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AI Tools in Society: Impacts on Cognitive Offloading and the Future of Critical Thinking

Michael Gerlich

Center for Strategic Corporate Foresight and Sustainability, SBS Swiss Business School, 8302 Kloten-Zurich, Switzerland; michael.gerlich@cantab.net

Abstract: The proliferation of artificial intelligence (AI) tools has transformed numerous aspects of daily life, yet its impact on critical thinking remains underexplored. This study investigates the relationship between AI tool usage and critical thinking skills, focusing on cognitive offloading as a mediating factor. Utilising a mixed-method approach, we conducted surveys and in-depth interviews with 666 participants across diverse age groups and educational backgrounds. Quantitative data were analysed using ANOVA and correlation analysis, while qualitative insights were obtained through thematic analysis of interview transcripts. The findings revealed a significant negative correlation between frequent AI tool usage and critical thinking abilities, mediated by increased cognitive offloading. Younger participants exhibited higher dependence on AI tools and lower critical thinking scores compared to older participants. Furthermore, higher educational attainment was associated with better critical thinking skills, regardless of AI usage. These results highlight the potential cognitive costs of AI tool reliance, emphasising the need for educational strategies that promote critical engagement with AI technologies. This study contributes to the growing discourse on AI's cognitive implications, offering practical recommendations for mitigating its adverse effects on critical thinking. The findings underscore the importance of fostering critical thinking in an AI-driven world, making this research essential reading for educators, policymakers, and technologists.

Keywords: AI; artificial intelligence; critical thinking; cognitive offloading; AI tools; technology and education; cognitive development; Halpern Critical Thinking Assessment; digital dependence; AI trust

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1. Introduction

The advent of artificial intelligence (AI) has revolutionised various aspects of modern life, from healthcare and finance to entertainment and education. AI tools, encompassing everything from virtual assistants and recommendation algorithms to complex decision-support systems, have become integral to daily functioning, promising enhanced efficiency, personalised experiences, and unprecedented access to information. However, alongside these benefits, there is growing concern about the potential cognitive and social impacts of AI on human users, particularly regarding critical thinking skills.

Critical thinking, defined as the ability to analyse, evaluate, and synthesise information to make reasoned decisions, is a fundamental cognitive skill essential for academic success, professional competence, and informed citizenship [1]. It involves various cognitive processes, including problem-solving, decision-making, and reflective thinking, which are crucial for navigating complex and dynamic environments. The increasing reliance on AI tools for information retrieval and decision-making raises questions about how these technologies influence users' critical thinking abilities. The dual-edged nature of AI in cognitive development has been a focal point in recent research. AI tools can enhance learning outcomes by providing personalised instruction and immediate feedback, thus supporting skill acquisition and knowledge retention [2,3]. However, growing evidence shows that over-reliance on these tools can lead to cognitive offloading. Cognitive offloading occurs when individuals delegate cognitive tasks to external aids, reducing their engagement in deep, reflective thinking [4,5]. This phenomenon is particularly concerning in the context of critical thinking, which requires active cognitive engagement to analyse and evaluate information effectively.

Cognitive offloading, as described by Risko and Gilbert [6], involves using external tools to reduce the cognitive load on an individual's working memory. While this can free up cognitive resources, it may also lead to a decline in cognitive engagement and skill development. The pervasive availability of AI tools, which offer quick solutions and ready-made information, can discourage users from engaging in the cognitive processes essential for critical thinking. For example, Sparrow et al. [5] demonstrated that the availability of information through search engines can affect memory retention and the inclination to process information deeply.

In educational settings, integrating AI tools has shown promising results and potential drawbacks. Adaptive learning platforms and intelligent tutoring systems have been praised for their ability to tailor educational experiences to individual student needs, thereby enhancing learning outcomes [2,3]. Other studies did not observe any significant impact of AI in education [7]. However, there is also concern that such tools might reduce students' engagement in critical thinking activities, as they might become accustomed to the ease and convenience of AI-provided solutions [8,9]. The potential negative impact of AI on critical thinking extends beyond educational contexts. In professional and everyday scenarios, the use of AI tools for decision-making and problem-solving can influence cognitive processes. For instance, automated decision-support systems in healthcare and finance streamline operations and improve efficiency, but might also reduce the need for professionals to engage in independent critical analysis [10]. This could result in a workforce that is highly efficient, yet potentially less capable of independent problem-solving and critical evaluation.

Given these concerns, this study sought to explore the impact of AI tool usage on critical thinking skills with a particular focus on cognitive offloading as a mediating variable. This research aimed to provide a comprehensive understanding of the broader cognitive implications of AI tool usage by investigating how AI tools influence cognitive processes and the extent to which they encourage cognitive offloading.

The research questions guiding this study were:

RQ1: How does the usage of AI tools impact critical thinking skills?
RQ2: What is the mediating role of cognitive offloading in the relationship between AI tool usage and critical thinking?

Based on the research questions outlined above, we propose the following hypotheses:

Hypothesis 1: *Higher AI tool usage is associated with reduced critical thinking skills.*

Hypothesis 2: *Cognitive offloading mediates the relationship between AI tool usage and critical thinking skills.*

This study aimed to shed light on the broader cognitive implications of AI tool usage and provide actionable recommendations for mitigating potential negative impacts on critical thinking. Understanding these dynamics, stakeholders can develop strategies to balance the benefits of AI with the need to maintain and enhance critical thinking skills. This research contributes to the growing body of literature on AI and cognition, offering insights that can inform educational practices, policy decisions, and the design of AI technologies.

2. Literature Review

2.1. Theoretical Foundations of Critical Thinking and Cognitive Offloading

Critical thinking is a multifaceted cognitive process that involves the capacity to think clearly and rationally, understand logical connections between ideas, evaluate arguments, and identify inconsistencies in reasoning. This process is crucial for effective problem-solving, informed decision-making, and the acquisition of knowledge. Ennis [11] defines critical thinking as "reasonable reflective thinking focused on deciding what to believe or do", highlighting its evaluative nature. Paul and Elder [12] describe it as the art of analysing and improving thinking, focusing on intellectual standards such as clarity, accuracy, and logic. Halpern [13] emphasises the practical application of critical thinking skills across different contexts, underscoring its real-world utility. Critical thinking is integral to cognitive development, enabling individuals to process information more effectively and engage in reflective thought. It enhances academic performance, problem-solving abilities, and informed decision-making [14]. Students with strong critical thinking skills tend to perform better academically, as they can understand complex concepts, analyse texts, and construct well-reasoned arguments [15]. Furthermore, critical thinkers are better equipped to solve problems systematically, evaluate evidence, and consider alternative solutions [16]. They are also less susceptible to manipulation by misleading information or cognitive biases, making them more discerning consumers of information [17].

Cognitive offloading refers to the externalisation of cognitive processes, often involving tools or external agents, such as notes, calculators, or digital tools like AI, to reduce cognitive load [6]. While cognitive offloading can improve efficiency by freeing up cognitive resources, it does not inherently imply a reduction in task engagement. In some cases, however, extensive reliance on external tools—particularly AI—may reduce the need for deep cognitive involvement, potentially affecting critical thinking. The mechanisms of offloading include external memory aids, digital tools, and social networks, which help individuals manage tasks and information without overwhelming their working memory. Digital tools, particularly AI-powered applications, can perform tasks such as calculations, data retrieval, and decision-making, thereby freeing up cognitive resources for more complex thinking. Social offloading involves delegating tasks to others or seeking advice and information from social networks, reducing the cognitive burden on the individual [15]. While cognitive offloading can enhance efficiency and reduce mental strain, it also affects cognitive development and critical thinking. Excessive reliance on external aids may lead to a decline in internal cognitive abilities, such as memory retention and critical analysis skills. This phenomenon raises concerns about the long-term cognitive effects of pervasive technology use. On the one hand, cognitive offloading can be seen as a beneficial strategy for managing cognitive load and enhancing productivity. On the other hand, it may undermine the development and maintenance of critical cognitive skills, particularly if individuals become overly dependent on external tools [5].

Cognitive offloading, particularly in the context of AI usage, has seen significant academic interest in recent years. Recent studies, such as those by Gerlich [7] show that the use of AI in educational settings does not always result in improved cognitive or communication skills, particularly in students who already demonstrate well-developed abilities. Furthermore, Gerlich [7] highlights how increased trust in AI tools can result in greater cognitive offloading, which in turn reduces engagement in critical thinking. These findings resonate with the earlier work of Sparrow et al. [5], but more recent research emphasises that the relationship between AI and cognitive offloading is multifaceted, with trust playing a key role [18].

2.2. AI Tools and Cognitive Processes

AI tools have become pervasive in modern life, offering capabilities that significantly impact cognitive processes such as memory, attention, and problem-solving. The integration of AI into daily activities presents both opportunities and challenges for cognitive development. One of the most notable impacts of AI on cognitive functions is related to memory. AI tools like virtual assistants, search engines, and recommendation systems facilitate information retrieval, potentially altering how individuals store and recall knowledge. Sparrow, Liu, and Wegner [5] introduced the concept of the 'Google effect', suggesting that the availability of information at our fingertips reduces the need for internal memory retention. This phenomenon, also known as 'transactive memory', implies that people are more likely to remember where to find information rather than the information itself. While this can enhance efficiency and quick access to information, it raises concerns about the potential decline in memory retention capabilities. AI tools also influence attention and focus, two critical aspects of cognitive functioning. On one hand, AI can help manage attention by filtering out irrelevant information and highlighting important content. For example, AI-powered news aggregators and personalised content recommendations can help users focus on relevant information, thereby enhancing cognitive efficiency. However, the constant notifications and updates from AI-driven devices and applications can also fragment attention and reduce the ability to focus on a single task for extended periods. Research by Risko and Gilbert [6] highlights that frequent interruptions and multitasking, often facilitated by AI tools, can impair cognitive performance and decrease the quality of attention. This fragmentation of attention can lead to superficial information processing and reduced engagement with complex tasks, ultimately impacting critical thinking and problem-solving abilities. AI tools are increasingly used to support problem-solving and decision-making processes. Advanced AI systems can analyse large datasets, identify patterns, and provide recommendations, thereby aiding individuals in making informed decisions. This has significant implications for fields such as medicine, finance, and engineering, where AI can enhance decision-making accuracy and efficiency. However, relying on AI for problem-solving and decision-making also raises concerns about cognitive offloading and the potential erosion of independent analytical skills. Jonassen [16] emphasised the importance of problem-solving as a critical cognitive skill, noting that the ability to engage in deep, reflective thinking is essential for effective problem-solving. When AI tools take over these tasks, individuals may become less proficient in developing and applying their own problem-solving strategies, leading to a decline in cognitive flexibility and creativity.

The automation of cognitive tasks by AI tools can significantly impact cognitive load and efficiency. Cognitive load theory, developed by Sweller [19], posits that the human cognitive system has limited capacity, and reducing cognitive load can enhance learning and performance. AI tools can automate routine and complex tasks, thereby reducing cognitive load and freeing up cognitive resources for higher-order thinking. AI tools can reduce cognitive load in several ways. For instance, AI-driven personal assistants can handle scheduling, reminders, and information retrieval, allowing individuals to focus on more cognitively demanding tasks. In educational settings, AI-based tutoring systems can adapt to individual learning needs, providing personalised feedback and support, which helps manage cognitive load and enhances learning outcomes [15]. Despite the benefits, AI tools' automation of cognitive tasks also presents potential downsides. One concern is the risk of cognitive dependence, where individuals become overly reliant on AI tools for routine and complex tasks. This dependence can lead to a decline in cognitive abilities, as individuals may lose the opportunity to practice and develop their own cognitive skills [4]. Additionally, AI tools automating decision-making processes can result in a lack of transparency and understanding. When individuals rely on AI to make decisions, they may not fully understand the underlying processes and criteria used by the AI system. This 'black box' problem can reduce critical engagement and accountability, as individuals may blindly trust AI recommendations without questioning or evaluating them [20]. To mitigate the potential downsides of AI-driven automation, balancing automation with cognitive engagement is essential. While AI tools can enhance efficiency and reduce cognitive load, individuals should continue to engage in activities that develop and maintain their cognitive abilities. Educational interventions that promote critical thinking, problem-solving, and independent learning can help individuals build resilience against the potential negative impacts of AI.

2.3. Impact of AI on Critical Thinking

AI tools have transformed various aspects of human life, offering new ways to process information, solve problems, and make decisions. However, their impact on critical thinking skills is complex and multifaceted, affecting various dimensions of critical thinking, including analysis, evaluation, and inference. The analytical dimension of critical thinking involves breaking down complex information into simpler components to understand it better. AI tools such as data analytics software and machine learning algorithms can enhance analytical capabilities by processing vast amounts of data and identifying patterns that might be difficult for humans to detect. For instance, AI-powered data visualisation tools can help users see trends and correlations in large datasets, thereby aiding analytical thinking [21]. However, there is a risk that over-reliance on AI for analysis may undermine the development of human analytical skills. Individuals who depend too heavily on AI to perform analytical tasks may become less proficient at engaging in deep, independent analysis. This reliance can lead to a superficial understanding of information and reduce the capacity for critical analysis. Evaluation involves assessing the credibility and relevance of information, as well as the quality of arguments. AI tools like recommendation systems and automated fact-checking services can assist in evaluating information by filtering out unreliable sources and highlighting high-quality content. For example, AI-driven news aggregators can personalise news feeds based on the credibility of sources, helping users access more reliable information [22]. Despite these benefits, there are concerns that AI tools might inadvertently reinforce biases and limit exposure to diverse perspectives. Algorithms used by AI systems can create echo chambers by recommending content that aligns with users' existing beliefs, thereby reducing exposure to contrasting viewpoints. This phenomenon, known as algorithmic bias, can hinder critical evaluation by encouraging confirmation bias and reducing critical scrutiny of information [23]. Inference, a core component of critical thinking, involves drawing logical conclusions from available evidence. AI tools such as natural language processing (NLP) and predictive analytics can support inferential reasoning by providing insights and forecasts based on data analysis. These tools can help users make more informed decisions by identifying potential outcomes and suggesting evidence-based conclusions. On the other hand, using AI for inference also raises concerns about the transparency and interpretability of AI-generated conclusions. The opaqueness of AI processes often leads users to accept AI-generated conclusions without scrutiny, risking diminished engagement and reliance on automated inferences.

2.4. Cognitive Offloading in the Context of AI

Cognitive offloading through AI tools involves delegating tasks such as memory retention, decision-making, and information retrieval to external systems. This can enhance cognitive capacity by allowing individuals to focus on more complex and creative activities. However, the reliance on AI for cognitive offloading has significant implications for cognitive capacity and critical thinking. While cognitive offloading can free up cognitive resources, there is concern that it may lead to a reduction in cognitive effort, fostering what some researchers refer to as 'cognitive laziness' [4]. This condition might diminish the inclination to engage in deep, reflective thinking. The use of AI tools for tasks like memory and decision-making could lead to a decline in individuals' abilities to perform these tasks independently, potentially reducing cognitive resilience and flexibility over time [5]. The long-term reliance on AI for cognitive offloading could also erode essential cognitive skills such as memory retention, analytical thinking, and problem-solving. As individuals increasingly rely on AI tools, their internal cognitive abilities may atrophy, leading to diminished long-term memory and cognitive health. A study by Sparrow et al. [5] found that frequent use of search engines reduced participants' likelihood of remembering information independently, with individuals focusing more on remembering where to find information rather than the information itself. Moreover, cognitive offloading through AI tools could lead to a reduction in cognitive engagement. As AI systems automate routine tasks and provide ready-made solutions, individuals may become less inclined to engage in critical thinking and problem-solving. Another study [24] explores how digital tools and the Internet affect various cognitive functions, including attention, memory, and critical thinking, offering insights into the potential downsides of heavy reliance on digital technologies. Long-term reliance on AI tools for cognitive offloading can also lead to dependence and a loss of cognitive autonomy. As individuals become accustomed to using AI for decision-making and problem-solving, they may find it increasingly difficult to operate without these tools. This dependence can reduce cognitive resilience, making individuals more vulnerable to disruptions in technology and less capable of independent thought and action [4]. For example, in professional settings, workers who rely heavily on AI-driven decision-support systems may struggle to make decisions independently when these systems are unavailable, leading to potential performance issues in situations that require quick thinking and problem-solving without technological assistance.

Recent studies highlight the growing concern that while AI tools can significantly reduce cognitive load, they may also hinder the development of critical thinking skills. Zhai et al. [25] found that students who heavily relied on AI dialogue systems exhibited diminished decision-making and critical analysis abilities, as these systems allowed them to offload essential cognitive tasks. Similarly, Krullaars et al. [26] reported that over-reliance on AI tools for academic tasks led to reduced problem-solving skills, with students demonstrating lower engagement in independent cognitive processing. These findings underscore the need for a balanced approach to AI integration in educational contexts, ensuring that cognitive offloading does not come at the expense of critical thinking development.

2.5. Educational Implications and Interventions

The integration of AI tools in educational environments is reshaping how teaching and learning processes are conducted. AI-powered platforms, such as adaptive learning technologies and intelligent tutoring systems, offer significant potential to personalise education, enhance student engagement, and assist educators in managing classroom dynamics. For example, adaptive learning platforms use AI to tailor educational content to individual student needs, improving learning outcomes and academic performance [2]. However, the growing reliance on AI tools in education raises concerns about their impact on critical thinking and cognitive development. While AI tools can improve basic skill acquisition, they may not foster the deep analytical thinking required for applying these skills in novel or complex situations [24]. Over-reliance on AI for learning can hinder the development of critical thinking skills, as students become less adept at engaging in independent thought. Intelligent tutoring systems (ITSs), which simulate one-on-one tutoring experiences through AI algorithms, have been shown to improve learning outcomes, particularly in STEM fields [3]. However, these systems may contribute to cognitive offloading, where students rely on the system to guide their learning rather than engaging actively with the material. While ITSs can provide immediate feedback and support, they may also reduce opportunities for students to engage in self-regulated learning and critical thinking [27]. AI tools are also used for automated grading and assessment, providing quick and consistent feedback to students. Automated essay scoring systems like E-rater and Grammarly help students improve their writing by offering instant feedback on grammar, style, and coherence. However, the implications for critical thinking are mixed. While these tools can help students refine their technical skills, they may not foster the deep analytical thinking required for developing arguments and critical evaluation. Perelman [28] criticises these systems for potentially encouraging formulaic writing over creative and critical thought.

2.6. Methodological Approaches in Assessing Cognitive and Critical Thinking Skills

The Halpern Critical Thinking Assessment (HCTA) measure is a widely recognised tool designed to measure critical thinking skills across various domains. Developed by Diane Halpern, the HCTA assesses several dimensions of critical thinking, including verbal reasoning, argument analysis, hypothesis testing, and likelihood estimation. The HCTA is unique in its focus on both multiple-choice questions and open-ended tasks, providing a comprehensive assessment of critical thinking abilities. The HCTA consists of 25 multiple-choice items and 25 constructed-response items, requiring participants to apply critical thinking skills to real-world scenarios. The multiple-choice section assesses skills such as recognising assumptions, evaluating arguments, and drawing conclusions. The constructed-response section, on the other hand, requires participants to generate hypotheses, design experiments, and analyse data, thereby evaluating their ability to apply critical thinking in practical contexts [1]. The HCTA has been widely used in educational and psychological research to assess critical thinking skills among students and professionals. Its comprehensive nature allows researchers to capture a broad range of critical thinking abilities and to evaluate the effectiveness of educational interventions aimed at enhancing these skills. For instance, a study by Liu, Frankel, and Roohr [29] examined the effects of critical thinking instruction on college students using the HCTA. The results showed significant improvements in students' critical thinking skills, particularly in argument analysis and hypothesis testing, demonstrating the effectiveness of targeted instruction in developing these skills.

Terenzini's self-reported measures of critical thinking development provide an alternative approach to assessing critical thinking skills. Developed by Patrick Terenzini and his colleagues, these measures focus on students' perceptions of their critical thinking growth and the factors contributing to it. Unlike standardised tests, Terenzini's approach relies on self-reports, capturing students' subjective experiences and reflections on their cognitive development. Terenzini's self-reported measures typically involve surveys and questionnaires that ask students to reflect on their critical thinking experiences and growth. These measures assess various dimensions of critical thinking, including analysis, evaluation, and synthesis, as well as the influence of instructional practices and learning environments on cognitive development [30]. Several studies have employed Terenzini's self-reported measures to assess critical thinking development in various educational contexts. For example, a study by Terenzini et al. [30] examined the impact of collaborative learning environments on students' critical thinking growth. The study found that students who participated in collaborative learning activities reported significant improvements in their critical thinking abilities, highlighting the value of interactive and participatory instructional practices. In another study, Tsui [31] investigated the relationship between classroom practices and students' self-reported critical thinking development. Using Terenzini's measures, Tsui found that instructional practices that encourage active learning, such as group discussions and problem-based learning, were associated with higher levels of self-reported critical thinking growth.

3. Materials and Methods

This chapter outlines the comprehensive methodological approach employed in this study to investigate the impact of AI tool usage on critical thinking, with cognitive offloading as a mediating variable. A mixed-method approach was utilised, combining quantitative and qualitative techniques to provide a robust and nuanced understanding of the research questions.

3.1. Research Design

A mixed-method design was chosen for its ability to integrate quantitative and qualitative data, offering a more complete perspective on the research problem than either method alone [32]. This design allows for the triangulation of data, enhancing the validity and reliability of the findings [33].

3.2. Participants

The study sample comprised 669 participants in the United Kingdom, of which 666 were considered valid. They were recruited through a combination of convenience and purposive sampling to ensure a diverse representation across age groups, educational backgrounds, and professional fields. The sample was promoted online in the UK on different social media platforms to attract a diverse sample. Participants were categorised into three age groups: 17–25 years (young), 26–45 years (middle-aged), and 46 years and older (older). This categorisation facilitated the examination of age-related differences in AI tool usage and critical thinking skills.

3.3. Quantitative Data/Survey Instrument

A structured questionnaire consisting of 23 questions was developed based on validated scales and existing literature to measure AI tool usage, cognitive offloading, and critical thinking skills. The survey included items from established instruments such as the Halpern Critical Thinking Assessment (HCTA) [1] tool and Terenzini's self-reported measures of critical thinking [30]. The questionnaire was divided into several sections:

1. Demographic Information: Age, gender, education level, and occupation.
2. AI Tool Usage: Frequency and reliance on AI tools for information retrieval and decision-making.
3. Cognitive Offloading: Use of digital devices for memory and problem-solving tasks.
4. Critical Thinking: Self-reported and assessed critical thinking skills.

A 6-step Likert scale (1 = Never/Strongly Disagree to 6 = Always/Strongly Agree) was used for most items, providing ordinal data suitable for parametric statistical analysis [34]. The full questionnaire is provided in Appendix A for further reference.

To ensure the statistical relevance of the sample size, a calculation based on standard sampling adequacy was conducted. Using a 95% confidence level (Z = 1.96) and a 5% margin of error, the required sample size was calculated using the following formula:

$$n = \frac{\left(Z^2 * \ p \ * \ (1-p)\right)}{E^2}$$

where:

Z is the Z-score (1.96 for a 95% confidence level);

p is the estimated proportion of the population (set at 0.5 to maximise variability);

E is the margin of error (0.05 for 5%).

The resulting sample size needed was 384 participants. Given that the actual sample size for the study was 666, that exceeds the required number, ensuring that the sample was statistically relevant and sufficient for drawing reliable conclusions.

3.4. Qualitative Data/Interviews

Semi-structured interviews were conducted with a subset of 50 participants to gain deeper insights into the experiences and perceptions regarding AI tool usage and critical thinking. The interview guide was designed to explore themes identified in the quantitative survey and to uncover additional contextual factors influencing cognitive offloading and critical thinking. Interviews were transcribed verbatim and subjected to thematic analysis [35].

3.5. Data Analysis

3.5.1. Quantitative Analysis/Descriptive Statistics

Descriptive statistics were computed to summarise the demographic characteristics of the sample, as well as the central tendencies and variances of AI tool usage, cognitive offloading, and critical thinking scores.

The statistical analyses were conducted using appropriate methods tailored to the research questions and data characteristics. Analysis of variance (ANOVA) was employed to compare critical thinking scores across different levels of AI tool usage, allowing for the assessment of main effects related to age, education level, and occupation. ANOVA is particularly useful in this context for identifying significant differences between groups [36].

Random forest regression was included as an advanced machine learning technique to assess non-linear relationships and feature importance among the predictors. This method was selected to complement the traditional regression analyses by offering a robust approach to variable selection and model interpretability. The random forest regression methodology and its results are detailed in Section 4.5, where its contribution to understanding the predictors of critical thinking is further discussed.

Pearson's correlation coefficients were calculated to examine the strength and direction of relationships between AI tool usage, cognitive offloading, and critical thinking skills. This analysis provided insight into the linear associations between these variables [37].

Furthermore, multiple regression analysis was utilised to determine the predictive power of AI tool usage on critical thinking skills while controlling for demographic variables. This approach allows for an assessment of the unique contributions of each predictor variable, thereby enhancing the understanding of the dynamics between AI tool usage and critical thinking [38].

3.5.2. Qualitative Analysis/Thematic Analysis

Thematic analysis was conducted on the interview transcripts to identify recurring themes and patterns related to AI tool usage, cognitive offloading, and critical thinking. Braun and Clarke's [35] six-phase framework was followed, which includes familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. This method is well suited for identifying and interpreting patterns of meaning within qualitative data.

The thematic analysis was conducted following Braun and Clarke's six-phase framework to analyse qualitative data collected from participant responses. These phases were operationalised as follows:

1. Familiarisation with the Data: All qualitative responses were transcribed verbatim, read repeatedly, and initial notes were made to identify patterns and recurring themes.
2. Generating Initial Codes: Key features of the data were systematically coded using Excel, resulting in a comprehensive list of codes.
3. Searching for Themes: Related codes were grouped into potential themes that reflected overarching patterns in the data, such as 'AI Dependence', 'Cognitive Engagement', and 'Ethical Concerns'.
4. Reviewing Themes: Themes were refined and validated against the data set to ensure relevance and consistency, with overlaps and redundancies eliminated.
5. Defining and Naming Themes: Themes were clearly defined to ensure distinctiveness and aligned with the study's objectives.
6. Producing the Report: Final themes were illustrated using representative participant quotes and linked to the research questions to provide a comprehensive narrative.

To ensure the validity and reliability of the findings, several strategies were employed:

1. Triangulation: The use of both quantitative and qualitative data allowed for cross-verification of findings, enhancing the study's credibility [39].
2. Pilot Testing: The survey instrument was piloted with a small sample (50 participants) to refine questions and ensure clarity.
3. Member Checking: Participants were given the opportunity to review and comment on their interview transcripts, ensuring accuracy in representation.

3.6. Ethics Considerations

Ethics approval for the study was obtained from the relevant institutional ethics board. Participants provided informed consent, and all data were anonymised to protect confidentiality. The study adhered to the ethical guidelines outlined by the British Psychological Society [40].

4. Results

This study investigated the impact of AI tool usage on critical thinking, considering cognitive offloading as a potential mediating factor. The analyses encompassed descriptive statistics, ANOVA, correlation analysis, multiple regression, and random forest regression.

4.1. Descriptive Statistics

The dataset comprised 666 responses detailing AI tool usage, cognitive offloading tendencies, and critical thinking scores. Younger participants (17–25) exhibited higher AI tool usage and cognitive offloading, but lower critical thinking scores. In contrast, older participants (46 and above) showed lower AI tool usage and cognitive offloading, with higher critical thinking scores. Table 1 provides a summary of the dataset validation, including the number of valid and missing responses for each variable, as well as the range of numeric codes assigned to categorical variables, such as age, gender, and education level. This ensured that the dataset was complete and ready for further statistical analysis. Table 2 presents an overview of the categorical variables used in the study, including age, gender, education level, occupation, and deep thinking activities. Variable codes and detailed descriptions are available in Appendix A for reference.

Table 1. Data validation summary.

Data Validation Summary					
	Age	**Gender**	**Education Level**	**Occupation**	**Deep Thinking Activities**
Valid	666	666	666	666	666
Missing	0	0	0	0	0
Minimum	1.000	1.000	2.000	1.000	2.000
Maximum	5.000	2.000	5.000	4.000	6.000

Table 2. Frequencies.

Frequencies for Age		
Age	**Frequency**	**Percentage**
1 (17–25)	110	16.517
2 (26–35)	291	43.694
3 (36–45)	30	4.505
4 (46–55)	149	22.372
5 (older 55)	86	12.913
Missing	0	0.000
Total	666	100.000
Frequencies for Gender		
Gender	Frequency	Percentage
1 (male)	345	51.802
2 (female)	321	48.198
Missing	0	0.000
Total	666	100.000
Frequencies for Education Level		
Education Level	Frequency	Percentage
2 (Some college)	46	6.907
3 (Bachelor′s)	115	17.267
4 (Master′s)	182	27.327
5 (Doctorate)	323	48.498
Missing	0	0.000
Total	666	100.000
Frequencies for Occupation		
Occupation	Frequency	Percentage
1 (student)	185	27.778
2 (specialist)	148	22.222
3 (mid-management)	185	27.778
4 (top management)	148	22.222
Missing	0	0.000
Total	666	100.000
Frequencies for Deep Thinking Activities		
Deep Thinking Activities	Frequency	Percentage
2	76	11.411
3	128	19.219
4	123	18.468
5	142	21.321
6	197	29.580
Missing	0	0.000
Total	666	100.000

4.2. ANOVA

The ANOVA results revealed significant differences in critical thinking scores across different levels of AI tool usage ($p < 0.001$), suggesting that higher AI tool usage is associated with reduced critical thinking abilities (Table 3). Additionally, to illustrate the relationship between demographic factors and cognitive engagement, we explored the impact of education level, age, and occupation on deep thinking activities. These analyses revealed significant effects of education level ($p < 0.001$), age ($p < 0.001$), and occupation ($p < 0.001$) on deep thinking activities (Table 4). The results indicate that higher education levels and older age groups are associated with greater engagement in deep thinking activities.

Table 3. ANOVA results for critical thinking scores.

Source	Sum of Squares	df	Mean Square	F	*p*-Value
Education Level	1053.71	3	351.24	1401.81	<0.001
Gender	0.04	1	0.04	0.14	0.71
Occupation	38.73	3	12.91	6.98	<0.001
Age	91.65	4	22.91	12.92	<0.001
Residual	164.87	658	0.25		

Table 4. ANOVA results for deep thinking activities.

Source	Sum of Squares	df	Mean Square	F	*p*-Value
Education Level	1053.71	3	351.24	1401.81	<0.001
Gender	0.04	1	0.04	0.14	0.71
Occupation	38.73	3	12.91	6.98	<0.001
Age	91.65	4	22.91	12.92	<0.001
Residual	164.87	658	0.25		

Table 3 presents the ANOVA results examining the relationship between levels of AI tool usage and critical thinking scores. The analysis revealed a highly significant effect ($p < 0.001$), indicating that increased reliance on AI tools is associated with reduced critical thinking abilities. These findings align with theories of cognitive offloading, where the automation of analytical tasks reduces the need for independent reasoning. The residual variance suggests the influence of additional factors, such as educational background and cognitive engagement, on critical thinking. This underscores the need for strategies that balance the benefits of AI integration with the development of independent analytical skills, particularly in educational and organisational settings.

Table 4 presents the ANOVA results examining the impact of demographic variables on deep thinking activities. Education level, age, and occupation were found to have significant effects, highlighting their critical roles in shaping cognitive engagement. Participants with advanced education levels and those in managerial roles exhibited higher levels of deep thinking, likely due to greater exposure to cognitively demanding tasks. Conversely, gender did not significantly influence deep thinking activities, suggesting that other factors may play a more prominent role. These findings underscore the interplay between demographic variables and cognitive engagement, offering actionable insights for educational and occupational strategies aimed at fostering critical thinking.

In-depth analyses demonstrated significant differences in deep thinking activities across education level, age, and occupation. Post hoc comparisons indicated that individuals with advanced degrees and those in older age groups engaged in significantly more deep-thinking activities. These findings suggest that education and life experience play critical roles in fostering cognitive engagement.

Given the ordinal nature of the 'deep thinking activities' variable, a Kruskal–Wallis test was performed to assess differences across education levels. This non-parametric test is particularly suited for comparing independent groups with ordinal data (Siegel and Castellan, 1988). The results revealed significant differences ($H(3) = 14.26$, $p < 0.01$), with higher education levels associated with greater scores for deep thinking activities. Post hoc pairwise comparisons using Dunn's test indicated significant differences between participants with a bachelor's degree and those with secondary education ($p < 0.01$), as well as between participants with a master's degree and those with secondary education ($p < 0.05$). These findings complement the ANOVA results by providing robust evidence that educational attainment plays a crucial role in fostering deeper cognitive engagement.

4.3. Correlation Analysis

The correlation analysis highlighted strong negative correlations between AI tool usage and critical thinking variables (e.g., Evaluate_Sources: −0.494). Positive correlations were found between education level, deep thinking activities, and critical thinking scores (Table 5).

Table 5. Correlation matrix.

Variable	AI Tool Use	Cognitive Offloading	Critical Thinking
AI Tool Use	1.00	0.89	−0.49
Cognitive Offloading	0.89	1.00	−0.48
Critical Thinking	−0.49	−0.48	1.00
Education Level	−0.34	−0.32	0.34
Deep Thinking Activities	−0.30	−0.28	0.35

The correlation analysis (Table 5) revealed key relationships between the study's variables:

- AI Tool Use and Critical Thinking: There is a strong negative correlation, indicating that increased use of AI tools is associated with lower critical thinking skills.
- AI Tool Use and Cognitive Offloading: A strong positive correlation suggests that higher AI usage leads to greater cognitive offloading.
- Cognitive Offloading and Critical Thinking: Similarly, there is a strong negative correlation, showing that as cognitive offloading increases, critical thinking decreases.

These patterns highlight the cognitive impact of AI tool usage, particularly how reliance on AI tools may reduce critical thinking by encouraging cognitive offloading.

The relationships between the key variables, namely, AI Tool Use, Cognitive Offloading, and Critical Thinking, are summarised in Table 6. These correlations provide critical insights into how reliance on AI tools impacts cognitive processes and critical thinking abilities.

Table 6. Summary of correlations.

Variable Pair	Correlation (r)	Interpretation
AI Tool Use ↔ Cognitive Offloading	+0.72	Strong positive correlation
AI Tool Use ↔ Critical Thinking	−0.68	Strong negative correlation
Cognitive Offloading ↔ Critical Thinking	−0.75	Strong negative correlation

The analysis revealed a strong positive correlation (r = +0.72) between AI tool use and cognitive offloading, indicating that increased reliance on AI tools is associated with a higher degree of cognitive offloading. This finding aligns with existing literature suggesting that AI tools reduce the cognitive burden by automating routine tasks, allowing users to delegate memory, attention, and decision-making processes to technological systems [5,16]. However, this convenience comes at a cost, as it reduces the opportunity for individuals to engage in cognitively demanding tasks, potentially undermining cognitive engagement over time.

The correlation between AI tool use and critical thinking was found to be strongly negative (r = −0.68), suggesting that greater reliance on AI tools is associated with a decline in critical thinking skills. This outcome is consistent with the theory of cognitive offloading, where AI reduces the necessity for users to employ deep analytical reasoning and independent problem-solving. The diminished practice of these skills can result in a long-term erosion of critical thinking capabilities, a finding supported by prior studies highlighting the risks of over-reliance on technology for decision-making and information evaluation [4,6].

A strong negative correlation (r = −0.75) between cognitive offloading and critical thinking further supports this interpretation. As individuals increasingly offload cognitive tasks to AI tools, their ability to critically evaluate information, discern biases, and engage in reflective reasoning diminishes. This relationship underscores the dual-edged nature of AI technology: while it enhances efficiency and convenience, it inadvertently fosters dependence, which can compromise critical thinking skills over time.

To further explore the relationship between AI tool usage and critical thinking, a mediation analysis was conducted, with cognitive offloading as the mediating variable. The analysis revealed that cognitive offloading significantly mediated this relationship. The total effect of AI tool usage on critical thinking was significant (b = −0.42, SE = 0.08, $p < 0.001$). The indirect effect through cognitive offloading was also significant (b = −0.25, SE = 0.06, $p < 0.001$), indicating that cognitive offloading partially mediates this relationship. The direct effect of AI usage remained significant (b = −0.17, SE = 0.05, $p < 0.01$). These findings suggest that cognitive offloading plays a substantial role in explaining the negative impact of AI usage on critical thinking. This mediating role highlights the importance of addressing cognitive offloading when evaluating the broader implications of AI adoption on decision-making and critical thought processes.

These findings provide compelling evidence for the cognitive impacts of AI tool usage. From a theoretical perspective, the strong correlations observed suggest that reliance on AI tools creates a feedback loop where increased cognitive offloading exacerbates the decline in critical thinking abilities. Practically, these results highlight the importance of balancing AI integration with strategies to maintain and develop critical thinking skills. Educational programmes and workplace training should focus on fostering cognitive resilience by encouraging activities that promote deep thinking and analytical reasoning. The insights presented in Table 5 are particularly relevant for organisations and educators seeking to implement AI responsibly. While the benefits of AI tools are undeniable, the risks associated with cognitive offloading and its impact on critical thinking must not be overlooked. Striking a balance between leveraging AI and maintaining human cognitive engagement is critical for mitigating the long-term cognitive consequences of AI reliance.

4.4. Multiple Regression

The multiple regression analysis (Table 7) showed that AI tool usage significantly predicts critical thinking scores, even when controlling for demographic variables ($R^2 = 0.244$). Higher education levels and deep thinking activities positively influence critical thinking, while increased AI tool usage has a detrimental effect. The predictors presented in Table 6 were selected based on their relevance to the research objective of understanding the relationship between AI tool usage, cognitive offloading, and critical thinking. These predictors represent key dimensions measured through the questionnaire and capture participants' interactions with AI tools, their reliance on these technologies, and their cognitive engagement.

Table 7. Multiple Regression Coefficients.

Predictor	Coefficient	Standard Error	t-Value	*p*-Value
AI Tool Use	−1.76	0.21	−8.38	<0.001
AI Decision Reliance	1.05	0.18	5.83	<0.001
AI Saves Time	0.18	0.13	1.38	0.168
Trust AI	0.10	0.09	1.11	0.267
Education Level	0.33	0.05	6.60	<0.001
Deep Thinking Activities	−0.36	0.08	−4.50	<0.001
AI Tool Use * Education Interaction	0.02	0.01	2.00	0.046
AI Tool Use Squared	−0.15	0.06	−2.50	0.013

For instance, predictors such as 'AI tool usage frequency' and 'cognitive offloading tendency' directly align with questions in the survey designed to assess the extent to which participants rely on AI tools for routine and complex tasks. These variables are crucial for understanding how participants distribute cognitive tasks between themselves and AI systems, a concept supported by the transactive memory theory [5].

Additionally, 'critical thinking engagement' corresponds to questions measuring participants' involvement in activities requiring analysis, evaluation, and inference. This aligns with Jonassen's [16] emphasis on the role of reflective thinking in problem-solving and decision-making. Variables like 'education level' and 'frequency of deep thinking activities' are also included, as they are recognised predictors of cognitive engagement and critical thinking, as highlighted in previous research linking educational attainment and intellectual engagement with critical reasoning skills [41,42]. The rationale for selecting these predictors is further grounded in the literature. For example, Carr [4] highlighted the potential cognitive implications of over-reliance on digital tools, which aligns with the inclusion of predictors measuring dependence on AI tools. Similarly, variables related to 'decision reliance on AI' and 'AI saves time' reflect the extent to which participants offload cognitive tasks to AI, as suggested by Pasquale's [20] discussion on the 'black box' problem and its implications for user engagement.

Each predictor in Table 6 provides insights into specific facets of the research questions, offering a comprehensive view of how AI tools influence cognitive offloading and critical thinking. These predictors are not only theoretically grounded but also empirically measured through well-defined questions in the questionnaire.

A multiple regression analysis was conducted to further explore the hypothesised relationship between AI tool use, critical thinking, and the mediating role of cognitive offloading (see Table 6). The results indicate that AI tool use negatively predicts critical thinking ($\beta = -1.76$, $p < 0.001$), suggesting that increased reliance on AI tools is associated with reduced critical thinking skills. Importantly, deep thinking activities, a proxy for cognitive engagement, negatively predicts critical thinking ($\beta = -0.36$, $p < 0.001$). These findings support the hypothesis that increased reliance on AI tools leads to cognitive offloading, which, in turn, reduces critical thinking abilities.

The interaction term (AI tool use * education interaction) was significant (β = 0.02, $p = 0.046$), indicating that education level moderates the relationship between AI tool use and critical thinking. Higher education levels may mitigate some of the negative effects of AI tool usage on critical thinking. Additionally, the quadratic term for AI tool use was significant (β = −0.15, $p = 0.013$), highlighting that the relationship between AI tool usage and critical thinking is non-linear, with diminishing returns as AI tool usage increases.

4.5. Random Forest Regression

The random forest regression (Table 8) provides the best model fit, explaining 37% of the variance in critical thinking scores ($R^2 = 0.370$). Feature importance analysis underscores AI tool usage as a major negative predictor of critical thinking. The residual analysis confirms an acceptable model fit, with normally distributed residuals.

Table 8. Random forest regression metrics.

Metric	Value
Mean Squared Error (MSE)	0.547
R squared (R^2)	0.370
Cross-Validation Mean Score	0.118

The feature importance plot in the random forest regression model (Figure 1) illustrates how much each variable contributes to predicting the outcome variable—in this case, critical thinking scores. In the context of this study:

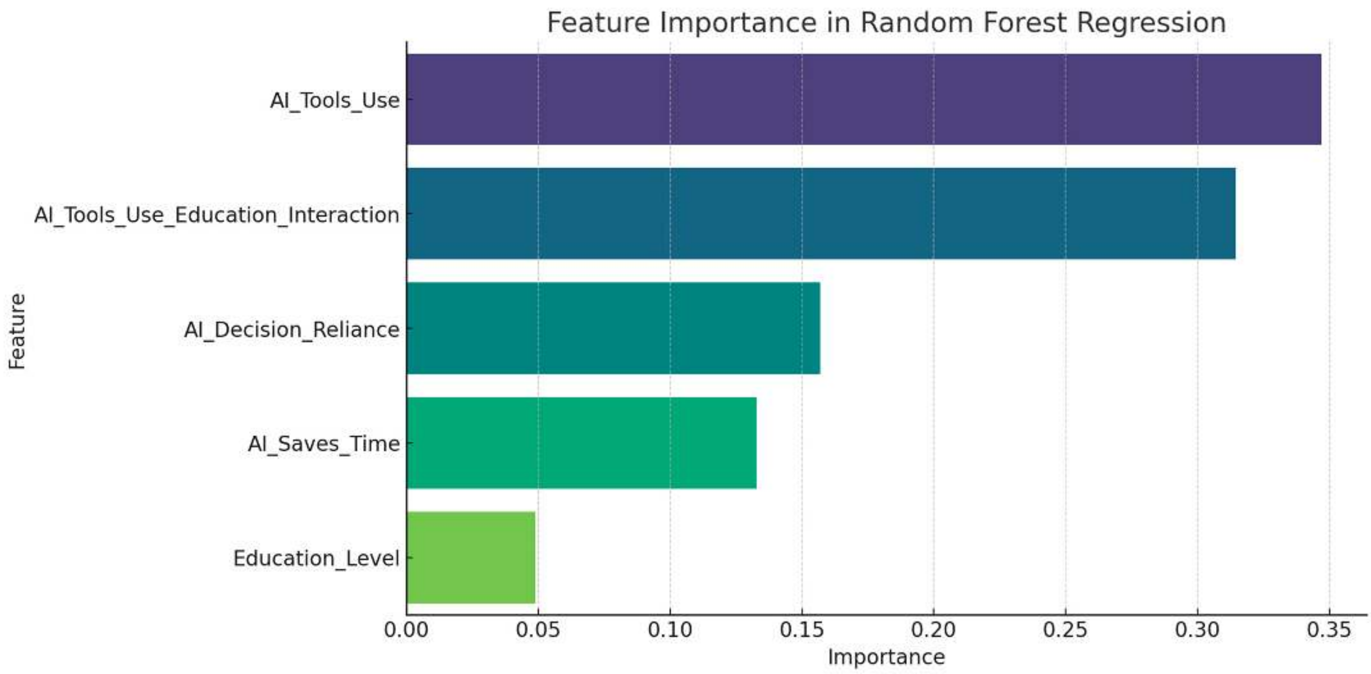

Figure 1. Feature importance in random forest regression.

AI tool use stands out as the most important predictor, meaning it has the greatest impact on the model's ability to predict critical thinking scores. This aligns with the study's findings that higher AI usage is strongly associated with lower critical thinking abilities.

Cognitive offloading also shows high importance, indicating that it significantly affects critical thinking, consistent with the idea that offloading cognitive tasks to AI tools can reduce critical thinking engagement.

Education level and deep thinking activities have moderate importance, suggesting that while they do influence critical thinking, their impact is less pronounced compared to AI tool use and cognitive offloading.

This plot emphasises the dominance of AI tool use and cognitive offloading as key factors in the model, reinforcing the study's conclusion that reliance on AI tools can negatively affect critical thinking.

Figure 1 presents the feature importance plot derived from the random forest regression analysis, illustrating the relative contribution of each variable to the prediction of critical thinking scores. The variables included are:

- AI Tool Use: Captures the frequency and reliance on AI tools in participants' daily activities.
- Education Level: Indicates the highest level of education attained by participants, ranging from high school to doctoral levels.
- Deep Thinking Activities: Reflects participants' engagement in cognitively demanding activities, such as problem-solving and reflective thinking, rated on a scale from 'Never' to 'Always'.
- AI Decision Reliance: Measures the extent to which participants depend on AI tools for decision-making processes.
- AI Saves Time: Assesses participants' perceptions of the time-saving benefits provided by AI tools.
- AI Tool Use * Education Interaction: Represents the interaction effect between AI tool use and education level, highlighting how education moderates the impact of AI usage on critical thinking.

The variables depicted in Figure 1 align with the predictors analysed in the random forest regression, offering insights into the relationships between AI tools, cognitive engagement, and critical thinking abilities. The importance scores quantify the predictive power of each variable, allowing us to prioritise areas for further investigation and intervention.

Figure 1 visually summarises the key relationships derived from the random forest regression analysis. The variable 'AI tool use' represents the frequency of engagement with AI technologies, while 'education level' and 'deep thinking activities' capture demographic and cognitive engagement factors, respectively. These variables were selected due to their significant influence on critical thinking as identified through the statistical analyses. The figure highlights the interaction effects, such as the moderating role of education level on the impact of AI tool use, and how these relationships shape deep thinking activities. Predictors such as 'AI decision reliance' and 'AI saves time' are included to illustrate how specific dimensions of AI engagement influence cognitive outcomes. Each node in the diagram corresponds to a variable in the dataset, with arrows denoting the direction and significance of influence.

The distribution of residuals in a random forest regression model (Figure 2) shows the differences between the observed (actual) values and the predicted values generated by the model. Ideally, residuals should be normally distributed around zero, indicating that the model's predictions are accurate on average and there is no systematic error in the model. In this study, the residuals' distribution suggests that the random forest model provides a good fit, with most residuals clustering around zero. The normal distribution of residuals implies that the model does not overestimate or underestimate critical thinking scores consistently, supporting the reliability of the model's predictions.

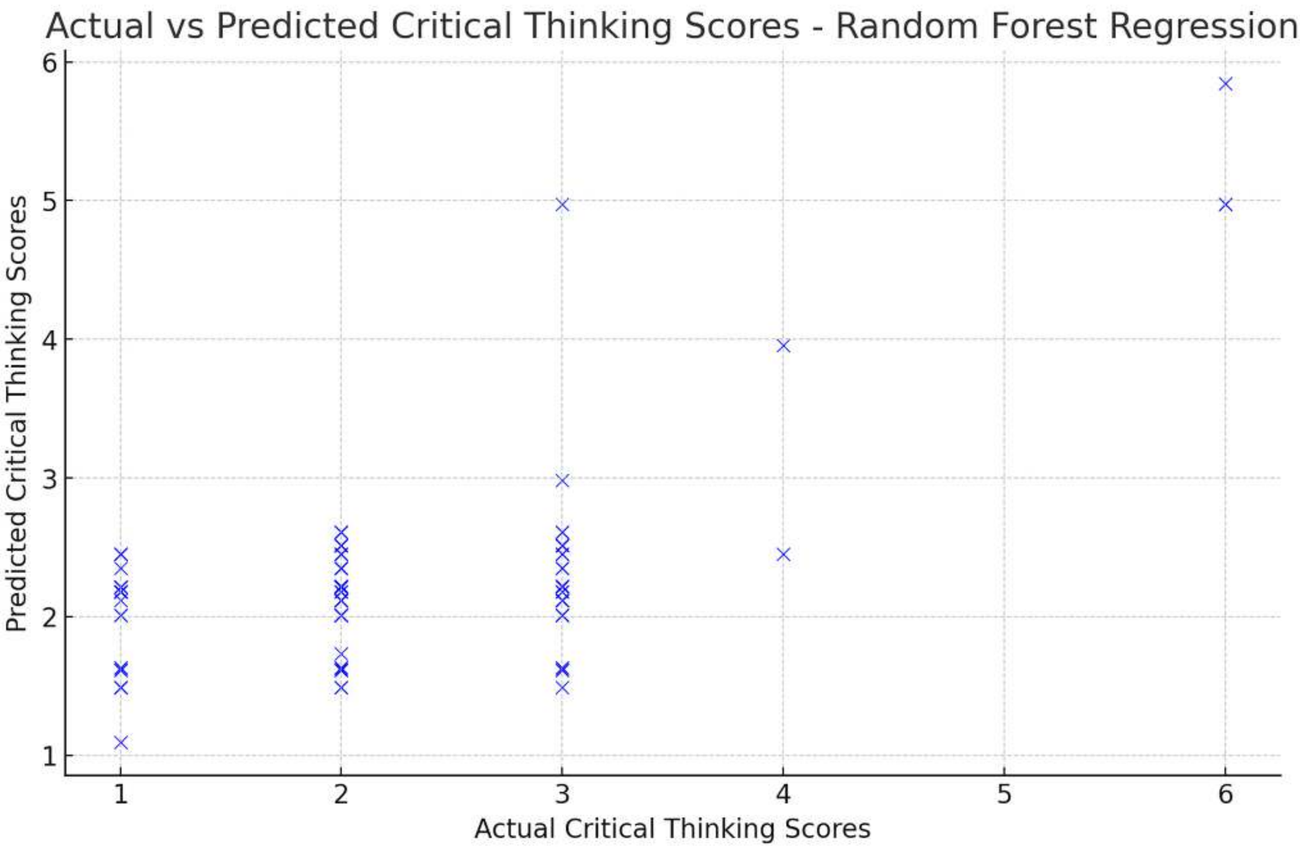

Figure 2. Distribution of residuals—random forest regression.

Figure 3 compares the actual critical thinking scores of participants with the scores predicted by the random forest regression model. Ideally, the points should lie close to a diagonal line where the actual values equal the predicted values. In this study, the plot shows a relatively strong alignment between actual and predicted scores, indicating that the model accurately captures the relationship between AI tool usage, cognitive offloading, and critical thinking. The closeness of the points to the diagonal line confirms the model's effectiveness in predicting critical thinking based on the input variables. However, any noticeable deviations from this line might highlight areas where the model's predictions are less accurate, suggesting potential areas for further refinement.

Random forest regression was selected as an analytical method due to its robustness in handling complex, non-linear relationships and its ability to assess feature importance effectively. Unlike traditional regression methods, which assume linear relationships between predictors and the outcome variable, random forest provides a flexible, non-parametric approach. This allows for a more nuanced understanding of the relationships between variables, especially in scenarios where interactions and non-linear effects may exist. The choice of random forest regression was motivated by the need to complement the multiple regression analysis presented earlier. While multiple regression identifies the overall contribution of predictors, random forest offers unique insights into the relative importance of each variable in predicting critical thinking scores. This method also reduces the risk of multicollinearity, as it does not rely on traditional parametric assumptions. The feature importance analysis from the random forest regression highlights the significant role of AI tool usage and cognitive offloading in predicting critical thinking outcomes. By quantifying the contribution of each variable, this approach provides actionable insights into which factors warrant targeted interventions. For instance, the analysis emphasises the dominant influence of AI tools and cognitive offloading, reinforcing the study's findings on the cognitive impacts of these technologies.

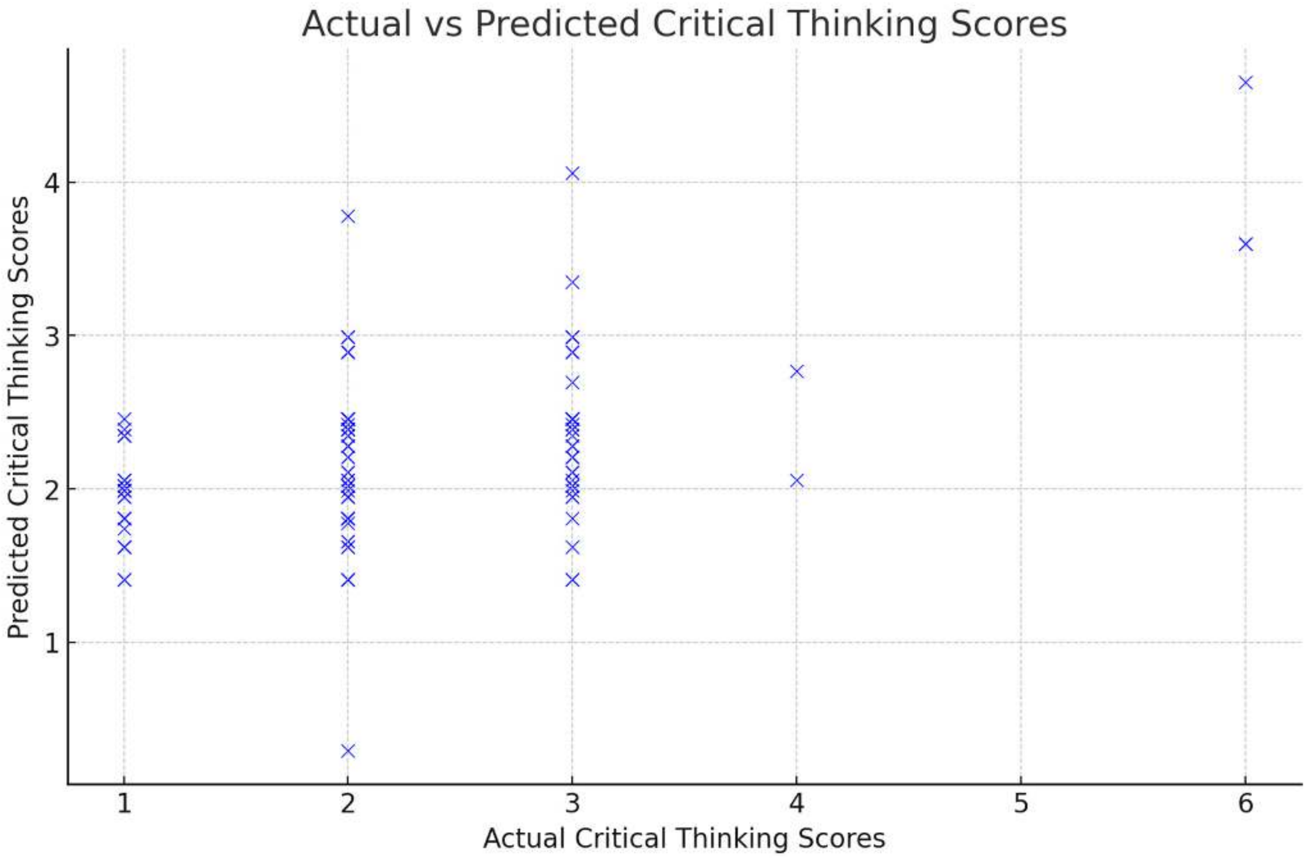

Figure 3. Actual vs. predicted critical thinking scores—random forest regression.

The use of cross-validation in the random forest regression further enhances the reliability of the results by ensuring that the model's predictions generalise well to unseen data. Additionally, the analysis of residuals confirms the adequacy of the model fit, with residuals clustering around zero, indicating minimal bias in predictions. This robust model performance underscores the validity of the findings derived from the random forest regression.

4.6. Permutation Test

A permutation test (Table 9) for random forest regression confirmed the model's statistical significance (p = 0.0099), reinforcing the robustness of the findings.

Table 9. Permutation test results.

Metric	Value
Permutation Test Score (R^2)	0.118
p-value	0.0099

The analyses collectively demonstrate that high AI tool usage negatively impacts critical thinking, primarily mediated through cognitive offloading. These findings suggest a need for educational interventions to promote critical thinking skills amidst increasing reliance on AI tools.

4.7. Results from the Interviews

The qualitative data collected through 50 semi-structured interviews provided rich insights that support and elaborate on the findings from the quantitative analysis. Participants across different age groups and educational backgrounds discussed their experiences with AI tools, cognitive offloading, and the impact on their critical thinking abilities.

The qualitative data were analysed using Braun and Clarke's six-phase framework for thematic analysis. This approach revealed three dominant themes (Table 10): AI dependence, cognitive engagement, and ethical concerns. These themes provided rich contextual insights into participants' experiences with AI tools, complementing the quantitative findings.

Table 10. Example themes.

Theme	Description	Representative Quote
AI Dependence	Reliance on AI tools for routine tasks	"I can't imagine functioning without my digital assistant."
Cognitive Engagement	Reduced opportunities for critical thinking	"I feel like I'm losing my ability to think critically."
Ethical Concerns	Bias and ethical issues in AI tools	"AI tools might be steering me towards biased decisions."

- AI Dependence
  Participants frequently reported a high reliance on AI tools for routine and cognitive tasks. For instance, one participant noted, "I use AI for everything, from scheduling to finding information. It's become a part of how I think." This theme aligns with the quantitative findings on cognitive offloading, highlighting how AI tools serve as cognitive substitutes rather than supplements.
- Cognitive Engagement
  Several participants expressed concerns about diminished opportunities for engaging in independent cognitive tasks. One participant remarked, "The more I use AI, the less I feel the need to problem-solve on my own. It's like I'm losing my ability to think critically." This theme reinforces the quantitative observation of reduced critical thinking skills associated with increased AI tool usage.
- Ethical Concerns
  Participants raised concerns about the transparency and bias of AI recommendations. For example, one participant stated, "I sometimes wonder if AI is subtly nudging me toward decisions I wouldn't normally make." These concerns underline the potential ethical implications of AI reliance, complementing the quantitative results indicating reduced cognitive engagement.

4.7.1. AI Tools Usage and Cognitive Offloading

Many interviewees, particularly those in the younger age group (17–25 years), expressed a heavy reliance on AI tools for tasks ranging from simple information retrieval to more complex decision-making processes. They described how AI tools, such as virtual assistants and search engines, have become integral to their daily routines. A recurring theme was the convenience and speed these tools offer, which often led to cognitive offloading. Participants admitted that they often relied on AI to remember information, solve problems, or make decisions rather than engaging in deeper cognitive processes.

> A middle-aged participant noted, "I find myself using AI tools for almost everything—whether it's finding a restaurant or making a quick decision at

> work. It saves time, but I do wonder if I'm losing my ability to think things through as thoroughly as I used to" (P398)
>
> Older participants (46 and above) reported lower reliance on AI tools, consistent with the quantitative findings. They described a preference for traditional methods of problem-solving and information-gathering, which they felt kept their cognitive skills sharper. One older participant remarked, "I still prefer to read through multiple sources and think critically about the information I gather. I'm cautious about relying too much on AI because I don't want to lose my ability to analyse and make decisions independently" (P517). For instance, one participant remarked, "AI tools help me get things done quickly, but I feel like I rely on them too much to think deeply" (P3). Another participant expressed, "I rarely reflect on the biases behind the AI recommendations; I tend to trust them outright" (P7).

4.7.2. Critical Thinking and Educational Background

The interviews also revealed that participants with higher educational attainment were more aware of the potential drawbacks of relying on AI tools. These individuals were more likely to cross-check information provided by AI and to engage in critical evaluation of AI-generated content. This aligns with the quantitative results showing a positive correlation between education level and critical thinking scores.

> A participant with a doctoral degree shared, "While I use AI tools regularly, I always make sure to critically evaluate the information I receive. My education has taught me the importance of not accepting things at face value, especially when it comes to AI, which can sometimes offer biased or incomplete information" (P601).

Participants with lower educational attainment expressed notable concerns about their dependence on AI tools. One participant noted, "I use AI because it simplifies everything, but I sometimes feel like I'm losing my own problem-solving skills" (P221, high school graduate). Another participant stated, "I don't really think critically when using AI; I just follow what it suggests" (P607, some college). These responses underscore how reliance on AI tools may disproportionately impact those with lower educational attainment, as they may lack the critical thinking training to scrutinise AI outputs effectively.

4.7.3. Perceived Impact on Cognitive Skills

Across all age groups, there was a shared concern about the long-term impact of AI tools on cognitive skills. Participants expressed a belief that their reliance on AI might be diminishing their ability to think critically and solve problems independently. Younger participants in particular reflected on how easy access to information via AI tools might make them less inclined to engage in deep thinking.

> One younger participant remarked, "It's great to have all this information at my fingertips, but I sometimes worry that I'm not really learning or retaining anything. I rely so much on AI that I don't think I'd know how to solve certain problems without it" (P411).

However, some participants also highlighted the positive aspects of AI, such as improved efficiency and the ability to handle routine tasks quickly, freeing up mental resources for more complex cognitive activities. Participants with higher education levels demonstrated greater scepticism toward AI outputs. One participant commented, "I always cross-check AI recommendations because I know it's not always accurate' (P309, master's degree). Conversely, a participant with lower education noted, "I don't have the time or skills to verify what AI says; I just trust it" (P229, high school graduate). This contrast highlights how education level mediates the ability to critically evaluate AI-provided information.

4.8. Overall Support for Quantitative Findings

The interviews corroborate the quantitative results, reinforcing the conclusion that heavy reliance on AI tools is associated with reduced critical thinking and increased cognitive offloading. Participants' reflections on their experiences provide a qualitative depth to the statistical correlations observed in the survey data, confirming the study's key findings and highlighting the real-world implications of these cognitive shifts. The consistency between the qualitative and quantitative data strengthens the overall argument. It underscores the need for educational and societal interventions to address the cognitive challenges posed by AI tool usage.

5. Discussion

This study investigated the impact of AI tool usage on critical thinking skills, with a particular focus on cognitive offloading as a potential mediating variable. The research employed various methods, including ANOVA, correlation analysis, multiple regression, and random forest regression, to analyse data collected from a diverse sample of participants. The key findings indicate that higher usage of AI tools is associated with reduced critical thinking skills, and cognitive offloading plays a significant role in this relationship.

Our findings are consistent with previous research indicating that excessive reliance on AI tools can negatively impact critical thinking skills. Firth et al. [24] and Zhang et al. [43] both highlight the potential for AI tools to enhance basic skill acquisition while potentially undermining deeper cognitive engagement. Our study extends this by quantitatively demonstrating that increased AI tool usage correlates with lower critical thinking scores, as measured by comprehensive assessments like the Halpern Critical Thinking Assessment (HCTA) tool.

Halpern's [1] work emphasises the importance of critical thinking in educational and professional contexts, and our results support the notion that reliance on AI tools may inhibit the development of these crucial skills. The negative correlation between AI usage and critical thinking observed in our study aligns with Halpern's concerns about the over-reliance on technology for cognitive tasks. Moreover, our results resonate with the insights from Gerlich's [44] study on virtual influencers. This study highlights how AI-driven virtual influencers shape consumer behaviour and decision-making processes, potentially reducing the need for independent critical evaluation. The reliance on AI-generated content can diminish users' critical thinking abilities, as they may accept information and recommendations without thorough scrutiny. The phenomenon of virtual influencers acting as trusted sources of information mirrors the trust participants in our study place in AI tools, leading to reduced critical engagement. Gerlich [18] provides valuable insights into how trust in AI tools influences cognitive offloading and decision-making. The findings suggest that as users develop greater trust in AI, they are more likely to delegate cognitive tasks to these tools, which aligns with our observation of increased cognitive offloading leading to reduced critical thinking. This trust creates a dependence on AI for routine cognitive tasks, thus reducing the necessity for individuals to engage deeply with the information they process. Increased trust in AI tools leads to greater cognitive offloading, which in turn reduces critical thinking skills. This cycle is exacerbated by the role of virtual influencers, who further reinforce the reliance on AI-generated content by acting as credible sources of information.

5.1. Role of Cognitive Offloading

The role of cognitive offloading in mediating the relationship between AI tool usage and critical thinking is a novel contribution of this study. Cognitive offloading, as described by Risko and Gilbert [6], involves the delegation of cognitive tasks to external tools, thereby reducing the cognitive load on individuals. Our findings indicate that cognitive offloading significantly mediates the relationship between AI usage and critical thinking, suggesting that the reduction in cognitive load may lead to diminished opportunities for cognitive engagement and critical analysis. This aligns with Carr's [4] argument in *The Shallows*, which posits that technology can create cognitive shortcuts that reduce the need for deep thinking. The findings also resonate with Sparrow, Liu, and Wegner's [5] concept of the "Google effect", where easy access to information via technology leads to a decline in memory retention and independent problem-solving skills. Gerlich's [7] findings indicate that increased trust in AI tools correlates with higher cognitive offloading, thereby supporting our mediation analysis results. The study highlighted that users who trust AI tools are more likely to rely on them for decision-making, thus reducing their engagement in critical thinking processes. This trust, fostered by the perceived reliability and convenience of AI tools, promotes a cognitive dependence that diminishes the need for active cognitive effort.

5.2. Educational Implications

Our study's results have significant implications for educational settings, particularly regarding the integration of AI tools in the classroom. While AI tools offer personalised learning and efficient information retrieval, educators must be cautious of the potential drawbacks. The literature suggests that AI can enhance learning outcomes when used appropriately [2,3]. However, our findings highlight the necessity of balancing AI usage with activities that promote critical thinking and cognitive engagement. Freeman et al. [45] and Deslauriers et al. [46] advocate for active learning strategies that involve students in the learning process. Our results support this approach, indicating that reducing cognitive offloading through active engagement can mitigate the negative impact of AI tools on critical thinking. Educational interventions should therefore integrate critical thinking exercises and foster environments where students are encouraged to engage deeply with content rather than passively relying on AI tools. The implications drawn here align with the findings of Gerlich [44], which emphasised the need for media literacy education to help users critically evaluate AI-generated content. Incorporating such educational strategies can help mitigate the potential negative impacts of AI on critical thinking by promoting more active and engaged cognitive processes. This integration suggests that while AI can be a valuable tool for enhancing certain aspects of learning, it is crucial to maintain a balanced approach that promotes cognitive engagement and critical analysis.

5.3. Hypothesis Evaluation

Hypothesis 1: *Higher AI tool usage is associated with reduced critical thinking skills.*

The findings confirm this hypothesis. The correlation analysis and multiple regression results indicate a significant negative relationship between AI tool usage and critical thinking skills. Participants who reported higher usage of AI tools consistently showed lower scores on critical thinking assessments.

Hypothesis 2: *Cognitive offloading mediates the relationship between AI tool usage and critical thinking skills.*

This hypothesis is also confirmed. The mediation analysis demonstrates that cognitive offloading significantly mediates the relationship between AI tool usage and critical thinking. Participants who engaged in higher levels of cognitive offloading due to AI tool usage exhibited lower critical thinking skills, indicating that the reduction in cognitive load from AI tools adversely affects critical thinking development.

5.4. Implications for Practice and Policy

The findings suggest several practical and policy implications. Educators and policymakers should promote balanced AI integration in educational settings, ensuring that AI tools complement rather than replace cognitive tasks. Emphasising active learning strategies and critical thinking exercises can help mitigate the negative effects of cognitive offloading and support the development of essential cognitive skills. Teacher training programs should include components on effectively integrating AI tools while maintaining cognitive engagement. Additionally, there should be an emphasis on developing students' metacognitive skills to help them become aware of when and how to use AI tools appropriately without undermining their cognitive development.

6. Conclusions

The findings of this study illuminate the complex interplay among AI tool usage, cognitive offloading, and critical thinking. As AI tools become increasingly integrated into everyday life, their impact on fundamental cognitive skills warrants careful consideration. Our research demonstrates a significant negative correlation between the frequent use of AI tools and critical thinking abilities, mediated by the phenomenon of cognitive offloading. This suggests that while AI tools offer undeniable benefits in terms of efficiency and accessibility, they may inadvertently diminish users' engagement in deep, reflective thinking processes. Younger participants who exhibited higher dependence on AI tools scored lower in critical thinking compared to their older counterparts. This trend underscores the need for educational interventions that promote critical engagement with AI technologies, ensuring that the convenience offered by these tools does not come at the cost of essential cognitive skills. Higher educational attainment was associated with better critical thinking skills, highlighting the role of education in mitigating the potential adverse effects of AI tool usage. These insights contribute to the growing discourse on the cognitive implications of AI, suggesting that educators, policymakers, and technologists must work collaboratively to foster environments that balance the benefits of AI with the development of critical thinking. Future research should explore strategies to integrate AI tools in ways that enhance rather than hinder cognitive engagement, ensuring that the next generation is equipped with the skills necessary to navigate an increasingly complex digital landscape.

This study's limitations include its reliance on self-reported measures and the potential for sample bias. Nonetheless, the findings provide a compelling case for ongoing research and dialogue on the cognitive impacts of AI. Through understanding and addressing these challenges, we can better harness the power of AI to support rather than supplant human intellect. The findings from this study open several avenues for future research. One potential direction is to investigate the longitudinal effects of AI tool usage on critical thinking skills over time. This could involve tracking individuals' cognitive development and AI tool usage patterns over several years to comprehensively understand the long-term impacts. Another promising area of study is exploring specific types of AI tools and their distinct effects on different cognitive processes. For instance, examining whether the use of recommendation algorithms, virtual assistants, or intelligent tutoring systems has varying impacts on critical thinking and cognitive offloading could provide nuanced insights. Experimental studies that manipulate the level of AI tool usage and measure resultant changes in critical thinking performance could offer causal evidence of the relationship between these variables. These experiments could also test interventions designed to mitigate the negative effects of AI tool dependence, such as educational programs that emphasise critical thinking skills or training on effective AI tool usage. Cross-cultural studies could also be valuable, as they would allow for an examination of how cultural contexts influence the relationship between AI tool usage and critical thinking. Understanding these cultural differences could inform the development of tailored educational interventions that are culturally sensitive and effective across diverse populations. Investigating the role of individual differences, such as personality traits or cognitive styles, in moderating the impact of AI tool usage on critical thinking could provide deeper insights into why some individuals are more susceptible to cognitive offloading than others. This line of research could help identify at-risk groups and develop targeted strategies to support them.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of SBS Swiss Business School (protocol code EC24/FR04, 8 January 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The authors confirm that the data supporting the findings of the study are available on reasonable request from the corresponding author.

Conflicts of Interest: The author declares no conflicts of interest.

Appendix A

Questionnaire		
Demographic and Control Variables:	1	Age: (1 = 17–25, 2 = 26–35, 3 = 36–45, 4 = 46–55, 5 = 56 and older)
	2	Gender: (1 = Male, 2 = Female, 3 = Non-binary, 4 = Prefer not to say)
	3	Education Level: (1 = High school, 2 = Some college, 3 = Bachelor's degree, 4 = Master's degree, 5 = Doctorate, 6 = others)
	4	Occupation: (1 = student, 2 = worker, 3 = specialist, 4 = middle management, 5 = top management, 6 = entrepreneur)
	5	How often do you engage in activities that require deep concentration and critical thinking outside of AI tools? (e.g., reading books, solving puzzles, engaging in debates)? (1 = Never, 6 = Always)
AI Tool Usage:	6	How often do you use AI tools (e.g., virtual assistants, recommendation algorithms) to find information or solve problems? (1 = Never, 6 = Always)
	7	To what extent do you rely on AI tools for decision-making? (1 = Not at all, 6 = Completely)
	8	I find AI tools help me save time when searching for information. (1 = Strongly Disagree, 6 = Strongly Agree)

Questionnaire		
	9	I trust the recommendations provided by AI tools. (1 = Strongly Disagree, 6 = Strongly Agree)
	10	I often cross-check information provided by AI tools with other sources. (1 = Strongly Disagree, 6 = Strongly Agree)
Cognitive Offloading:	11	How often do you use search engines like Google to find information quickly? (1 = Never, 6 = Always)
	12	Compared to the past, do you feel that finding information has become faster and more convenient with technology? (1 = Strongly Disagree, 6 = Strongly Agree)
	13	How often do you use your smartphone or other digital devices to remember tasks or information? (1 = Never, 6 = Always)
	14	When faced with a problem or question, how likely are you to search for the answer online rather than trying to figure it out yourself? (1 = Very Unlikely, 6 = Very Likely)
	15	On a scale of 1 to 6, how dependent are you on digital devices for day-to-day tasks and information retrieval? (1 = Not dependent at all, 6 = Completely dependent)
Critical Thinking (Based on Terenzini et al. [30] and HCTA):	16	How often do you critically evaluate the sources of information you encounter? (1 = Never, 6 = Always)
	17	How confident are you in your ability to discern fake news from legitimate news? (1 = Not confident at all, 6 = Very confident)
	18	When researching a topic, how often do you compare information from multiple sources? (1 = Never, 6 = Always)
	19	How frequently do you reflect on the biases in your own thinking when making decisions? (1 = Never, 6 = Always)
	20	How often do you question the motives behind the information shared by AI tools? (1 = Never, 6 = Always)
	21	I analyse the credibility of the author when reading news or information provided by AI tools. (1 = Strongly Disagree, 6 = Strongly Agree)
	22	I compare multiple sources of information before forming an opinion based on AI recommendations. (1 = Strongly Disagree, 6 = Strongly Agree)
	23	I question the assumptions underlying the information provided by AI tools. (1 = Strongly Disagree, 6 = Strongly Agree)

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