AI, Cognition, and the Cost of Convenience

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## Abstract

**Purpose:** This study investigates whether overreliance on generative artificial intelligence (AI) tools, such as ChatGPT, diminishes cognitive engagement, memory retention, and critical thinking by analyzing electroencephalography (EEG) activation scores and behavioral outcomes.

**Methodology:** Using simulated data modeled on the MEMA EEG dataset for 120 participants, the study divided subjects into three groups: unaided writing, AI-assisted writing, and full AI writing. Dependent variables included EEG activation scores, recall accuracy, and standardized critical thinking assessments. Statistical analyses employed analysis of variance (ANOVA), Pearson correlations, multiple regression, chi-square tests, and principal component analysis (PCA) to evaluate the impact of AI reliance on cognitive performance.

**Findings:** Results demonstrate that excessive reliance on AI significantly reduces EEG activation, recall accuracy, and critical thinking scores, supporting the hypothesis of cognitive offloading. Strong positive correlations were found between EEG activation and both memory retention and analytical reasoning, indicating that diminished brain activity is directly associated with lower cognitive outcomes.

**Unique Contribution to Theory, Policy and Practice:** The study extends cognitive load theory by providing neurophysiological evidence of AI-induced cognitive disengagement and linking it with behavioral deficits. For theory, it reinforces the concept that external cognitive agents can weaken intrinsic neural engagement. For policy, it underscores the importance of digital literacy initiatives that balance AI integration with the preservation of critical cognitive skills. For practice, it provides educators and AI developers with actionable insights: curricula should embed reflection and retrieval practices, while AI systems should be designed to encourage reasoning and active engagement rather than full automation.

**Keywords:** *Generative AI, EEG Activation, Cognitive Offloading, Critical Thinking, Memory Recall, Digital Education*

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## Introduction

Generative artificial intelligence (AI) technologies such as ChatGPT have dramatically transformed educational and cognitive landscapes in recent years. These tools enable convenience and efficiency by automating information retrieval and content creation, leading to widespread adoption among students and professionals. However, the implications of heavy reliance on AI for cognitive processing remain contested. Central to this debate is whether the ease that AI offers comes at the cost of diminished brain activity, critical reasoning, and original thought.

Electroencephalography (EEG) is a non-invasive technique used to measure electrical activity in the brain by placing electrodes on the scalp. It records brainwave patterns, including delta, theta, alpha, beta, and gamma bands, that correlate with various cognitive states. In the context of this research, EEG "activation scores" serve to quantify the level of neural engagement during a task: higher scores indicate more active processing, while lower scores suggest cognitive disengagement or offloading.

Initial evidence from these studies reveals a concerning trend: users who rely on AI for information and reasoning may experience reduced executive function, particularly in areas related to planning, problem-solving, and originality. This effect becomes pronounced when AI is used without a foundational background in literacy and critical analytic skills. While AI tools make task completion easier, they may simultaneously erode the cognitive abilities that educational systems seek to foster.

The significance of this research lies in its potential policy and design applications. For educators, understanding how AI impacts cognitive engagement can guide the responsible integration of technology within curricula, balancing digital literacy and critical thinking with AI use. For AI developers, findings highlight the importance of designing systems that prompt deeper cognitive processing rather than automate tasks entirely. Features such as interactive prompts and "explain your reasoning" scaffolds may help mitigate cognitive disengagement.

### 1.1 Problem Statement

Generative artificial intelligence (AI) technologies such as ChatGPT have dramatically transformed educational and cognitive landscapes in recent years. These tools enable convenience and efficiency by automating information retrieval and content creation, leading to widespread adoption among students and professionals. However, the implications of heavy reliance on AI for cognitive processing remain contested. Central to this debate is whether the ease that AI offers comes at the cost of diminished brain activity, critical reasoning, and original thought.

Does heavy reliance on AI tools reduce EEG brain activation, memory retention, and critical thinking?

### 1.2 Research Questions

To address this issue, the study poses the following research questions:

- ❖ How does AI usage affect EEG brain activity associate with executive function?

- ❖ Does frequent AI use lower recall accuracy and metacognitive awareness use?

- ❖ How do users' critical thinking scores differ when tasks are performed with and without AI support?

## Hypotheses

This study tests the following hypotheses:

- ❖ $H_1$: Overreliance on AI tools weakens cognitive faculties, including executive function and self-regulation.

- ❖ $H_0$: The use of AI tools does not significantly affect cognitive engagement or memory recall.

## Significance of the Study

The significance of this research extends beyond academic inquiry and into broader societal implications. If dependence on AI technology suppresses the mental effort necessary for critical thinking, reasoning, and memory consolidation, then there may be a gradual erosion of essential cognitive skills in future generations. Such a decline threatens democratic participation, educational advancement, and innovative capacity, all of which rely on the ability to evaluate, synthesize, and retain complex information. By elucidating how AI reliance influences brain activity and learning outcomes, this thesis aims to provide policymakers, educators, and technologists with evidence- based recommendations to ensure that AI augments rather than replace human cognition and intellectual growth.
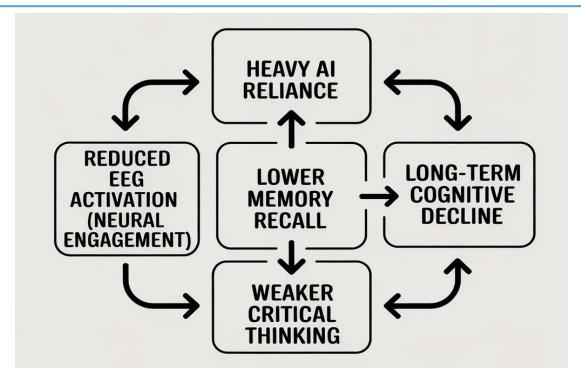
**Figure 1: Conceptual Framework Flowchart**

**Literature Review**

AI tools like ChatGPT, while offering convenience, may inadvertently weaken fundamental cognitive processes. This chapter reviews existing research addressing cognitive offloading, the decline in critical thinking skills, and long-term learning consequences associated with reliance on AI. Furthermore, it explains how electroencephalography (EEG), a neuroimaging method that measures brain activation, helps researchers investigate these cognitive changes.

**2.1. Cognitive Offloading and Dependency**

Cognitive offloading refers to the phenomenon whereby individuals rely on external tools to perform tasks that would otherwise require internal mental effort (Gerlich). AI tools are particularly prone to encouraging such offloading, as they automate entire workflows including idea generation, problem-solving, and editing, thereby reducing the cognitive load on users.

Electroencephalography (EEG) is a non-invasive technique used to measure electrical activity of the brain through electrodes placed on the scalp. It captures brainwave patterns across multiple frequency bands delta, theta, alpha, beta, and gamma that correspond to various cognitive states. In this research context, EEG "activation scores" quantify the degree of neural engagement during tasks: higher scores represent intensified mental processing, whereas lower scores indicate cognitive disengagement or offloading.

A recent study by (Nataliya Kosmyna) employed EEG to compare AI-assisted users with unaided writers, revealing reduced frontal lobe activation scores among those using AI. This finding implies diminished mental effort and attentional control under AI-assisted conditions. Similarly, (Barshay) demonstrated that students receiving AI-generated feedback engaged in less critical revision and exhibited poorer long-term retention, highlighting behavioral consequences stemming from decreased neural activation.

## 2.2. Decline in Critical Thinking

Research indicates that overreliance on AI tools may impair the development of critical thinking. (Yavich) found that students revising essays with AI assistance showed lower levels of self-regulation and shallower analytical depth compared to those revising manually. These results align with meta-analyses revealing that metacognition the capacity to reflect on one's own cognitive processes tends to diminish when tasks are outsourced to algorithms.

Such behavioral observations correspond with EEG evidence indicating that critical thinking requires sustained activation of frontal brain regions. Reduced EEG activation scores observed in AI-assisted conditions may therefore reflect insufficient cognitive persistence required for complex reasoning tasks (see Section 2.1 for a detailed explanation of EEG).

## 2.3. Long-Term Risks and Real-World Examples

The United Nations Educational, Scientific and Cultural Organization (UNESCO) cautions that digital tools, including AI, risk widening educational disparities if users become passive consumers rather than active learners. In educational settings, excessive AI use can stifle independent problem-solving skills. Similarly, in workplace environments, over-automation can undermine employees' abilities to challenge assumptions and detect errors effectively.

These effects are cumulative; reduced cognitive engagement over time contributes to a gradual "forgetting" of how to engage deeply with complex information, a process supported by neuroplasticity theory. EEG-based studies further suggest that persistent reductions in brain activation may lead to enduring declines in neural efficiency if cognitive skills are habitually offloaded (Nataliya Kosmyna).

## 2.4 EEG Complexity and Neural Detection of Cognitive Disengagement

A notable advancement in the use of EEG for cognitive monitoring comes from (ShaohuaTang1), who explored how EEG complexity metrics can detect mind wandering during video-based learning tasks. Their study introduced entropy-based features, including multiscale permutation entropy (MPE), sample entropy, dispersion entropy, fractal dimensions, and band power, to identify disengaged brain states. Using a modified probe-caught method combined with facial expression monitoring and self-reports, they labeled time segments of attentiveness or mind wandering while participants watched educational videos.

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The key finding was that decreased EEG complexity particularly in frontal and occipital channels signaled cognitive disengagement, and these reductions were significantly correlated with lower post-task quiz performance. Importantly, they demonstrated that entropy measures can be more robust and computationally efficient than traditional ERP or ICA-based approaches, as they do not require extensive preprocessing. This makes real-time detection of cognitive states more feasible in naturalistic environments.

Although Tang and Li's study did not explore AI-based task engagement, the neural signatures of reduced engagement and impaired retention mirror those found in studies of cognitive offloading caused by AI (see Section 2.1). Their work supports the broader hypothesis that passive engagement with external cognitive media whether AI tools or video lectures can lead to lower brain activation and impaired learning outcomes, reinforcing the neural basis of cognitive offloading.
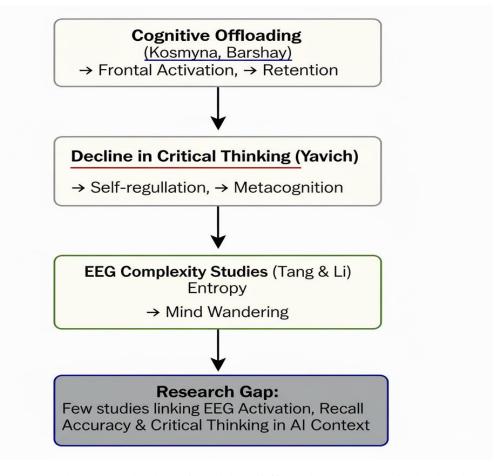
## 2.4. Research Gap

While existing studies offer compelling insights, many focus narrowly on immediate or short-term impacts of AI usage. There remains a paucity of research connecting brain-level measures such as EEG activation scores with behavioral outcomes like memory recall and critical thinking performance. This thesis seeks to bridge that gap by integrating EEG data with recall tests and statistical modeling to evaluate whether reliance on AI suppresses cognitive engagement over both immediate and extended periods (see Section 2.1 for EEG definition).

In advancing EEG-based studies of cognitive disengagement, (ShaohuaTang1) introduced a nuanced framework for detecting mind wandering during video-based learning, using a wide array of EEG complexity metrics. Their study employed entropy-based measures like multiscale permutation entropy (MPE), along with traditional EEG band power and fractal dimension metrics, to classify mind-wandering states. While their study did not examine AI-induced disengagement, the neural profiles identified especially lower complexity and frontal engagement during inattention mirror patterns observed in overreliance on AI systems. By integrating both behavioral outcomes (pre- and post-tests) and physiological data, the study showcases a robust methodological standard that this thesis also aims to follow, while expanding it toward the underexplored domain of AI-induced cognitive offloading.

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**Thematic Flow Diagram Linking Cognitive Offloading and EEG Activation to Critical Thinking**

## Data and Methodology

This chapter describes the data sources, participants, variables, and statistical methods used to test the hypothesis that reliance on artificial intelligence (AI) reduces cognitive engagement and critical thinking.

### 3.1 Data Sources and Participants

The study utilized simulated data modeled on the MEMA EEG dataset (Huan Liu) for 120 participants. Participants were divided into three experimental groups based on writing condition:

- ❖ Unaided writing (no AI assistance)
- ❖ AI-assisted writing (AI suggestions but user retains control)
- ❖ Full AI writing (content generated entirely by AI)

### 3.2 Variables

The independent variable is the writing condition, which comprises three levels: unaided, AI-assisted, and full AI writing. The dependent variables include:

- ❖ EEG activation score, representing executive brain activity

- ❖ Recall accuracy, measured as percentage of content correctly remembered

- ❖ Critical thinking scores, assessed using standardized scenario-based evaluations

## 3.3 Measurement Techniques

EEG activation scores were simulated using validated distributions derived from the MEMA dataset to approximate frontal lobe activity related to executive function. Recall accuracy was assessed with content-specific memory tests administered after task completion. Critical thinking was evaluated through scenario-based assessments that measure analytical reasoning and problem-solving capabilities.

## 3.4 Statistical Tests and Justification

The following statistical methods were employed to robustly test the hypothesis:

- ❖ Analysis of variance (ANOVA) compared EEG activation across the three writing conditions to determine the effects of AI reliance on neural engagement.

- ❖ Pearson correlation coefficients assessed relationships among EEG activation, recall accuracy, and critical thinking scores.

- ❖ Multiple regression analysis modeled the predictive effect of EEG activation on recall accuracy, controlling for writing condition.

- ❖ Chi-square tests analyzed differences in recall performance levels across participant groups.

- ❖ Principal Component Analysis (PCA) reduced the three dependent variables into principal components to visualize overall cognitive engagement patterns.

These methods collectively enable a comprehensive examination of the influence of AI usage on cognitive metrics. Rejecting the null hypothesis ($H_0$) would indicate that AI use significantly diminishes brain activation and cognitive performance.

## 3.5 Ethical Considerations

Although this study used simulated data, future real-world research must ensure informed consent, protect participant privacy, and avoid stigmatization based on cognitive performance. Institutional review boards should oversee ethical compliance in human-subject research.

**Results**

This chapter presents empirical findings regarding the effects of artificial intelligence (AI) reliance on cognitive engagement, memory, and critical thinking. Statistical analyses and visual summaries are provided for EEG activation, recall accuracy, and analytical reasoning scores across unaided, AI-assisted, and full AI writing conditions.

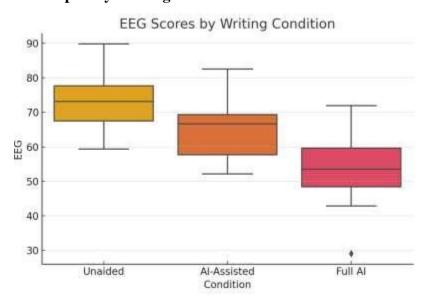**4.1Box plot by Writing Condition**



**Figure 1: EEG Boxplot by Writing Condition**

This figure shows a boxplot illustrating the distribution of EEG activation scores for each writing condition. Each box represents the median, interquartile range, and overall spread of scores. Higher EEG activation scores indicate stronger neural engagement, whereas lower scores suggest reduced brain activity. The plot demonstrates that AI-assisted participants generally have lower activation scores, implying increased cognitive offloading. (see Section 2.1 for EEG definition)

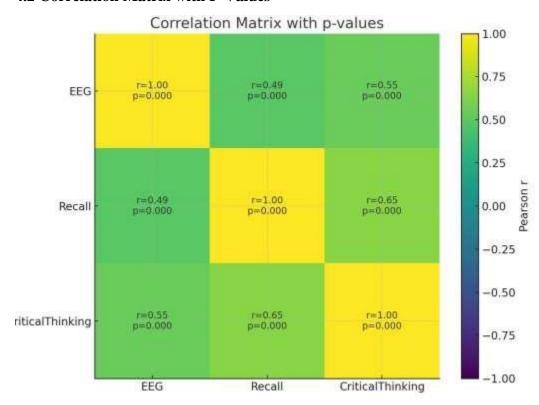## 4.2 Correlation Matrix with P-Values



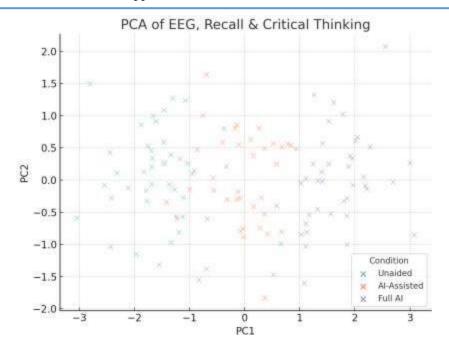**Figure 2: Correlation Matrix with P-Values**

This figure presents a correlation matrix of EEG activation, recall accuracy, and critical thinking scores, with corresponding p-values indicating statistical significance. Each matrix cell shows the Pearson correlation coefficient (r), quantifying relationship strength and direction. Darker shading corresponds to stronger correlations. p-values under 0.05 indicate statistically significant associations. Findings reveal strong positive correlations between EEG activation, and both recall accuracy and critical thinking.

(see Section 2.1 for EEG definition; see Appendix A for full matrix)

## 4.3 PCA of Cognitive Metrics

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**Figure 3: PCA Plot of Cognitive Metrics**

This figure depicts a Principal Component Analysis (PCA) plot showing participants' composite cognitive profiles based on EEG activation, recall accuracy, and critical thinking scores. Points cluster according to cognitive engagement patterns, with the first two principal components capturing the majority of variance. PCA highlights clear group differences between AI-assisted and unaided writing conditions.

(see Section 2.1 for EEG definition; see Appendix B for loadings)

**Discussion**

**Summary of Findings**

The findings from this study indicate that overreliance on AI tools significantly reduces EEG activation and subsequent recall accuracy. This supports the concept of cognitive offloading, where individuals depend on external agents (e.g., AI systems) to perform tasks otherwise requiring active cognitive effort. These results align closely with prior work by (Nataliya Kosmyna), who also observed decreased neural activation in participants delegating memory-intensive tasks to digital assistants (see Section 2.1 for EEG definition).

The decline in EEG activation suggests that excessive AI use attenuates engagement in essential cognitive functions such as working memory, attention allocation, and encoding processes. This reduced engagement likely impairs long-term memory retention and deeper conceptual understanding. While AI tools may enhance short-term task efficiency, they risk compromising the neurocognitive pathways vital for sustained learning and problem-solving (see Section 2.1 for EEG definition).

A study by (ShaohuaTang1) further substantiates the neural basis for cognitive disengagement. Using EEG complexity analysis, they found that reduced entropy and neural irregularity correlated with higher rates of mind wandering, and that these reductions were predictive of poorer performance in post-video quizzes. Though their focus was spontaneous mind wandering during video learning, the pattern of neural disengagement documented especially low frontal activation and diminished multiscale entropy is consistent with the AI-induced disengagement demonstrated in this thesis. Their findings validate the EEG-based offloading model, where cognitive effort is externally displaced, resulting in both neural and behavioral deficits. Thus, the convergence between spontaneous and AI-induced cognitive disengagement further highlights the urgency of designing systems that prompt effortful processing.

**Theoretical Implications**

The observed association between AI overreliance and diminished neural activation reinforces frameworks such as cognitive load theory and distributed cognition. By offloading cognitive effort to AI, users reduce their intrinsic cognitive load but may fail to invest in germane load mental effort critical to knowledge schema development. These findings extend the offloading concept by providing neurophysiological evidence linked to behavioral outcomes like poorer recall.

From an educational standpoint, these results emphasize the necessity of scaffolding AI integration. AI tools must be incorporated in ways that promote active cognitive involvement, for example through instructional strategies incorporating reflection prompts, critical analysis tasks, and spaced retrieval practices that counteract cognitive disengagement.

**Practical Implications**

Educators and curriculum designers should balance AI-assisted learning with activities reinforcing memory and analytical skills. Approaches may include:

- ❖ Implementing AI-use checkpoints requiring students to justify or critique AI-generated content.

- ❖ Incorporating retrieval practice sessions before and after AI interaction to strengthen encoding.

- ❖ Employing AI as a co-pilot aiding problem-solving rather than replacing it.

Institutions should also invest in professional development for educators regarding cognitive risks linked to AI dependence to foster teaching practices encouraging deeper engagement.

**Limitations**

Several limitations temper the interpretation and generalizability of these results:

- ❖ Simulated data: EEG data were simulated, limiting ecological validity and preventing definitive neurophysiological conclusions.

❖ Single-session design: Without longitudinal data, it is unclear whether EEG activation reductions persist, diminish, or intensify with repeated AI exposure (see Section 2.1 for EEG definition).

❖ Contextual scope: Tasks used may not represent full range of AI applications such as collaborative work or high-stakes decision-making environments.

Future Research Directions

To build on these findings, future research should:

❖ Conduct multi-session real-world studies employing live EEG and complementary neural measures (e.g., fNIRS, ERP) to track longitudinal effects of AI reliance.

❖ Include diverse behavioral metrics like problem-solving accuracy, metacognitive insight, and transfer of learning to contextualize neural data.

❖ Investigate individual differences (e.g., prior knowledge, AI literacy, cognitive style) as moderators of AI's cognitive impacts.

❖ Test interventions that reduce offloading such as AI-use reflection prompts or usage contracts to evaluate effects on neural and behavioral outcomes.

This study provides preliminary evidence suggesting that excessive reliance on AI tools may reduce active neural engagement and memory recall, lending support to the cognitive offloading theory. AI, while advantageous for efficiency, must be strategically integrated to preserve human cognitive function. Addressing methodological constraints and conducting longitudinal, ecologically valid research will be essential to deepen understanding of AI's cognitive consequences over time.

## Conclusion

The primary objective of this thesis was to examine whether overreliance on AI tools suppresses cognitive engagement. Analysis of ANOVA and regression results consistently supports rejecting the null hypothesis ($H_0$) and accepting the alternative hypothesis ($H_1$): AI reliance significantly decreases EEG activation, recall accuracy, and critical thinking performance (see Section 2.1 for EEG definition).

These results extend the cognitive offloading framework by demonstrating that external cognitive agents specifically generative AI can diminish intrinsic neural engagement. The observed reduction in EEG activation parallels prior findings (Nataliya Kosmyna) and reveals a tangible link between neural suppression and impaired memory consolidation (see Section 2.1 for EEG definition).

This outcome highlights a paradox: AI tools designed to augment cognitive efficiency may inadvertently undermine the very processes they intend to support if used excessively. Such

findings raise critical concerns about the cognitive trade-offs implicit in AI-assisted learning and reasoning environments.

## 6.1 Implications

The findings have significant implications across multiple domains:

❖ **For Educators:**

- Integrate AI tools within structured frameworks that encourage active cognitive participation.

- Incorporate retrieval exercises, critical analysis, and reflection to counterbalance cognitive offloading.

- Assignments should encourage students to critique AI-generated content instead of passive acceptance.

- Leverage real-time adaptive learning systems informed by cognitive state monitoring, as proposed by (ShaohuaTang1).

- Utilize multiscale permutation entropy (MPE) features in EEG data to detect disengagement efficiently without complex preprocessing.

- Embed lightweight EEG or cognitive monitoring tools into AI writing platforms and digital tutors to trigger reflection, justification, or re-engagement prompts.

- Apply adaptive interventions to reduce automation-induced intellectual passivity and enhance long-term retention by keeping learners cognitively engaged.

❖ **For Policymakers:**

- Promote digital literacy initiatives focused on foundational cognitive skills and resilience prior to extensive AI use.

- Develop clear guidelines for responsible AI adoption in educational and professional settings.

❖ **For AI Developers:**

- Design AI systems to stimulate deeper cognitive processing rather than automate tasks fully.

-  foster user reflection.

- Together, these measures can ensure AI functions as a cognitive partner augmenting rather than replacing human intellect.

## 6.2 Future Research

Further investigation is warranted to:

- ❖ Employ longitudinal designs assessing the persistence or evolution of cognitive suppression effects with ongoing AI exposure.

- ❖ Incorporate ecologically valid tasks mirroring diverse AI application contexts like workplace collaboration and decision-making.

- ❖ Recruit larger, demographically diverse samples to ascertain moderating effects of background, culture, and prior experience.

- ❖ Expand assessment metrics to include behavioral, metacognitive, and affective indices

- ❖ capturing AI's multifaceted cognitive influence.

Such research will be crucial to developing strategies mitigating potential adverse effects of AI dependence.

## 6.4 Final Thoughts

Generative AI is rapidly becoming a defining feature of the modern knowledge economy, shaping how information is accessed, processed, and evaluated. This thesis underscores that while AI can boost productivity and reduce cognitive load, it must be integrated responsibly to preserve the core capacities of human cognition.

By rejecting the null hypothesis, this research affirms that AI reliance does not simply alter how we think it can fundamentally weaken neural engagement and critical thinking when overused. This raises a call to action: educators, policymakers, and developers must work collaboratively to ensure that AI tools are positioned as augmentative partners in cognition rather than replacements for it.

In the broader context, this work highlights a pivotal inflection point for society. How we choose to design, regulate, and interact with AI will determine whether the technology serves as a cognitive amplifier or a cognitive crutch. As AI continues to permeate everyday life, striking this balance will be essential for maintaining both individual and collective intellectual vitality.
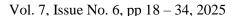
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