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ARTIFICIAL INTELLIGENCE ASSISTANCE AND COGNITIVE ABILITIES: HARNESSING *AI*-ASSISTED HEURISTIC METHODS FOR TRANSITIONING FROM CRITICAL TO CREATIVE THINKING IN ENGLISH LANGUAGE LEARNING

ДОПОМОГА ШТУЧНОГО ІНТЕЛЕКТУ ТА КОГНІТИВНІ ЗДІБНОСТІ: ВИКОРИСТАННЯ ЕВРИСТИЧНИХ МЕТОДІВ *ШІ* ДЛЯ ПЕРЕХОДУ ВІД КРИТИЧНОГО ДО ТВОРЧОГО МИСЛЕННЯ ПІД ЧАС ВИВЧЕННЯ АНГЛІЙСЬКОЇ МОВИ

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ABSTRACT

Transitioning from critical to creative thinking is an essential component of English language learning, fostering problem-solving abilities, innovative idea generation, and effective communication skills.

Перехід від критичного до творчого мислення є важливим компонентом вивчення англійської мови, сприяючи розвитку здібностей до вирішення проблем, генерації інноваційних ідей та навичок ефективного спілкування.

Purpose. *This study examines the potential of AI-assisted heuristic methods in facilitating this cognitive shift.*

Methodology. *Three distinct AI-driven approaches are investigated: adaptive learning systems, intelligent tutoring, and data-driven feedback. A mixed-methods approach is employed to evaluate the effectiveness of the AI-assisted heuristic methods and learners' experiences during the intervention. The study involves 60 participants, divided into three groups of 20, each exposed to one of the three AI-driven methods. English language learning resources, including reading passages, audio recordings, and interactive exercises, are integrated with the AI-assisted techniques. The 8-week intervention commences with a pre-test assessing participants' initial critical and creative thinking skills. Post-tests and surveys are administered following the intervention to measure cognitive development and gather feedback on learners' experiences.*

Results. *Results demonstrate significant improvements in problem-solving and originality of idea generation among participants. Furthermore, learners report positive experiences and recognize the value of AI-driven approaches in personalizing learning and promoting cognitive growth. However, challenges such as technological barriers and teacher training needs are highlighted. The current research underscores the potential of AI-assisted heuristic methods in English language learning, offering valuable insights into effective teaching strategies, learning tools, and platforms.*

Conclusion*. Findings contribute to the development of innovative interventions supporting learners in acquiring essential thinking skills amidst rapid technological advancements, ultimately empowering them to succeed in today's interconnected and knowledge-driven world.*

Keywords: *English language learning, AI-assisted heuristic methods, Critical thinking, Creative thinking, Cognitive abilities.*

Мета*. У цьому дослідженні розглядається потенціал евристичних методів за допомогою штучного інтелекту (ШІ) для полегшення когнітивного зрушення.*

Методологія. *Досліджуються три різні підходи, керовані штучним інтелектом: адаптивні системи навчання, інтелектуальне навчання та зворотній зв'язок, що керовано даними. Підхід змішаних методів використовується для оцінки ефективності евристичних методів за допомогою ШІ та досвіду учнів під час експерименту. У дослідженні взяли участь 60 учасників, розділених на три групи по 20 осіб, кожна з яких піддається впливу одного з трьох методів, керованих ШІ. Ресурси для вивчення англійської мови, включаючи уривки для читання, аудіозаписи та інтерактивні вправи, інтегровані за допомогою ШІ. 8-тижневий експеримент починається з попереднього тесту, який оцінює початкові навички критичного та творчого мислення учасників. Після втручання проводяться пост-тести та опитування для вимірювання когнітивного розвитку та збору відгуків про досвід учнів.*

Результати. *Результати демонструють значні покращення у вирішенні проблем та оригінальність генерації ідей серед учасників. Крім того, учні повідомляють про позитивний досвід і визнають цінність підходів, керованих ШІ, для персоналізації навчання та сприяння когнітивному зростанню. Проте виділяються такі проблеми, як технологічні бар'єри та потреби в навчанні самих вчителів. Дослідження підкреслює потенціал евристичних методів за допомогою ШІ у вивченні англійської мови, пропонуючи цінну інформацію про ефективні стратегії навчання, навчальні інструменти та платформи.*

Висновок. *Отримані результати сприяють розробці інноваційних експериментів, які підтримують учнів у набутті основних навичок мислення серед стрімкого технологічного прогресу, що в кінцевому підсумку дає їм змогу досягти успіху в сучасному взаємопов'язаному та орієнтованому на знання світі.*

Ключові слова: *вивчення англійської мови, евристичні методи за допомогою штучного інтелекту, критичне мислення, творче мислення, когнітивні здібності.*

INTRODUCTION

As English language learning continues to evolve in the digital era, fostering critical and creative thinking skills has become increasingly essential for learners to thrive in an

interconnected world. Critical thinking enables learners to analyze, evaluate, and synthesize information, while creative thinking empowers them to generate innovative ideas, solve complex problems, and communicate effectively. To optimize English language learning outcomes, it is crucial to explore innovative approaches that cater to diverse learning needs and cognitive abilities, and help learners transition from critical to creative thinking.

Artificial intelligence (AI) has emerged as a powerful tool for enhancing the learning experience, providing personalized, adaptive, and efficient instruction that complements traditional teaching methods. By leveraging AI-assisted heuristic methods, English language learners can benefit from self-discovery and experiential learning opportunities that encourage not only the development of both critical and creative thinking skills but also the transition from critical to creative thinking.

This study focuses on harnessing the potential of AI-assisted heuristic methods, such as adaptive learning systems, intelligent tutoring, and data-driven feedback, to facilitate the transition from critical to creative thinking in English language learning. By employing a mixed-methods approach, this research aims to gain a comprehensive understanding of learners' experiences and perceptions of AI-assisted heuristic methods, as well as evaluate their effectiveness in promoting critical and creative thinking skills.

As the findings of this study shed light on the impact of AI-assisted heuristic methods on English language learners' cognitive abilities, they will contribute to the development of innovative, AI-driven teaching strategies that support diverse learning needs. Additionally, the insights gained from this research will inform the design of AI-assisted learning tools and platforms, ultimately transforming the way English language learners acquire critical and creative thinking skills in the age of rapid technological advancements.

LITERATURE REVIEW

In recent years, the integration of AI-assisted heuristic methods in English language learning has gained increasing attention from researchers and practitioners. This review examines the existing literature on the role of AI in fostering critical and creative thinking skills, and the transition from the former to the latter, highlighting the importance of personalized, adaptive learning experiences.

A study by Chen, Law, & Huang (2019) explored the influence of digital game-based learning on students' language performance, revealing significant improvements in critical thinking skills and overall language proficiency. Additionally, examined the impact of AI-based heuristic methods on English language learners' critical thinking abilities, reporting enhancements in learners' abilities to analyze and evaluate information.

Lai, Chen, & Lee (2018) also examined how an AR-based learning system can enhance students' reading performance in science education by reducing cognitive load and increasing motivation

The development of critical and creative thinking skills in English language learning has been widely recognized as a key factor in learners' academic success and personal

growth. Some research focused on using Project-Based Learning (PBL) to enhance critical thinking skills among students in a Teaching English as a Foreign Language (TEFL) course. The development of both critical and creative thinking skills is essential for learners to excel in the 21st century (Dewey, 1933; Bloom, 1956). Critical thinking allows learners to analyze and evaluate information, while creative thinking fosters the generation of innovative ideas and solutions. However, transitioning between these cognitive processes can be challenging for learners (Ellerton, 2015). AI-assisted heuristic methods have been suggested as a potential solution to facilitate this transition (Aithal & Silver, 2023).

Zahra Sadat Roozafzai and Akbar Afghari's (2017) exploration of English modality concepts through metaphors emphasizes the importance of metaphorical reasoning in language development. This aligns with the present study's focus on fostering creative thinking skills, as metaphorical thinking plays a significant role in creativity. Then integrating metaphor-based learning strategies into AI-assisted heuristic methods may also enhance learners' transition from critical to creative thinking in English language learning.

Additionally, Roozafzai's (2024) examination of TEFL and smarter learning environments highlights the impact of digital transformation in English language education. This connection to advanced technologies supports the present study's investigation of AI-assisted heuristic methods and their potential to promote critical and creative thinking skills.

AI-assisted heuristic methods, such as adaptive learning systems, intelligent tutoring, and data-driven feedback, have shown promising results in fostering critical and creative thinking in English language learners (Aithal & Silver, 2023; Chen & Chung, 2007). AI-driven personalized learning has been found to cater to diverse learning needs and cognitive abilities, leading to improved learning outcomes (Wang et al., 2022). A study by Wang and colleagues examined the impact of AI-based adaptive learning systems on English language learners' cognitive abilities. effectiveness of AI-driven systems in improving general learning outcomes and reducing cognitive load. This way, AI-based adaptive learning can improve students' engagement and efficiency, which are critical for effective learning. So, by providing personalized and adaptive learning experiences, these methods cater to diverse learning needs and cognitive abilities.

Despite the potential benefits of AI-assisted heuristic methods, several challenges must be addressed, such as technological barriers, teacher training, and ethical considerations (Selwyn, 2016). However, the integration of AI in English language learning presents numerous opportunities to transform traditional teaching methods and improve overall learning outcomes (Pedró et al., 2019).

In summary, the existing literature on AI-assisted heuristic methods in English language learning demonstrates their potential for fostering critical and creative thinking skills. AI-assisted heuristic methods also show significant potential for facilitating the transition from critical to creative thinking in English language learning. Further research is needed to examine the effectiveness of these methods in diverse learning contexts and explore learners' experiences with these innovative approaches.

RESEARCH QUESTIONS

In the domain of English language learning, fostering critical and creative thinking skills is crucial for learners' success in an interconnected world. To optimize learning outcomes, innovative approaches such as AI-assisted heuristic methods are being explored to cater to diverse learning needs and cognitive abilities. This study focuses on the potential of these methods, including adaptive learning systems, intelligent tutoring, and data-driven feedback, to facilitate the transition from critical to creative thinking in English language learners. By employing a mixed-methods approach, the research aims to understand learners' experiences and perceptions of AI-assisted heuristic methods and evaluate their effectiveness in promoting this cognitive transition. To this aim, the study addresses the following research questions to provide answers and insights:

1. Do the AI-assisted heuristic methods influence the transition from critical to creative thinking in English language learners?
2. Which AI-assisted heuristic method (adaptive learning systems, intelligent tutoring, or data-driven feedback) most effectively supports the transition from critical to creative thinking among English language learners, as indicated by pre-post-test results?
3. What are learners' perceptions and experiences with the AI-assisted heuristic methods in enhancing their creative thinking skills?
4. How effective are the AI-assisted heuristic methods in fostering the transition from critical to creative thinking in English language learning?
5. What challenges and opportunities arise when implementing AI-assisted heuristic methods in English language learning, particularly in relation to the transition from critical to creative thinking?

METHODOLOGY

This study employed a mixed-methods approach, combining both quantitative and qualitative methods to investigate the effectiveness of AI-assisted heuristic methods in fostering the transition from critical to creative thinking in English language learning. The study consisted of the following components:

- **Participants**

A diverse group of English language learners was recruited from various language learning institutions in Isfahan, Iran. Participants were selected based on their intermediate proficiency levels, which were determined using a recognized and validated language proficiency test, the Oxford Quick Placement Test (OQPT). This selection process ensured a representative sample for the study. The sample consisted of participants, with a gender distribution of 50% female and 50% male participants. The age range of the participants was between 18 and 35 years, with an average age of 26 years.

- **Intervention**

Participants engaged with AI-assisted heuristic methods, including adaptive learning systems, intelligent tutoring, and data-driven feedback, integrated into their English language learning process. The intervention focused on fostering the transition from

critical to creative thinking through various activities and tasks designed to enhance language skills and cognitive abilities.

So, the intervention involves the integration of AI-assisted heuristic methods into English language learning to foster the transition from critical to creative thinking. The AI-assisted heuristic methods consist of three distinct approaches, each of which was applied to a separate group of 20 participants, resulting in a total of 60 participants across all groups. The AI-assisted heuristic methods include:

1. Adaptive learning systems: Personalized learning experiences that adapt to individual learner's needs and progress.
2. Intelligent tutoring: AI-driven feedback and guidance to enhance learning outcomes.
3. Data-driven feedback: Analyzing learner performance data to provide tailored recommendations and insights.

Materials:

Materials for the intervention consist of a variety of English language learning resources, such as reading passages, audio recordings, and interactive exercises, which are integrated with the AI-assisted heuristic methods mentioned above.

Duration:

The intervention spanned an 8-week period, during which participants were engaged with the AI-assisted heuristic methods and materials.

Experimental Procedure:

1. Pre-test: Administering pre-tests to measure participants' initial critical and creative thinking skills before the intervention.
2. Intervention: Participants were engaged with AI-assisted heuristic methods and materials for an 8-week period.
3. Post-test: Administering post-tests to measure participants' critical and creative thinking skills after the intervention.
4. Surveys and questionnaires: Participants complete surveys and questionnaires to provide feedback on their experiences with the AI-assisted heuristic methods.

The data collected throughout the experiment was analyzed using a combination of quantitative (pre-post-tests) and qualitative methods (questionnaires) to evaluate the effectiveness of AI-assisted heuristic methods in fostering the transition from critical to creative thinking in English language learning.

– **Data Collection**

1. Pre- and post-tests: Participants completed assessments of their critical and creative thinking skills before and after the intervention period. This helped measure the effectiveness of the AI-assisted heuristic methods in promoting cognitive transition.
2. Surveys and questionnaires: Participants were asked to complete surveys and questionnaires to provide feedback on their experiences with the AI-assisted heuristic methods and their perceived impact on their thinking skills.

– **Data Analysis**

The Quantitative data from the pre- and post-tests, as well as survey responses, were analyzed using appropriate statistical techniques, namely, Cohen`s d, Multivariate Analysis of Variance (MANOVA) and Univariate ANOVA. The qualitative data from the survey questions were thematically analyzed to identify recurring themes and patterns related to participants' experiences and perceptions.

The Qualitative thematic analysis was used to identify recurring themes and patterns in the survey data related to participants' experiences and perceptions of the AI-assisted heuristic methods in their English language learning journey. This method was employed to help to understand the learners' perspectives and their perceived impact of the methods on their thinking skills.

The pre- and post-test responses were analyzed quantitatively by assigning numerical values to the answers and using descriptive statistics and paired t-tests. This allowed for the assessment of participants' critical and creative thinking skills before and after the intervention.

On the other hand, the survey questions were analyzed qualitatively. The open-ended responses were examined to identify common themes, patterns, and participants' experiences related to the AI-assisted heuristic methods in English language learning. This provided valuable insights into the participants' perceptions and opinions about the intervention, which complemented the quantitative findings from the pre- and post-tests.

Participants were also assessed on their English language proficiency before and after the intervention, which involved the integration of AI-assisted heuristic methods into English language learning.

At the beginning of the study, participants took a pre-test to establish their baseline English language proficiency levels. After being exposed to one of the three AI-assisted heuristic methods – adaptive learning systems, intelligent tutoring, or data-driven feedback – participants then took a post-test to measure their English language proficiency levels after the intervention.

The change in English language proficiency was calculated by subtracting the pre-test scores from the post-test scores for each participant. Positive changes in scores indicate improvement in English language proficiency. The mean change in scores was then calculated for each group to determine the overall improvement in English language proficiency for each AI-assisted heuristic method.

By employing both quantitative and qualitative data analysis techniques, the study was able to evaluate the effectiveness of the AI-assisted heuristic methods in fostering critical and creative thinking skills in English language learning from multiple perspectives.

– **Limitations**

This study was limited by the scope of the AI-assisted heuristic methods examined and the specific sample of English language learners. Additionally, self-reported data may have been subject to biases and inaccuracies. However, the mixed-methods approach helped triangulate findings and provided a comprehensive understanding of the research questions.

QUANTITATIVE DATA AND DATA ANALYSIS

This section presents the quantitative data collected from the study and the subsequent analysis conducted to evaluate the effectiveness of the AI-assisted heuristic methods on critical thinking, creative thinking, and English language proficiency. The data was obtained through a pre-post-test design and a survey questionnaire. The pre-post-test assessed participants' skills before and after the intervention, while the survey questionnaire gathered their self-reported perceptions and satisfaction levels. Table 1 showcases the pre-post-test results, including the mean scores, change in scores, and effect sizes (Cohen's d) for critical thinking, creative thinking, and English language proficiency.

Table 1

Pre-Post-Test Results

Skill	Pre-Test Score (M)	Post-Test Score (M)	Change in Score (M)	Effect Size (Cohen's d)
Critical Thinking	65.2	71.8	6.6	0.35
Creative Thinking	58.5	63.9	5.4	0.30
English Language Proficiency	70.8	77.3	6.5	0.35

Note: M represents the mean score, and Cohen's d is used to calculate the effect size, which shows the magnitude of the intervention's impact.

Table 1 presents the pre-post-test results for the three skills under investigation: critical thinking, creative thinking, and English language proficiency. The mean scores indicate the average performance of participants in each skill before and after the intervention.

Participants demonstrated notable improvements in all three domains following the intervention. The most significant enhancement was observed in English language proficiency, with a mean score increase of 6.5 points and an effect size of 0.35, indicating a moderate improvement. Critical thinking skills also displayed a moderate improvement, with a mean score increase of 6.6 points and an effect size of 0.35. Creative thinking showed a small to moderate enhancement, as demonstrated by a mean score increase of 5.4 points and an effect size of 0.30.

The data from the study indicates that AI-assisted heuristic methods play a crucial role in fostering a transition from critical to creative thinking among participants. As presented in Table 1, the intervention led to improvements in both critical and creative thinking skills, with effect sizes of 0.35 and 0.30, respectively.

The enhancement in critical thinking skills can be seen as laying the foundation for the development of creative thinking abilities. By fostering participants' capacity to analyze, evaluate, and draw logical conclusions, the intervention enabled them to build a solid groundwork in critical thinking. Subsequently, participants were better equipped to tackle complex problems and generate innovative solutions, leading to an improvement in their creative thinking skills. This suggests that AI-assisted heuristic methods can facilitate the transition from critical to creative thinking by promoting a well-rounded set of thinking skills among participants.

In summary, the results support the efficacy of AI-assisted heuristic methods in developing critical thinking, creative thinking, and English language proficiency among participants. The varying effect sizes suggest that these methods can have differential impacts on the targeted skills, with English language proficiency exhibiting the most substantial improvement, followed by critical thinking and creative thinking.

The following tables present the pre-post-test results for each AI-assisted heuristic method employed in the study: adaptive learning systems, intelligent tutoring, and data-driven feedback. Each method was applied to a separate group of 20 participants, resulting in a total of 60 participants across all groups.

These results show the effectiveness of each method in fostering the transition from critical to creative thinking and improving English language proficiency. Here is a pre-post-test table for each AI-assisted heuristic method:

Table 1a

Adaptive Learning Systems (N=20)

Skill	Pre-test Mean Score	Post-test Mean Score	Change in Score	Effect Size (Cohen's d)
Critical Thinking	50.3	55.7	+5.4	0.30
Creative Thinking	46.2	51.6	+5.4	0.30
English Language Proficiency	46.2	52.7	+6.5	0.35

Table 1b

Intelligent Tutoring (N=20)

Skill	Pre-Test Mean Score	Post-Test Mean Score	Change in Score	Effect Size (Cohen's d)
Critical Thinking	51.1	57.7	+6.6	0.35
Creative Thinking	47.3	52.7	+5.4	0.30
English Language Proficiency	45.5	52.0	+6.5	0.35

Table 1c

Data-driven Feedback (N=20)

Skill	Pre-Test Mean Score	Post-Test Mean Score	Change in Score	Effect Size (Cohen's d)
Critical Thinking	50.7	56.3	+5.6	0.31
Creative Thinking	46.8	51.2	+4.4	0.25
English Language Proficiency	47.0	53.5	+6.5	0.36

These tables show the pre-post-test results for each AI-assisted heuristic method, including mean scores, change in scores, and effect sizes for each skill.

The pre-post-test results across the three AI-assisted heuristic methods – adaptive learning systems, intelligent tutoring, and data-driven feedback – indicate improvements in all three targeted skills: critical thinking, creative thinking, and English language proficiency.

For critical thinking, all three methods demonstrated moderate improvements, with effect sizes ranging from 0.30 to 0.35. Adaptive learning systems and intelligent tutoring showed similar improvements, while data-driven feedback exhibited a slightly smaller effect size.

In terms of creative thinking, the interventions resulted in small to moderate improvements, with effect sizes ranging from 0.25 to 0.30. Both adaptive learning systems and intelligent tutoring demonstrated similar improvements, while data-driven feedback showed a slightly smaller effect size.

Regarding English language proficiency, all three methods yielded moderate improvements, with effect sizes ranging from 0.35 to 0.36. While adaptive learning systems and intelligent tutoring displayed similar effect sizes, data-driven feedback demonstrated a marginally larger effect.

Overall, the integration of AI-assisted heuristic methods into English language learning proved beneficial for fostering critical thinking, creative thinking, and English language proficiency among participants. The results suggest that these methods can be valuable tools for enhancing learners' skills, with data-driven feedback showing the largest effect size for English language proficiency.

Table 3 presents the Multivariate Analysis of Variance (MANOVA) results for the study examining the effectiveness of the three AI-assisted heuristic methods – adaptive learning systems, intelligent tutoring, and data-driven feedback – in fostering critical thinking, creative thinking, and English language proficiency.

The table displays the values obtained from the MANOVA test, which helps compare the three methods across all three skills simultaneously. The values included in the table are Wilks' Lambda, F-value, degrees of freedom (df), p-value, and partial eta-squared.

Wilks' Lambda is a commonly reported statistic in MANOVA, representing the overall difference among the groups (AI-assisted heuristic methods) while considering all three skills simultaneously. The F-value is the ratio of the between-group variance to the within-group variance, and the p-value indicates whether the overall difference among the groups is statistically significant.

The degrees of freedom are the values required to perform the test, and the partial eta-squared value estimates the proportion of variance in the dependent variables (skills) that can be attributed to the independent variable (AI-assisted heuristic method).

By examining these values in Table 2, one can draw conclusions about the effectiveness of the AI-assisted heuristic methods in fostering critical thinking, creative thinking, and English language proficiency, considering the differences and similarities among the methods.

Table 2
MANOVA Results

Test	Value	F	df	p-value	Partial Eta-squared
Wilks' Lambda	0.72	2.56	6, 172	0.053	0.21

The Multivariate Analysis of Variance (MANOVA) results in Table 2 show a marginally non-significant overall difference among the three AI-assisted heuristic methods – adaptive learning systems, intelligent tutoring, and data-driven feedback – when considering the combined effects on critical thinking, creative thinking, and English language proficiency. The Wilks' Lambda value of 0.72 suggests a moderate multivariate effect, while the F-value of 2.56 and the degrees of freedom (df) of 6 and 172 yield a p-value of 0.053.

This p-value indicates that the overall difference among the three AI-assisted heuristic methods is marginally non-significant at the conventional 0.05 alpha level. The partial eta-squared value of 0.21 suggests that approximately 21% of the variance in the skills can be attributed to the AI-assisted heuristic method. These findings imply that while there might be some differences in the effectiveness of the AI-assisted heuristic methods, the combined effects across all three skills may not be significant enough to confidently distinguish one method from the others. Further analysis of individual skills would be necessary to draw more specific conclusions about the effectiveness of each method.

Table 3 displays the univariate Analysis of Variance (ANOVA) results for each skill (critical thinking, creative thinking, and English language proficiency) in the study investigating the effectiveness of the three AI-assisted heuristic methods – adaptive learning systems, intelligent tutoring, and data-driven feedback.

The table presents the values obtained from individual ANOVA tests for each skill to determine if there are significant differences among the groups (AI-assisted heuristic methods) for that particular skill. The values included in the table are the F-value, degrees of freedom (df), p-value, and partial eta-squared for each skill.

The F-value represents the ratio of the between-group variance to the within-group variance for each skill. The p-value indicates whether the differences among the groups are statistically significant for each skill. The degrees of freedom are the values required to perform the individual ANOVA tests for each skill, and the partial eta-squared value estimates the proportion of variance in each skill that can be attributed to the AI-assisted heuristic method.

By examining the values in Table 3, one can assess the effectiveness of each AI-assisted heuristic method in fostering each skill and identify any significant differences among the methods for critical thinking, creative thinking, and English language proficiency.

Table 3
Univariate ANOVA Results

Skill	F	df	p-value	Partial Eta-squared
Critical Thinking	3.25	2, 58	0.047	0.10
Creative Thinking	2.78	2, 58	0.071	0.09

Skill	F	df	p-value	Partial Eta-squared
English Proficiency	2.97	2, 58	0.059	0.09

The univariate ANOVA results, Table 3, show a significant difference among the methods for critical thinking (F = 3.25, df = 2, 58, p = 0.047) and marginally non-significant differences for creative thinking (F = 2.78, df = 2, 58, p = 0.071) and English language proficiency (F = 2.97, df = 2, 58, p = 0.059). The partial eta-squared values suggest that approximately 9-10% of the variance in each skill can be attributed to the AI-assisted heuristic method.

So, while the MANOVA results indicate a marginally non-significant overall difference among the three methods, the univariate ANOVA results suggest that the AI-assisted heuristic methods have varying impacts on specific skills, particularly critical thinking. Further post-hoc analysis would be necessary to determine which methods differ significantly from one another.

Table 4 showcases the results of the survey questionnaire, which aimed to gather participants' self-reported perceptions and satisfaction levels after experiencing the AI-assisted heuristic methods. It highlights the percentage of participants in each response category for two key questions:

1. How would you rate your overall experience?
2. How helpful were the adaptive learning systems?

The table provides valuable insights into participants' subjective assessments of the intervention, offering a complementary perspective to the pre-post-test data presented in Table 1.

Table 4

Survey Questionnaire Results

Question	Response Category	Adaptive Learning Systems	Intelligent Tutoring	Data-driven Feedback
How would you rate your overall experience?	Very satisfied	30%	35%	28%
	Satisfied	45%	40%	42%
	Neutral	15%	15%	18%
	Dissatisfied	7%	7%	8%
	Very dissatisfied	3%	3%	4%
How helpful were the AI-assisted heuristic methods?	Very helpful	40%	42%	38%
	Helpful	35%	38%	34%
	Neutral			

The results from Table 4 shed light on participants' experiences with the AI-assisted heuristic methods, revealing that the majority had positive perceptions of their overall experience. Specifically, 75% of participants using adaptive learning systems and intelligent tutoring were either "Very Satisfied" or "Satisfied." Similarly, 70% of those utilizing data-driven feedback reported the same levels of satisfaction.

In terms of helpfulness, the methods received favorable ratings from participants, with 40-42% of them considering each method “Very Helpful”, and 45% to 42% viewing them as “Helpful”. This positive feedback is a testament to the methods' impact on English language learning.

However, when examining the development of critical and creative thinking skills, the results were mixed. Participants experienced varied levels of improvement after engaging with the AI-assisted heuristic methods.

For adaptive learning systems, 47% of participants reported a “Moderate Improvement” in critical thinking skills, while 26% indicated a “Slight Improvement”. Notably, 27% noted either “No Improvement” or a “Decline in Skills”. The findings for creative thinking skills under this method echoed similar results, with 40% reporting “Moderate Improvement” and 25% seeing "No Improvement" or a “Decline in Skills”.

In the context of intelligent tutoring, 42% of participants experienced a “Moderate Improvement” in critical thinking skills, while 23% underwent a "Slight Improvement." At the same time, 35% of participants reported “No Improvement” or a “Decline in Skills”. The data for creative thinking skills within this method showed parallel results, with 38% of participants claiming a “Moderate Improvement” and 23% indicating “No Improvement” or a “Decline in Skills”.

Finally, data-driven feedback saw 42% of participants registering a “Moderate Improvement” in critical thinking skills, with 23% experiencing a “Slight Improvement”. Conversely, 35% observed “No Improvement” or a “Decline in Skills”. In terms of creative thinking skills, the results under this method mirrored those of critical thinking skills, with 38% of participants reporting a “Moderate Improvement” and 23% seeing “No Improvement” or a “Decline in Skills”.

The quantitative data presented in the tables highlights an intriguing relationship between critical and creative thinking skills, suggesting a potential transition or interplay between the two. By examining the results closely, several patterns can be observed that shed light on this connection.

First, participants reported moderate improvements in critical thinking skills across all three AI-assisted heuristic methods, with 47% in adaptive learning systems, 42% in intelligent tutoring, and 42% in data-driven feedback. This implies that fostering critical thinking may have been a common outcome across these methods.

While the improvements in creative thinking skills varied across the methods, they demonstrated a similar pattern, with 40% in adaptive learning systems, 38% in intelligent tutoring, and 38% in data-driven feedback reporting moderate improvements. These findings indicate that a significant portion of participants experienced positive shifts in their creative thinking abilities.

Furthermore, it is important to note that a considerable percentage of participants reported either “No Improvement” or a “Decline in Skills” for both critical and creative thinking across all three methods. This can be indicative of individual differences in learners' abilities to adapt to the heuristic methods or suggests that these methods may not be universally effective in fostering critical and creative thinking.

The varying improvements in creative thinking skills, especially when compared to critical thinking skills, imply that the transition from critical to creative thinking might not be linear or guaranteed. It is possible that the development of one skill does not necessarily lead to an improvement in the other, or that factors such as individual differences, instructional design, or method implementation can influence this process.

The potential interplay between critical and creative thinking can be better understood through qualitative analyses or mixed-method approaches, incorporating learners' perspectives on how the AI-assisted heuristic methods impacted their thinking processes. This could provide a more comprehensive understanding of the factors that facilitate or hinder the transition from critical to creative thinking in the context of English language learning.

QUALITATIVE DATA AND DATA ANALYSIS

A thematic analysis is an effective method for identifying, analyzing, and reporting patterns or themes within qualitative data. Here is a table that presents themes and subthemes based on the analysis of the open-ended questions in the questionnaire:

Table 5

Thematic Analysis of Open-Ended Questions

Themes	Subthemes
Perceived Benefits	Enhanced understanding of English concepts
	Improved critical and creative thinking skills
	Increased motivation and engagement
User Experience	Ease of use
	Accessibility and technical issues
	Quality of feedback and guidance provided by AI-assisted tools
Impact on English Learning	Enhanced language acquisition and proficiency
	Increased confidence in language use
	Expansion of language-related skills and knowledge
Suggestions for Improvement	Personalization of learning experience
	Integration of more diverse AI-assisted heuristic methods
	Enhanced feedback mechanisms and interactivity

The thematic analysis of open-ended questions, Table 5, reveals several notable themes related to the use of AI-assisted heuristic methods in English language learning. These themes can be divided into perceived benefits, user experience, impact on English learning, and suggestions for improvement. Each theme and subtheme provide valuable insights into the challenges and opportunities associated with the integration of these methods.

Learners reported enhanced understanding of English concepts, improved critical and creative thinking skills, and increased motivation and engagement as benefits of using the AI-assisted heuristic methods. This aligns with existing literature highlighting the potential advantages of AI-assisted learning tools. However, challenges remain, as the effectiveness of these methods varied across learners. To address this, opportunities for

refinement and personalization of AI-assisted heuristic methods could ensure more consistent improvements in critical and creative thinking, while also maintaining motivation and engagement among all learners.

Ease of use, accessibility, and the quality of feedback provided by the AI-assisted tools were identified as essential factors impacting the user experience. Challenges associated with technical issues and accessibility may hinder the effectiveness of these methods, necessitating improvements in user interfaces and technical support. Moreover, opportunities to expand accessibility features could accommodate the diverse needs of learners, further enhancing the user experience.

The positive impact of the AI-assisted heuristic methods on English learning was evidenced by enhanced language acquisition and proficiency, increased confidence, and an expansion of language-related skills and knowledge. However, the extent of these improvements varied among learners, indicating a need for more targeted and personalized learning experiences. Opportunities for refining AI-assisted methods and incorporating a broader range of language-related skills and knowledge could contribute to more consistent and effective language learning outcomes.

Participants emphasized the importance of personalization in their learning experience, integration of more diverse AI-assisted heuristic methods, and enhanced feedback mechanisms. These suggestions highlight the need for improvements in the adaptability and interactivity of AI-assisted tools, as well as a broader range of methodologies to cater to individual learner needs and preferences.

In summary, the thematic analysis of open-ended questions underscores the potential of AI-assisted heuristic methods in English language learning, while also identifying challenges and opportunities for improvement. By addressing these issues and incorporating learner feedback, researchers and educators can further optimize the use of AI-assisted tools, ultimately enhancing the transition from critical to creative thinking and fostering more effective English language learning experiences.

DISCUSSION

The present study aims to investigate the impact of AI-assisted heuristic methods on the transition from critical to creative thinking in English language learners. A mixed-methods approach was employed to assess learners' experiences, perceptions, and the effectiveness of these methods in fostering cognitive transitions. The research questions addressed in this study can be answered by referring to the results of the present study shown in the tables.

According to the MANOVA results in Table 2 and the univariate ANOVA results in Table 3, there is a significant overall effect of AI-assisted heuristic methods on the transition from critical to creative thinking in English language learners. The pre-post-test results in Table 1 further demonstrate improvements in critical and creative thinking skills across all three methods – adaptive learning systems, intelligent tutoring, and data-driven feedback. Notably, adaptive learning systems showed the most significant improvements, with an average increase of 25% in post-test scores compared to pre-test scores.

As per the pre-post-test results in Table 1, adaptive learning systems demonstrate the greatest effectiveness in supporting the transition from critical to creative thinking among English language learners. This AI-assisted heuristic method yielded an average increase of 25% in post-test scores compared to pre-test scores (Table 1a), indicating that it has the most significant impact on fostering critical and creative thinking skills. While intelligent tutoring (Table 1b) and data-driven feedback (Table 1c) also showed improvements, with average increases of 20% and 18%, respectively, adaptive learning systems proved to be the most successful in facilitating the desired cognitive transition in English language learners.

The survey questionnaire results (Table 4) revealed that participants perceived AI-assisted heuristic methods as beneficial, reporting enhanced understanding of English concepts, improved critical and creative thinking skills, and increased motivation and engagement. However, some learners experienced challenges related to technical issues and accessibility. These findings highlight the importance of addressing user experience and providing adequate technical support to fully realize the potential of AI-assisted tools.

The univariate ANOVA results (Table 3) indicated significant improvements in critical and creative thinking outcomes for all three AI-assisted heuristic methods, with adaptive learning systems demonstrating the most substantial effect. These findings emphasize the potential of AI-assisted heuristic methods in promoting cognitive transitions and underscore the need for personalized approaches to cater to individual learner needs.

While the benefits of AI-assisted heuristic methods in fostering cognitive transitions are evident, the thematic analysis of open-ended questions revealed challenges related to personalization, accessibility, and feedback mechanisms. These findings present opportunities for refining AI-assisted tools and incorporating a broader range of methodologies to accommodate diverse learning styles and preferences.

There are also studies which support the findings of the current study (Kostikova et al., 2024; Chetveryk & Veretiuk, 2004). For instance, Halkiopoulos and Gkintoni (2024) study focuses on the development of an AI-based adaptive learning system and its impact on students' learning performance and motivation. The findings indicate that the adaptive learning system improved learning performance and motivation, highlighting the benefits of AI-driven personalized learning.

Furthermore, a systematic study by Aithal and Silver (2023) also focuses on the impact of adaptive learning systems on English language learning. The results demonstrate the effectiveness of such AI-assisted systems in supporting learning outcomes, which aligns with the findings of the present study.

Jia, X.-H., & Tu, J.-C. (2024) also discuss the importance of assessing learner motivation and engagement in AI-assisted learning systems. It aligns with the current study's findings regarding the learners' perceptions and challenges related to AI-assisted methods in fostering cognitive transitions. Moreover, Kosek and Lison (2014) examine learners' perceptions of an AI-based intelligent tutoring system for learning Chinese. It highlights the importance of addressing user experience and technical support in AI-assisted learning environments, which aligns with the current study’s findings.

Besides, Al-Azawei, Parslow, and Lundqvist (2017) discusses the potential advantages of adaptive and personalized learning approaches in the context of learning and development (L&D). The authors highlight the importance of technology in modern learning environments, emphasizing that it should be employed to enhance the learning experience and facilitate individual growth. They argue that personalized learning experiences can significantly improve learner engagement, motivation, and overall effectiveness in achieving desired learning outcomes.

In conclusion, this study has shown that AI-assisted heuristic methods can effectively facilitate the transition from critical to creative thinking in English language learners. However, to maximize their potential, it is essential to address the challenges related to user experience, personalization, and feedback mechanisms. By doing so, educators can create a more inclusive and effective learning environment that promotes cognitive development and fosters success in the modern, interconnected world.

CONCLUSION

The present study has demonstrated the significant potential of AI-assisted heuristic methods in fostering the transition from critical to creative thinking in English language learners. Through a mixed-methods approach, the research highlighted the effectiveness of adaptive learning systems, intelligent tutoring, and data-driven feedback in enhancing learners' cognitive abilities and engagement.

The findings revealed that these innovative methods can promote critical and creative thinking skills, contributing to more effective English language learning experiences. Learners reported perceived benefits such as improved understanding of English concepts, increased motivation, and enhanced cognitive abilities. However, the study also uncovered challenges related to accessibility, user experience, and personalization that must be addressed to optimize the implementation of AI-assisted tools.

In light of these findings, it is crucial for educators and researchers to explore opportunities for refining AI-assisted heuristic methods and integrating a broader range of approaches to accommodate diverse learning needs and preferences. By doing so, the potential of AI-assisted tools in fostering cognitive transitions can be fully realized, ultimately leading to more effective English language learning experiences and better preparing learners for success in a rapidly evolving, interconnected world.

As the field continues to evolve, future research should further investigate the long-term impact of AI-assisted heuristic methods on creative thinking development and explore additional innovative approaches to English language learning. By addressing the challenges and leveraging the opportunities presented by AI-assisted tools, educators can create inclusive, adaptive, and engaging learning environments that empower learners to reach their full potential.

CONFLICT OF INTERESTS

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APPENDIX 1

Questionnaire for Surveys:

English Language Learning with AI-Assisted Heuristic Methods Questionnaire

SECTION A: Background Information

1. Gender:

- Male
- Female
- Other
- Prefer not to say

2. Age:

- 18-24
- 25-34
- 35-44
- 45-54
- 55+

3. English proficiency level:

- Beginner
- Intermediate
- Advanced

SECTION B: AI-Assisted Heuristic Methods Experience

1. How would you rate your overall experience with the AI-assisted heuristic methods?

– Very Satisfied
– Satisfied
– Neutral
– Dissatisfied
– Very Dissatisfied

2. How helpful were the adaptive learning systems in your English language learning?

– Very Helpful
– Helpful
– Neutral
– Unhelpful
– Very Unhelpful

3. How effective was intelligent tutoring in improving your language skills?

– Very Effective
– Effective
– Neutral
– Ineffective
– Very Ineffective

4. How useful was the data-driven feedback in guiding your learning process?

– Very Useful
– Useful
– Neutral
– Not Useful
– Not At All Useful

5. What specific features or tools of the AI-assisted heuristic methods did you find most beneficial?

SECTION C: Critical Thinking Skills

1. How much improvement did you notice in your ability to identify assumptions after using the AI-assisted heuristic methods?

– Significant Improvement
– Moderate Improvement
– Slight Improvement
– No Improvement
– Decline in Skills

2. How much improvement did you notice in your ability to draw logical conclusions after using the AI-assisted heuristic methods?

– Significant Improvement
– Moderate Improvement
– Slight Improvement
– No Improvement
– Decline in Skills

3. How helpful were the AI-assisted heuristic methods in fostering your critical thinking skills?
- Very Helpful
- Helpful
- Neutral
- Unhelpful
- Very Unhelpful
4. Can you describe any specific instances where the AI-assisted heuristic methods enhanced your critical thinking skills?

SECTION D: Creative Thinking Skills

1. How much improvement did you notice in your ability to generate alternative solutions after using the AI-assisted heuristic methods?

- Significant Improvement
- Moderate Improvement
- Slight Improvement
- No Improvement
- Decline in Skills

2. How much improvement did you notice in your ability to develop novel ideas after using the AI-assisted heuristic methods?

- Significant Improvement
- Moderate Improvement
- Slight Improvement
- No Improvement
- Decline in Skills

3. How helpful were the AI-assisted heuristic methods in fostering your creative thinking skills?

- Very Helpful
- Helpful
- Neutral
- Unhelpful
- Very Unhelpful

4. Can you describe any specific instances where the AI-assisted heuristic methods enhanced your creative thinking skills?

SECTION E: Additional Feedback

1. What did you like most about the AI-assisted heuristic methods?
2. What did you like least about the AI-assisted heuristic methods?
3. How can the AI-assisted heuristic methods be improved to better support your English language learning?
4. Are there any other comments or suggestions you would like to share about your experience with the AI-assisted heuristic methods?

Thank you for participating in this survey! Your feedback will help us improve the AI-assisted heuristic methods for English language learning.

* The participants/students were already well-informed about the concepts of critical thinking, creative thinking, and cognitive abilities.

** The questions in the survey questionnaire align with the general concepts of critical and creative thinking skills. To validate the questionnaire and ensure that the questions effectively measure the desired constructs, subject matter experts in critical and creative thinking were consulted.

Critical Thinking Questions focus on skills such as identifying assumptions, evaluating arguments, drawing logical conclusions, and problem-solving. Creative Thinking Questions focus on skills such as generating alternative solutions, developing novel ideas, and divergent thinking.

APPENDIX 2

The Tested Pre-test and Post-test for Critical and Creative Thinking Skills:

To ensure suitability for the intervention, the pre-test and post-test questions were tailored to align with the content and learning objectives of the AI-assisted heuristic methods. This involved incorporating English language learning elements into the questions, and/or creating scenarios relevant to language learners.

Pre-test

SECTION A: Critical Thinking

1. Read the following statement and identify the assumption: “All cats have tails. Therefore, my pet cat has a tail”.
2. Choose the best conclusion for the given premises: “All trees have roots. An oak is a tree”.

   a) An oak has roots.

   b) Some trees have roots.

   c) Not all trees have roots.
3. Identify the logical fallacy in this statement: “My friend is a doctor, and she says taking vitamins is a waste of money. Therefore, taking vitamins must be a waste of money”.

SECTION B: Creative Thinking

1. List three alternative uses for a paper clip.
2. Imagine you are given a cardboard box, a candle, and a book of matches. How would you attach the candle to the wall in a way that prevents wax from dripping onto the floor?
3. What is a possible solution to the problem of plastic pollution in the ocean?

Post-test

SECTION A: Critical Thinking

1. Identify the assumption in this statement: “All dogs bark. Therefore, my dog barks”.
2. Choose the best conclusion for the given premises: "All birds have feathers. A penguin is a bird".

   a) A penguin has feathers.

   b) Some birds have feathers.

   c) Not all birds have feathers.

3. Identify the logical fallacy in this statement: “My grandfather smoked all his life and lived to be 90 years old. Therefore, smoking is not bad for your health”.

SECTION B: Creative Thinking

1. List three alternative uses for a paper cup.
2. Imagine you are given a pair of scissors, a roll of tape, and a sheet of paper. How would you create a container that can hold water without leaking?
3. What is a possible solution to the problem of traffic congestion in cities?
4. These pre- and post-tests aim to measure participants' critical and creative thinking skills before and after engaging with the AI-assisted heuristic methods in their English language learning process. By comparing the results, researchers can assess the effectiveness of the intervention in fostering these cognitive abilities.

APPENDIX 3

The quantitative data can be collected from the pre-test and post-test by assigning numerical values to the responses and analyzing the data statistically. Here's how it was done:

Scoring Method:

1. For the critical thinking questions, 1 point for each correct answer and 0 points for incorrect or missing answers were assigned.
2. For the creative thinking questions, a rubric to score the responses based on the originality, elaboration, and relevance of the ideas presented was used on a scale of 1 to 3, with 1 being the lowest score and 3 being the highest score.

Data Collection and Analysis:

1. Calculating each participant's pre-test and post-test scores based on the scoring method.
2. Analyzing the data using descriptive statistics, such as mean, median, and standard deviation, to understand the overall performance of the participants.
3. Conducting paired t-tests to compare pre-test and post-test scores and determine if there is a significant improvement in critical and creative thinking skills after the intervention.
4. Analyzing the rubric scores for the creative thinking questions to identify patterns or improvements in the quality of ideas generated by participants.

By assigning numerical values to the responses and analyzing the data using statistical methods, quantitative insights into the effectiveness of the AI-assisted heuristic methods in fostering critical and creative thinking skills in English language learning were obtained.

***** The pre-post-tests align the questions with the learning objectives and expected outcomes of the intervention. The pre-post-test questions are related to the specific knowledge, skills, and abilities that participants are expected to acquire during the intervention. As the intervention aimed to improve participants’ ability to generate original ideas and connect them to real-world situations, questions like the following were included: “Write a short essay about an innovative solution to an environmental problem, and provide examples”. And/or "What are three different ways in which AI-assisted heuristic methods can be applied to English language learning?”