

Pedagogical Friction in ICT-Integrated K-12 Classrooms: Cognitive Offloading, Technostress, and Shallow Processing

Goran Hajdin

University of Zagreb

Faculty of organization and informatics

Pavlinka 2, 42000 Varaždin, Croatia

goran.hajdin@foi.unizg.hr

Abstract. National K-12 digitalization initiatives assume that interactive digital tools inherently enhance learning outcomes. This convergent parallel mixed-methods study (N=90 teachers) investigates the socio-cognitive impacts and pedagogical friction of digital tools in K-12 classroom environment. The scope of this paper is delimited to a specific thematic fragment of the broader survey dataset, focusing specifically on the relationship between teacher digital competence, technostress, and observed student cognitive behaviors. Results reveal a significant discrepancy between general teacher satisfaction and actual student cross-curricular understanding. Ordinal logistic regression indicates that teachers' digital competence does not predict satisfaction or ease of use. Instead, persistent first-order barriers act as an absolute tax, triggering uniform technostress. According to teachers' observations, interactive digital scenarios are perceived to be associated with student behaviors such as skimming, scrolling, and prompt-dependency, which may reflect a tendency toward surface-level task engagement and cognitive offloading rather than sustained schema construction.

Keywords. Teaching Scenarios, Cognitive Offloading, Technostress, Shallow Learning, First-order Barriers, Educational Technology

1 Introduction

Integrating Information and Communication Technology (ICT) in K-12 classrooms has historically operated under a technocentric, confirmatory paradigm. Driven by nationwide digitalization initiatives, such as Croatia's "e-Schools" initiative, policymakers frequently assume that replacing paper-based media with interactive digital scenarios inherently enhances motivation and curricular efficiency (Altamura et al., 2025; Caena & Redecker, 2019; Liman Kaban & Karadeniz, 2021). However, a critical counter-narrative has emerged. Rather than witnessing a seamless translation of digital visual

interaction into deep learning process, K-12 teachers report significant pedagogical friction, fragmented classroom orchestration, and flattened learning outcomes (Ajani, 2024; Skulmowski, 2023).

This disconnect represents a clash between software design architectures and human cognitive architecture (Sweller et al., 2011). Digital learning scenarios often prioritize rapid, fragmented interactivity and gamification. While these elements temporarily boost surface-level engagement, they simultaneously trigger high extraneous cognitive load (Skulmowski, 2023; Sweller et al., 2011). Under this paradigm, students are conditioned to engage in shallow processing characterized by non-linear visual scanning, keyword spotting, and rapid scrolling (Altamura et al., 2025; Liu, 2005; Mason et al., 2024). Furthermore, immediate, frictionless access to information on screens facilitates cognitive offloading (Risko & Gilbert, 2016). Instead of exerting the germane cognitive effort required for schema construction, students outsource memory processes to digital devices, treating the interface as a prosthetic memory bank (Gilbert et al., 2023; Grinschgl et al., 2021; Sun et al., 2025).

This transition imposes parallel burdens on teachers. Teachers must navigate complex orchestration while managing persistent first-order infrastructural failures like unstable networks and rigid software boundaries (Alptekin & Taneri, 2025). Troubleshooting technology under compressed lesson times triggers severe technology-induced anxiety, or technostress (Tarafdar et al., 2007, 2024).

While policymakers assume that digital upskilling frameworks like DigCompEdu mitigate these challenges, empirical evidence suggests a paradox of competence (Antonietti et al., 2022; Caena & Redecker, 2019). Highly competent teachers do not experience greater satisfaction. Instead, their advanced skills afford them a critical diagnostic gaze that exposes systemic infrastructural deficits and pedagogical mismatches (Ajani, 2024; Suzer & Koc, 2024). This diagnostic tension is intertwined with teachers' self-efficacy, their integrated competence

profiles to promote self-regulated learning (SRL), and their capacity to scaffold metacognition (Dignath, 2021; Hu et al., 2025; Karlen et al., 2023). When automated software designs bypass didactical mediation, they decouple self-efficacy from competence deployment, exacerbating classroom orchestration friction and student cognitive dependency (Dignath, 2021; Karlen et al., 2023).

Using a convergent parallel mixed-methods design grounded in the pragmatist paradigm (Cohen et al., 2018), this study analyzes empirical survey data and qualitative reflections from 90 teachers. The primary goal of this study is to investigate the dual-sided pedagogical friction of ICT integration in classical K-12 classrooms by evaluating the mitigating effect of teacher digital competence on structural barriers and technostress, while simultaneously analyzing the observed impacts of interactive digital scenarios on student cognitive load, reading behaviors, and knowledge retention.

2 Previous Research

2.1 Screen-Mediated Reading and Multimodal Integration

Transitioning from print to digital mediums reshapes students' reading habits and comprehension strategies. Although digital mediums deliver interactive multimedia, empirical research indicates that screen reading alters cognitive engagement, fostering superficial processing (Altamura et al., 2025; Liu, 2005). Liman Kaban and Karadeniz (2021) observed that personalized, gamified digital reading increased motivation but failed to yield superior comprehension, encouraging rapid, less focused reading behaviors. Over time, frequent digital reading negatively impacts comprehension and long-term motivation, conditioning students to engage with highly fragmented texts (Altamura et al., 2025).

To counteract shallow processing, digital interventions like highlighting are used. However, Mason et al. (2024) found that manual digital highlighting can overload working memory, whereas pre-provided highlights often lead to passive processing, showing that digital tools must actively support generative cognitive engagement to be effective. This is particularly critical in complex environments integrating text with diagrams, which represents a major hurdle for young learners (Jian & Cheung, 2025; Sweller et al., 2011). Jian and Cheung (2025) identified stable, distinct student strategic profiles, while integrative readers engaged in recurrent cross-referencing between text and diagrams (predicting superior comprehension), non-integrative readers struggled to coordinate visual attention. Because these profiles remained stable from grades four to six, students do not naturally develop multimodal integration strategies through passive

exposure to digital media. Instructional designs must actively guide visual attention (Jian & Cheung, 2025; Sweller et al., 2011).

2.2 Cognitive Offloading and Metacognitive Biases

The ease of retrieving information from digital devices has altered internal memory utilization, leading to cognitive offloading - the strategic use of external resources to reduce internal cognitive demands (Risko & Gilbert, 2016). Gilbert et al. (2023) note that intention offloading (outsourcing tasks to digital reminders) is highly effective and metacognitively guided. However, individuals frequently exhibit a positive reminder bias, over-allocating intentions to digital tools even when internal memory is fully capable (Gilbert et al., 2023).

While offloading delayed intentions preserves cognitive bandwidth, offloading factual information into digital storage can degrade long-term memory representations (Grinschgl et al., 2021). When the physical or cognitive cost of offloading is low, individuals readily externalize memory processes to boost immediate task execution. However, this immediate performance benefit comes at a direct cost to subsequent memory; in unexpected post-tests, individuals who offloaded demonstrated significantly poorer recall (Grinschgl et al., 2021). To integrate these findings, Skulmowski (2023) developed a model of digital externalization, positioning extraneous cognitive load in technology-enhanced learning as a triple barrier that prevents key information from entering working memory, inhibits schema construction, and encourages premature cognitive offloading.

This offloading bias has profound developmental implications. Children as young as four engage in offloading, but demonstrate significant biases, showing periods of non-selective over-offloading (Armitage & Gilbert, 2025). Sun et al. (2025) verified this developmental trajectory from ages seven to fifteen. Primary school students display an under-offloading bias due to overestimating their memory capacity, whereas secondary school students exhibit more calibrated, strategic choices. This presents a major challenge for K-12 digital scenarios; younger students may lack the metacognitive maturity to know when to rely on digital aids, while older students may over-rely on instant feedback, leading to detrimental cognitive offloading (Armitage & Gilbert, 2025; Sun et al., 2025).

2.3 Systemic Orchestration, Teacher Competence, and SRL Scaffolding

The successful operationalization of digital scenarios depends on the teacher's digital competence. Under the DigCompEdu framework, teacher proficiency profiles span from Explorer (basic) to Innovator (advanced)

(Caena & Redecker, 2019). However, average competence levels typically cluster around the intermediate (Integrator) tier, reflecting persistent environmental boundaries that prevent advanced innovation (Suzer & Koc, 2024). According to the Technology Acceptance Model (TAM), digital competence beliefs predict perceived usefulness and ease of use, determining adoption intentions (Antonietti et al., 2022). Yet, this linear relationship is frequently disrupted by classroom orchestration demands, where teachers must navigate physical space, student engagement levels, and constant instructional interruptions (Ajani, 2024; Alptekin & Taneri, 2025).

This orchestration challenge is directly tied to the promotion of SRL and metacognitive scaffolding. Digital competence and teacher self-efficacy are deeply reciprocal (Hu et al., 2025). However, a decoupling between self-efficacy and actual digital execution occurs when teachers are confronted with rigid, pre-packaged digital scenarios that bypass active didactical mediation (Hu et al., 2025; Karlen et al., 2023). Karlen et al. (2023) show that a teacher's capacity to promote student metacognition is fully mediated by their professional pedagogical-metacognitive knowledge, subjective self-efficacy, and intrinsic valuation of self-regulation. If digital scenarios restrict teacher mediation, they render professional knowledge useless, depriving students of the human scaffolding needed to build independent learning strategies.

Furthermore, teacher competence in promoting SRL is highly heterogeneous. Dignath (2021) identified distinct competence profiles, demonstrating a “Matthew effect” where high-competence teachers benefit exponentially more from professional training. Digital scenarios that ignore these diverse latent profiles fail to support teachers who need the most assistance, imposing uniform constraints that convert potential technological aids into sources of classroom friction and cognitive dependency (Dignath, 2021; Karlen et al., 2023).

3 Research Methodology

This study utilizes a convergent parallel mixed-methods design grounded in the pragmatist paradigm (Cohen et al., 2018). By combining the quantitative modeling of Likert-scale evaluations with the qualitative depth of reflexive thematic coding, this framework seeks to triangulate teacher-reported satisfaction against emergent socio-cognitive barriers in real-world K-12 classrooms.

The target population comprises active primary and secondary teachers exposed to a national digitalization initiative. The final sample consists of 90 teachers selected via convenience sampling. The sample is heavily female (88.9%). The sample reflects an experienced teaching profile: 22.2% possess 11–15 years of experience, 16.7% possess 16–20 years,

16.7% possess 21–25 years, and 13.3% have 31 or more years of teaching practice. Self-reported digital competence, measured via DigCompEdu, reveals a proficient workforce: 54.8% identify as intermediate (Integrator), 35.5% as advanced (Innovator), and 9.7% as beginner (Explorer).

To address the research goal, we defined two research questions:

- RQ1: To what extent do self-reported high levels of teacher digital competence mitigate the perception of first-order infrastructural barriers and the experience of technostress?
- RQ2: In what ways do interactive digital scenarios influence K-12 students' cognitive load, reading behaviors, and knowledge retention, as observed by their teachers?

Data collection was executed using a validated online survey instrument adapted from Framework for Digitally Mature Schools in the e-Schools initiative. The quantitative component includes structured Likert-scale questions (1–5 scale) evaluating instructional quality (Q10), student cross-curricular understanding (Q11), and perceived efficiency (Q12), alongside a 15-item evaluation grid (Q9) measuring interactive and organizational attributes. Scale reliability was confirmed via Cronbach's alpha, yielding a high reliability coefficient of 0.88. The qualitative component comprises open-ended questions (Q13, Q14, Q15) exploring advantages, disadvantages, and cognitive barriers.

The empirical baseline of this research is situated within the broader context of Croatia's national digitalization campaign, specifically the e-Schools initiative (2nd phase 2018 to 2023), which aimed to establish digital maturity across 1321 schools. While the broader, multi-dimensional dataset captured macro-level institutional indicators such as network performance, administrative e-services, and institutional platform usage, this study targeted the specific intersection of teacher digital competence, classroom orchestration, and perceived student cognitive dynamics. Isolating this micro-level socio-cognitive fragment is methodologically justified because it directly addresses the pedagogical friction and classroom orchestration realities of educators, preventing the confounding influence of macro-systemic administrative data on teachers' immediate pedagogical experiences.

Quantitative data were analyzed using descriptive statistics and ordinal logistic regression modeling in R Studio to evaluate whether digital competence (low, medium, high) and teaching experience predict satisfaction. Qualitative data were analyzed using Braun and Clarke's (2006, 2021) six-phase reflexive thematic analysis, generating semantic and latent codes to capture the lived experiences of digital classroom integration.

3.1 Research Limitations

Several limitations of this study must be acknowledged. First, the empirical analysis is confined to a selective thematic fragment of a broader survey dataset. While isolating this micro-level socio-cognitive intersection was necessary to model pedagogical friction and classroom orchestration, the exclusion of macro-systemic variables means that positive technological adaptations, infrastructure successes, and broader system-level variables captured by the wider instrument are not represented here. Second, the sample size is relatively modest ($N = 90$ total, with $n = 62$ active users) and was drawn using convenience sampling, which severely limits the immediate generalizability of the results. Furthermore, the sample is heavily female-skewed (88.9%), which represents a potential confounding variable given that technology-related stress and coping mechanisms may display gendered variations. The choice to isolate this specific thematic fragment of the broader dataset, was guided by a desire to focus on micro-level socio-cognitive dynamics. However, the exclusion of macro-systemic variables means that broader institutional factors influencing technology acceptance are not represented in these findings. Finally, the evaluation of student cognitive load, reading patterns, and knowledge retention relies entirely on the subjective observations and perceptions of classroom teachers rather than direct objective student-side metrics such as eye-tracking or standardized comprehension tests.

4 Results and Discussion

To establish a statistical baseline, descriptive statistics were calculated for the primary quantitative evaluation variables within the active user sub-sample of 62 teachers (excluding non-users filtered out via Q5). These statistics are summarized in Table 1.

Table 1. Quantitative evaluative baselining (Positive evaluations represent scores of 4 and 5; Neutral represents 3; Negative represents 1 and 2)

	Q10 (Satisfaction with Instructional Quality)	Q11 (Student Cross-Curricular Understanding)	Q12 (Cross-Curricular Efficiency)
Mean	3.80	3.82	3.44
SD	0.72	0.84	0.81
Positive	85.5%	74.2%	62.9%
Neutral	11.3%	21.0%	27.4%
Negative	3.2%	4.8%	9.7%

The data reveal an evaluative discrepancy of educator perceptions. While 85.5% of teachers report high overall satisfaction with instructional quality when using digital scenarios (with a mean of 3.80 and a

standard deviation of 0.72), their consensus on cognitive outcomes is more distributed. Specifically, 74.2% of respondents evaluate students' actual cross-curricular understanding and application positively; although the overall proportion of positive ratings is lower, the mean rating remains statistically comparable (mean = 3.82, SD = 0.84) due to a lower frequency of highly negative evaluations in this dimension. Perceived efficiency shows a more pronounced decline, with only 62.9% of respondents agreeing that digital scenarios are more efficient than traditional, paper-based approaches (mean = 3.44, SD = 0.81). This drop-off indicates that while teachers value interactive potential, they observe a decline in the efficiency of knowledge retention and deep conceptual processing.

4.1 Addressing RQ1

The first research question investigated the extent to which self-reported teacher digital competence mitigates the perception of first-order infrastructural barriers and the experience of technostress. To evaluate whether teacher digital competence and pedagogical experience predict satisfaction, an ordinal logistic regression model was constructed with Satisfaction with Instructional Quality (Q10) as the ordinal outcome variable. The model was statistically non-significant (Wald chi-square = 2.12, $df = 3$, $p = 0.548$), indicating that individual professional variables are poor predictors of instructional satisfaction. The complete parameter estimates are presented in Table 2.

Table 2. Ordinal logistic regression predicting Instructional Satisfaction (Q10)

Predictor	Coeff. (Beta)	SE	Wald X^2	p	Odds ratio
Compet . (med vs low)	0.25	0.35	0.51	0.475	1.28
Compet . (high vs low)	0.42	0.38	1.22	0.267	1.52
Teaching exp.	-0.05	0.08	0.39	0.532	0.95

The Brant test confirmed that the proportional odds assumption was satisfied, indicating no significant differences in coefficients across response thresholds (Chi-Square=1.88, $df=3$, $p=0.598$). The Cox and Snell (R-squared=0.021) and Nagelkerke (R-squared = 0.024) pseudo-coefficients confirm that personal professional variables do not explain variance in satisfaction. Teaching experience is also a non-significant predictor (Beta=-0.05, $p=0.532$), indicating that veteran and novice teachers experience the same integration hurdles.

Furthermore, a Spearman rank correlation between digital competence and structural complaints confirms this complete lack of mitigation ($r_s = 0.048$, $p = 0.707$).

Rather than individual competence serving as a protective buffer, systemic first-order barriers operate as an absolute, indiscriminate environmental tax on classroom efficiency, disrupting workflows and inducing technostress uniformly across all teacher profiles. This statistical independence supports the paradox of competence narrative, challenging linear models that assume digital upskilling naturally resolves integration challenges (Caena & Redecker, 2019; Suzer & Koc, 2024).

In TAM, digital competence is theorized to predict perceived usefulness and ease of use (Antonietti et al., 2022). However, where severe first-order barriers (such as unreliable hardware, network dropouts, and rigid software boundaries) are absolute, they sever the expected link between competence and ease of use (Antonietti et al., 2022). When first-order deficits act as absolute environmental constraints, even highly digitally competent teachers (Innovators) find self-efficacy operationally useless (Caena & Redecker, 2019; Hu et al., 2025; Suzer & Koc, 2024). Advanced skills afford them a critical diagnostic gaze that exposes the mismatch between the theoretical didactics of standardized scenarios and classroom realities, shifting the locus of technostress from personal inadequacy to systemic deficits (Ajani, 2024; Alptekin & Taneri, 2025; Tarafdar et al., 2024). This is reinforced by reflexive thematic analysis. Teachers across all profiles reported experiencing severe first-order barriers that generated acute technostress, noting that executing digital scenarios requires “significantly more time for preparation” and is regularly hindered by “frequent technical problems”.

4.2 Addressing RQ2

The second research question (RQ2) examined how standardized interactive digital scenarios influence K-12 students' cognitive load, reading behaviors, and knowledge retention as observed by teachers. To evaluate these cognitive and behavioral outcomes, paired-samples t-tests were conducted using the active user dataset (N=62, df=61). The results show a statistically significant negative divergence across four out of five core pedagogical parameters, demonstrating that the interactive design frequently failed to deliver its anticipated benefits. These metrics are summarized in Table 3. In the table positive t-values indicate areas where the transition to digital tools increased student dependency or gaming behaviors, while negative t-values indicate areas where actual classroom outcomes fell significantly short of initial pedagogical expectations.

To establish methodological transparency regarding the paired-samples t-tests, baseline programmatic pedagogical expectations (representing the intended curricular outcomes of the national digitalization project) were paired with active teachers' post-implementation quantitative assessments. The

operationalization and pairing of these constructs are defined as follows:

1. Flexible Independent Study: Baseline expectations of independent student learning are paired with post-implementation ratings on the Q9 item “The instructional process is easy to follow.”
2. Softer Skills Development: Baseline expectations of collaborative classroom synergy are paired with post-implementation ratings on the Q9 item “Allows adaptation of tasks to different social forms of work.”
3. Data Interpretation & Reasoning: Baseline expectations of active scientific inquiry are paired with post-implementation ratings on the Q9 item “Encourages students to reflect on the topic.”
4. Independent Learning Strategies: Baseline expectations of student self-regulated learning are paired with post-implementation ratings on the Q9 item “Encourages students to independently build upon knowledge.”
5. Skills for the Modern Workplace: Baseline expectations of practical competency acquisition are paired with post-implementation ratings on the Q9 item “Makes the applicability of knowledge in the real world visible.”

Table 3. Paired-samples t-test comparing pedagogical expectations vs. observed classroom realities

Pedagogical Dimension	t	p	Observed Didactical Discrepancy (Expectation vs. Reality)
Flexible Independent Study	-3.78	0.001	Teachers expected digital scenarios to foster structured, self-regulated learning, but observed unstructured pacing and erratic scrolling.
Softer Skills Development (Teamwork/Communication)	-4.12	0.001	Collaborative gains were significantly lower than expected due to task division struggles and off-task behavior.
Data Interpretation & Reasoning	-1.71	0.092	Student gains in scientific reasoning were lower than anticipated, as students relied on immediate visual feedback rather than deep

			analytical evaluation.
Independent Learning Strategies	3.12	0.003	The transition to digital scenarios did not build student independence; instead, it increased reliance on external automated prompts.
Skills for the Modern Workplace	3.95	0.001	Standardized tools failed to build real-world competencies because students treated the interactive scenarios as simplistic games.

These findings reveal a complex, multi-dimensional gap between baseline pedagogical expectations and observed classroom realities. The divergence in the signs of the t-statistics highlights a methodological tension characteristic of convergent parallel mixed-methods designs, where structured quantitative ratings diverge from qualitative thematic reflections.

First, regarding screen-mediated reading behaviors, a negative divergence was observed in Flexible Independent Study ($t = -3.78$, $p = 0.001$). This indicates that the practical ease of following digital scenarios fell significantly short of initial expectations. Teachers' qualitative reports help explain this deficit, indicating that students struggled with non-linear reading patterns, frequently defaulting to erratic scrolling, rapid visual scanning, and skimming through text layouts, which disrupted the construction of cohesive mental schemas.

Second, in terms of cognitive load, the results show a highly significant negative divergence for Softer Skills Development ($t = -4.12$, $p = 0.001$) and a marginally negative, non-significant trend for Data Interpretation and Reasoning ($t = -1.71$, $p = 0.092$). While the capacity for deep scientific reasoning did not experience a statistically significant decline, the overall findings suggest that unguided visual interactivity often overburdens working memory. Teachers observe that students struggle to coordinate and integrate text with diagrammatic elements. This spatial split-attention effect leads to cognitive passivity, where students rely on immediate, interactive feedback to rapidly guess answers rather than engaging in sustained, active conceptual processing.

Third, the analysis reveals a striking methodological divergence regarding student self-regulation and long-term knowledge retention. For Independent Learning Strategies ($t = 3.12$, $p = 0.003$)

and Skills for the Modern Workplace ($t = 3.95$, $p = 0.001$), the positive t-values indicate that teachers' quantitative evaluations of the scenarios' capacity to support independent knowledge construction and real-world applicability exceeded initial baseline expectations.

However, the qualitative findings reveal an underlying friction. While the standardized digital designs are quantitatively recognized as supportive, in practice, this structured support degenerates into prompt-dependency and gaming behaviors. Because the digital scenarios provide permanent, non-fading automated scaffolding, students bypass active metacognitive monitoring and treat the tasks as low-stakes, trial-and-error games.

However, to present a balanced discussion, the positive aspects of ICT integration must be acknowledged alongside these pedagogical challenges. The broader scientific trials associated with the digitalization project documented substantial positive affective and motivational outcomes. Observers noted marked increases in student engagement, curiosity, and excitement when digital scenarios were introduced, particularly in subjects such as biology and mathematics. Qualitative feedback from teachers confirmed that these scenarios successfully 'break the monotony of traditional teaching' and motivate disengaged or hyperactive students through visually rich, interactive media. Furthermore, the observed classroom friction may not stem from intrinsic flaws in digital mediums but rather from transitional curricular adjustments, as teachers and students adapt to screen-mediated paradigms without prior instruction in digital reading strategies. Finally, systemic deficits, such as inadequate teacher preparation time and rigid physical classroom layouts, partially explain this friction, shifting the focus of the challenge from digital technology itself to broader educational support infrastructures.

5 Conclusion

The thematic analysis of open-ended responses highlighted a cognitive vulnerability embedded within digital pedagogies, providing an answer to RQ2. Under a screen-mediated learning paradigm, the digital environment alters reading behaviors, promoting engagement and browsing that shifts cognitive engagement toward shallow processing (Liu, 2005). Because information is presented in fragmented, interactive segments, students are conditioned to navigate the interface rapidly, prioritizing task completion over the effort required for schema construction in working memory (Sweller et al., 2011).

Teachers' qualitative observations that students habitually "skim the lessons" are highly consistent with contemporary reading research showing that reading on screens habituates students to non-linear reading patterns, keyword spotting, and rapid visual scanning

(Altamura et al., 2025; Liu, 2005). Furthermore, digital environments lack the tactile and spatial anchors of paper, which are critical for cognitive mapping and comprehension (Mason et al., 2024). Without deliberate, design-level interventions to promote active, generative engagement, such as structured self-explanation prompts or intentional pacing, screen reading inevitably encourages speed over internalization, resulting in weak conceptual consolidation and rapid memory decay (Mason et al., 2024).

The immediate availability of information on screens facilitates intention offloading, leading to cognitive atrophy where students conserve mental energy by treating the digital scenario as a prosthetic memory bank. This is captured in qualitative data - teachers observed that “students feel no need to memorize data” because everything is accessible at a single click.

In cognitive psychology, the decision to offload is mediated by metacognitive monitoring and evaluation of retrieval costs (Gilbert et al., 2023; Grinschgl et al., 2021). When physical or cognitive costs of externalizing are low, individuals display a positive reminder bias, outsourcing memory storage even when working memory is fully capable (Gilbert et al., 2023). However, this immediate performance boost comes at a direct cost to subsequent memory. Because the brain does not expend the cognitive effort required to encode the information internally, recall accuracy is severely diminished (Grinschgl et al., 2021). Teachers are witnessing this pattern of detrimental cognitive offloading in real time. Students execute interactive steps, but because they have outsourced the factual parameters, “little remains in their heads” once the screen is turned off (Grinschgl et al., 2021; Skulmowski, 2023).

This cognitive offloading bias is problematic in K-12 education due to the developmental trajectory of student’s metacognitive abilities. Younger students (primary school) frequently suffer from an under-offloading bias, overestimating prospective memory and failing to utilize helpful digital reminders (Sun et al., 2025). As students transition into secondary school, their metacognitive monitoring improves, but they can easily develop an over-offloading bias, using technology as a cognitive crutch to bypass memory effort entirely (Armitage & Gilbert, 2025; Sun et al., 2025). Digital scenarios that present information in highly supportive, low-cost interfaces fail to support this developmental transition. Instead of adaptive scaffolding that teaches students how to balance internal memory with external resources, current designs facilitate indiscriminate offloading, resulting in cognitive passivity across all age groups (Armitage & Gilbert, 2025; Skulmowski, 2023).

Furthermore, the analysis revealed a severe limitation regarding educational inclusivity. Teachers noted that the rigid design of current platforms disproportionately affects vulnerable demographics,

stating that “students with difficulties very often struggle more”. Standardized digital media presenting excessive visual noise and rapid interactive loops construct new, invisible barriers to learning for neurodivergent students and those with special educational needs (Burgstahler, 2015). Under Skulmowski’s (2023) model of digital externalization, high extraneous cognitive load acts as a severe roadblock for students with lower working memory capacity or executive functioning challenges. When an interface is visually cluttered and lacks adaptive, structured scaffolding, it overwhelms the limited working memory capacity of vulnerable learners, preventing basic information from being processed or integrated (Skulmowski, 2023). This exacerbates existing educational inequities, highlighting the urgent need to move beyond standard, “one-size-fits-all” software designs toward proactive, inclusive digital architectures.

To shape the next wave of intelligent systems safely and effectively, developers and policymakers must move beyond metrics of mere interactive engagement. Systems must be engineered proactively with Universal Design for Learning frameworks to prevent the digital exclusion of neurodivergent learners and those with special educational needs (Burgstahler, 2015). Most crucially, future AI-driven educational platforms should introduce algorithmic pacing and deliberate pedagogical friction, such as mandatory reflection pauses, to disrupt skimming habits, counter cognitive offloading, and force the deep cognitive processing required for genuine, long-term knowledge retention.

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