional distance theory," *Educ. Sci.*, 2023.
[29] M. G. Moore, "Transactional distance theory," 1993.

[30] M. G. Moore, "Technology & distance learning," *IRRODL*, 2018.
[31] M. G. Moore, "Distance learning satisfaction," 2018.
[32] M. G. Moore and G. Kearsley, *Distance Education*, 3rd ed., 2012.
[33] T. T. Chiu, "Student engagement in blended learning," 2021.
[34] T. T. Chiu, "SDT in online learning," 2021.
[35] H. Wang et al., "Motivation in online learning," *SAGE Open*, 2021.
[36] E. L. Deci and R. M. Ryan, "Self-determination theory," 2012.
[39] H. Du et al., "Media richness & online learning," *Front. Psychol.*, 2022.
[40] R. L. Daft and R. H. Lengel, "Media richness theory," *Manage. Sci.*, 1986.
[41] R. Daft and R. Lengel, "Media naturalness & learning," 2017.
[42] R. E. Rice, "Media appropriateness," *Hum. Commun. Res.*, 1993.
[43] N. Kim et al., "Cognition & neural networks," *PNAS*, 2025.
[45] R. Coll and M. Marek, "Distributed cognition," *Front. AI*, 2022.
[47] P. Nguyen, "Cognitive load in design," *Int. J. Technol. Des. Educ.*, 2026.
[48] A. Dalton and L. Kim, "Sociotechnical learning systems," 2023.

