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LLM-Generated Personalized Analogies to Foster AI Literacy in Adult Novices

Cassie Chen CAO[a*], Eason CHEN[b], Zoe FANG[c], Lydia Y CAO[d], Jionghao LIN[b] & Ruizhe LI[e]
[a]*University of Sheffield, UK*
[b]*Carnegie Mellon University, US*
[c]*Harvard University, US*
[d] *University of Toronto, Canada*
[e]*University of Aberdeen, UK*
*ccao5@sheffield.ac.uk

Abstract:
Broad AI literacy is essential in today's rapidly advancing technological landscape, extending beyond AI specialists to encompass the general public. However, the complexity of AI concepts poses significant barriers to learning for individuals without prior AI knowledge. While teaching through analogies is a well-recognized method to simplify complex information by connecting it to familiar concepts, adapting these analogies to match individual learner profiles remains a substantial challenge. This paper addresses this gap by proposing a novel method for personalizing educational analogies, enhancing the accessibility and engagement of AI concepts for a diverse audience. Our approach uses Large language models (LLMs) to dynamically tailor content to each learner's cognitive and cultural contexts, grounded in educational theories and practices. Utilizing a crowdsourced A/B testing framework through Prolific (N=60), this research contrasts conventional instructional methods with content incorporating LLM-enhanced personalized analogies. Data collection comprised pre- and post-tests, activity logs, and surveys featuring Likert-scale and open-ended questions. Quantitative analysis of key learning outcomes revealed significant improvements in comprehension and retention, evidenced by enhanced pre-and post-test scores ($p < 0.01$ and $p < 0.05$, respectively) and motivation, as indicated by increased engagement in survey responses ($p < 0.05$). Qualitative analysis revealed a need for more examples and visual aids to complement analogies and a preference for balancing analogies with detailed technical content. This study demonstrates the potential of AI-generated analogies to make complex AI concepts more accessible and engaging. Future research should refine analogy generation, incorporate multimedia elements, and explore long-term and cross-cultural impacts to further enhance AI education.

Keywords: AI literacy, Analogical reasoning, Generative AI, AI education

1. Introduction

AI literacy is increasingly recognized as a crucial competency, essential not just for specialists but for the general populace navigating today's technology-driven world. Research has identified significant barriers for non-specialists engaging with AI, chiefly due to its abstract nature and rapid technological advancements (Gao et al., 2018; Bérubé et al., 2021). Adult learners present unique challenges and considerations in AI education compared to traditional student populations. Unlike students in formal educational settings, adult learners often have diverse backgrounds, experiences, and responsibilities (Song et al., 2010; Korhonen & Portaankorva-Koivisto, 2021). Many adult learners enter AI education with varying prior knowledge and technological fluency, posing challenges in designing effective instructional materials and approaches that cater to their heterogeneous needs (Gudoniene et al., 2023; Cao, 2023). Furthermore, adult learners may face time constraints due to work, family

obligations, or other commitments, making it challenging to engage in structured, time-intensive learning experiences (Pihlainen et al., 2021; Fairchild, 2003). Additionally, misconceptions or apprehensions about technology and AI may act as barriers to learning, requiring educators to employ strategies that foster confidence and motivation among adult learners (Leeuwen et al., 2020; Urbanovich et al., 2023). Traditional educational methods struggle to bridge the growing gap in technological proficiency, which can limit diverse societal groups' access to emerging technological benefits. Innovative educational strategies that can adapt to the pace of technological change are thus critically needed.

Analogies are a powerful educational tool, especially in science domains, aiding in reducing cognitive load and making abstract concepts more tangible (White & Brown, 2022). However, applying generic analogies often needs to account for individual learning styles and cultural backgrounds, leading to potential misconceptions (Dagher, 2005). While personalized analogies improve learning outcomes, the field lacks a robust methodology for effectively tailoring these analogies based on rigorous educational theories and systematic evaluations, particularly in diverse learning environments. Current applications of LLM-enhanced personalization in education are widespread yet rarely based on rigorously defined educational theories or iteratively refined through expert evaluations. Furthermore, there is a notable deficiency in solid empirical research and systematic assessment of such interventions, with AI research often needing a deeper understanding of LLMs' reasoning capabilities. This gap underlines a critical need for a methodologically sound approach to developing and assessing personalized educational content.

This study addresses these gaps by leveraging Large Language Models (LLMs), such as GPT-4, to create personalized educational analogies deeply grounded in interdisciplinary analogy-related theories and refined through iterative expert assessments. Our research employs a robust mixed-methods approach, incorporating both quantitative and qualitative analyses, to provide a comprehensive evaluation of the effectiveness of these personalized analogies in enhancing AI literacy. By integrating LLMs with well-founded educational strategies and expert insights, our study not only enhances the understanding and engagement of learners with diverse backgrounds but also contributes to the broader AI education discourse by 1) demonstrating the application of LLMs in generating educationally effective, personalized content that is empirically validated through rigorous, learner-sourced A/B testing; 2) Offering insights into the reasoning capabilities of LLMs within the context of educational content generation in AIED research; 3) providing a methodological framework for future research on the integration of AI in education, emphasizing the importance of grounding AI applications in solid educational theory and expert-driven content refinement.

The study investigates three main Research Questions (RQ):

RQ1: How do AI-generated analogies influence learners' learning outcomes of AI concepts compared to plain explanations?

RQ2: How do AI-generated analogies affect learners' experience during the learning process relative to traditional analogies?

RQ3: How do learners perceive the quality and helpfulness of AI-generated analogies compared to plain explanations?

2. Related work

2.1 The Use of Analogy in Education

Analogical reasoning holds promising potential in the educational domain, particularly for adult learners entering interdisciplinary fields or tackling subjects without prior knowledge. These learners often find the initial learning stages tedious and challenging. Analogies can significantly reduce cognitive load and enhance the learning experience by making new information more relatable and easier to assimilate (Low et al., 2010). Several key theories underpin the efficacy of educational analogies. Gentner's (1983) structure-mapping theory explains how comprehension is facilitated by mapping a well-known source concept onto a

less familiar target, emphasizing structural similarities to enhance understanding. Duit (1991) emphasized the importance of recognizing learners' misconceptions when using analogies to ensure that they contribute to accurate understanding rather than reinforcing incorrect assumptions. Thorndike and Woodworth's (1901) theory of transfer of learning demonstrates how analogies promote the transfer of learning by identifying and relating commonalities between known and new contexts, crucial for applying learned concepts to different situations. Sweller's (1988) cognitive load theory also argues that effective analogies can significantly reduce the mental effort required to grasp new concepts by linking them directly to prior knowledge, thereby optimizing cognitive resources (Son et al., 2023).

Analogies have been successfully applied across various educational fields to enhance active learning and problem-solving abilities. However, despite their success, several gaps remain in applying analogies in education. Existing theories related to analogies do not provide explicit guidance on tailoring analogies to meet individual learners' needs, which is critical for ensuring the relevance and effectiveness of educational content. The processes for ensuring successful analogical transfer are underexplored, particularly in terms of providing explicit prompts that guide learners in making correct associations. Furthermore, analogies must be carefully structured to avoid potential pitfalls such as unjustified analogical transfer or cognitive overload, which can detract from their educational value (Puspa et al., 2020; Jong, 2010).

2.2 LLM-enhanced Personalized Analogies

Large Language Models, such as GPT-4, represent a significant leap forward in natural language processing and machine learning technologies. These models are trained on diverse and extensive datasets, enabling them to generate coherent, contextually appropriate text based on input prompts. LLMs have been increasingly integrated into educational platforms to provide tutoring, generate practice questions, and explain complex topics across various subjects (Currie, 2023). Their ability to rapidly produce tailored content makes them ideal for adapting educational material to the needs of individual learners.

While LLMs excel at generating content, crafting effective educational analogies requires a nuanced understanding of both the subject matter and the learner's background. One challenge is ensuring that the analogies generated by LLMs are factually accurate, pedagogically relevant, and tailored to individual learning profiles. Existing literature indicated that the performance of LLMs like GPT-4 in analogical reasoning is mixed. While GPT-4 can approach human-like reasoning levels in short phrases, LLMs lack crucial mechanisms for robust analogy-based reasoning, especially in understanding and reasoning through complex sentences or narratives. From an AI perspective, existing datasets are often limited to the vocabulary level and lack high-quality sentence or narrative analogy pairs that are necessary for training or evaluating models. Furthermore, analogies are frequently generated and evaluated manually, relying on subjective judgment and experience. This approach lacks solid theoretical support and systematic metrics, resulting in low credibility and consistency in analogy assessments.

3. Methods

3.1 Participants and Sampling

Participants were recruited through Prolific[1], a crowdsourcing platform known for its diverse participant pool. They were randomly assigned to either the control group, which received standard learning materials, or the experimental group, which used AI-generated analogies tailored to their profiles. A total of 60 participants were recruited to ensure sufficient statistical power. Demographic information such as age, gender, and educational background was collected for learner profile creation and data analysis.

[1] https://www.prolific.com/

3.2 Materials and Measures

Table 1. *Evaluation Metrics that Applied to Our Themes. SQ Denotes Survey Questions.*

Theme	Evaluation Metrics	Instruments
Learning Gain	Learning Gain	Multiple-choice quiz in Pre and post-test SQ: *My understanding of the concepts improved after learning the material.*
	Efficiency	SQ: *I quickly grasped the concepts after reading the material.*
	Self-efficacy	SQ: *I am confident in explaining the concepts I learned to someone else.*
	Retention	Self-explaining questions in Pre and post-test; SQ: *I can still recall the concepts of linear regression and CNNs and how they were explained through the material.*
Learning Experience	Learning Satisfaction	SQ: *The learning experience is enjoyable;* *I am satisfied with how the material helped me understand the concepts.*
	Motivation and Engagement	SQ: *I was fully engaged while learning about the concepts;* *The material sparked my interest in learning more about the concepts.*
	Cognitive Load	SQ: *I felt mentally exhausted after learning the material;* *The material made it easier for me to process the information about the concepts.*
User Perception	Accuracy	SQ: *The material accurately represented the concepts of linear regression and CNNs*
	Relatedness	SQ: *I could relate the material to my personal experiences or knowledge.*
	Retention	SQ: *I can still recall the concepts of linear regression and CNNs and how they were explained through the material.*

Both groups received educational content on basic AI concepts, focusing on linear regression and convolutional neural networks (CNNs). Linear Regression and CNNs represent different aspects of AI - the former being a fundamental statistical method for predictive modeling and the latter an advanced technique for decision-making and learning from interaction. Both concepts have practical relevance and wide applications in real-world scenarios. By choosing one low-difficulty and one high-difficulty concept, the study can explore how the effectiveness of personalized analogies varies with the complexity of the AI concept. The control group received standard explanations and generic analogies selected from the free online learning platform Elements of AI[2]. In contrast, the experimental group received personalized instructional content with LLM-generated analogies tailored to learners' prior knowledge and personal interests, which were collected through a survey before the study. Participants took a pretest and posttest to assess their knowledge of the AI concepts before and after the intervention, and a follow-up survey was administered to measure the learning outcomes and learning experiences during the learning process. Table 1 illustrates the evaluation metrics we adopted in the study.

[2] https://www.elementsofai.com/

3.3 Prompt Design

The prompt for generating personalized analogy using GPT4 was developed by comprehensively reviewing educational practices and literature. The initial prompt was piloted with experts, leading to iterative refinements to better align with educational goals. A prototype was developed and improved through six rounds of pilot testing (participants were recruited from Prolific with the same selection criteria as the formal study), incorporating user feedback to enhance the AI-generated content and user experience. After piloting, the system was launched on Prolific for the crowd-sourcing study. Figure 2 presents the heuristics of the prompt design. By incorporating continuous feedback from experts in various fields, our study aims to ensure that the generated analogies are both technically sound and pedagogically effective.

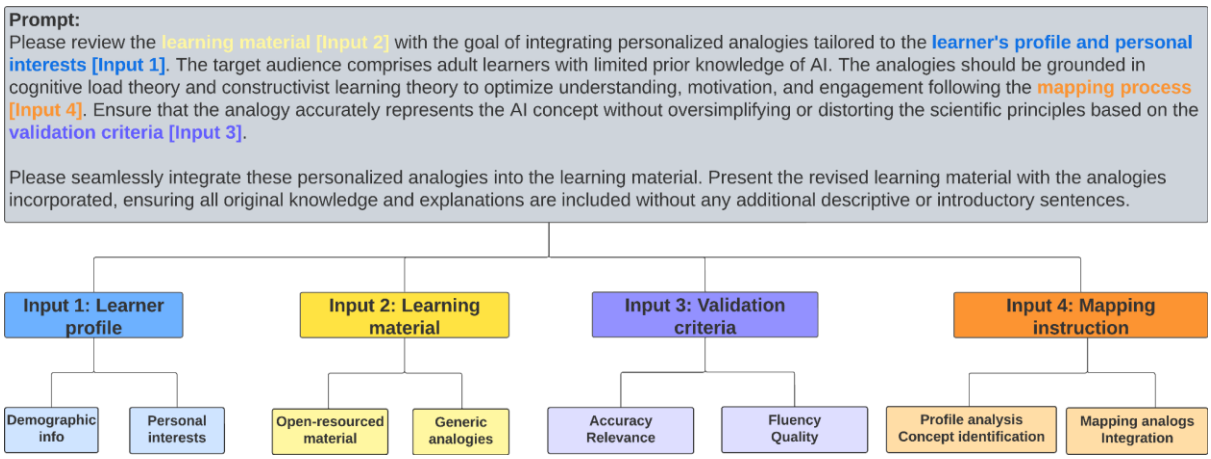

Figure 2. Heuristics of the prompt design after iterative refinement through expert review and pilot studies with potential users

3.4 Data Analysis

Quantitative analysis included t-tests and ANOVA to compare pretest and posttest scores and confidence ratings between groups, assessing immediate learning gains and retention over time. Chi-square tests and ANOVA were used to analyze differences in engagement and cognitive load between groups. Regression analyses and multivariate analysis of variance (MANOVA) explored how demographic variables influenced the effectiveness of AI-generated analogies.

The qualitative analysis involved thematic analysis of open-ended responses to identify common themes related to the effectiveness of the analogies and content analysis of learners' descriptions of particularly effective or ineffective analogies to gain insights into possible improvements in analogy design. We also invited two experts with AI backgrounds who teach AI in higher education experience to evaluate participants' understanding of the concepts. Figure 4 shows the evaluation workflow by human experts, including scoring rubrics and reliability tests.

3.5 Ethical Considerations

Ethical approval was obtained from the University of Sheffield's institutional review board (IRB). Participants provided informed consent and were informed of their right to withdraw at any time. They were assured of data confidentiality and anonymity throughout the study.

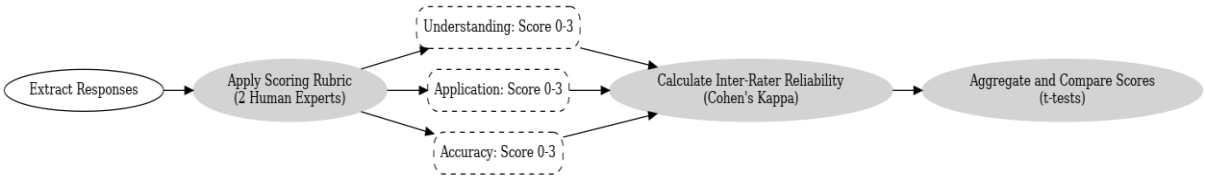

Figure 3. Workflow for Expert Evaluation of Participants' Understanding of Concepts.

4. Results

4.1 Impact of Analogy on Learning Outcomes

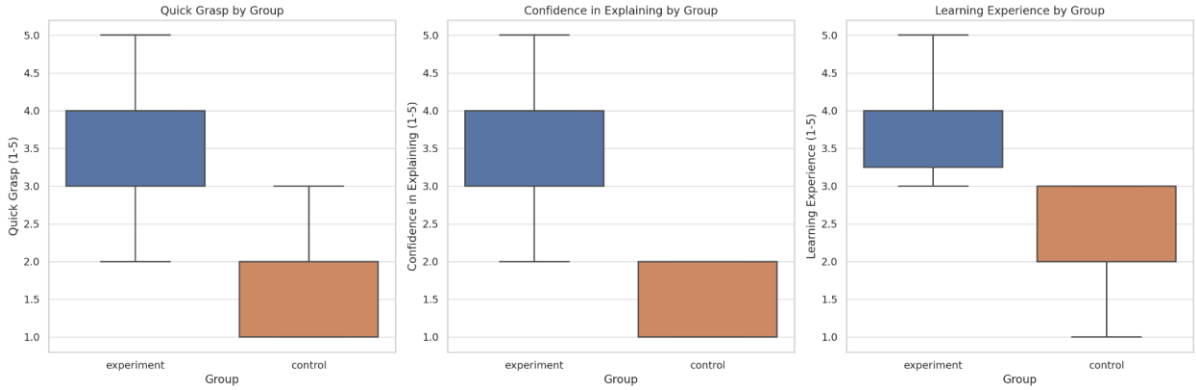

Figure 4. Analysis of the Impact of Analogies on Efficiency, Self-Efficacy, and Overall Learning Experience Based on Survey Responses (n=60)

Learning Gain. The analysis of the pre- and post-test scores indicated significant improvements in understanding among the control and experiment groups. Learners in the control group exhibited a mean increase of 2.64 points ($t(60) = -2.64$, $p < 0.0001$), while those in the experiment group showed a mean increase of 2.56 points ($t(60) = -2.56$, $p < 0.05$). This suggests that both teaching methods effectively enhanced the understanding of AI concepts, with plain explanations showing a slightly greater improvement. The slightly greater improvement in understanding shown by the control group could be attributed to the high quality of the instructional content we chose and the straightforward and familiar nature of plain explanations, which may be easier for some learners to process and comprehend quickly than the additional cognitive steps required to understand and relate to AI-generated analogies. The result highlights the importance of considering individual learning preferences and the potential cognitive load introduced by more complex instructional methods.

Efficiency and Self-efficacy. Survey responses revealed a significant difference in efficiency between the control and experiment groups. Participants in the experiment group reported quicker grasping of concepts ($t(60) = -3.49$, $p < 0.0001$), indicating that AI-generated analogies facilitated a more efficient learning process compared to plain explanations (see Figure 4). The experiment group also demonstrated higher self-efficacy compared to the control group. Participants reported greater confidence in their ability to explain learned concepts to others ($t(60) = -3.45$, $p < 0.0001$), indicating that exposure to personalized analogies improved learners' confidence in their knowledge and communication skills.

Retention. Participants in the experiment group exhibited better concept retention than the control group. They reported being able to recall the concepts of linear regression and CNNs more effectively ($t(60) = -3.52$, $p < 0.01$), suggesting that AI-generated analogies contributed to enhanced long-term memory retention.

Table 2. *Mean Scores and Standard Deviation for the Pre- and Post-tests by Groups*

Criteria	Control Group (Pretest Mean Score)	Control Group (Posttest Mean Score)	Experiment Group (Pretest Mean Score)	Experiment Group (Posttest Mean Score)	Standard Deviation
Understanding	0.92	1.99	1.05	2.81	0.51
Accuracy	1.02	2.06	1.00	1.87	0.47
Application	0.24	0.96	0.20	2.04	0.47

The qualitative analysis provided additional insights into the impact of personalized analogies on learners' understanding and articulation of AI concepts. By evaluating responses based on criteria such as understanding, accuracy, and application, we gained a deeper understanding of the qualitative effects of AI-driven educational interventions. Specifically, responses from both the control and experiment groups showed improved understanding, accuracy, and application from the pretest to the posttest (see Table 2). However, participants exposed to AI-generated analogies demonstrated a more pronounced improvement in understanding and application, indicating a richer understanding of AI concepts.

Overall, the data analysis supports the hypothesis that learners exposed to AI-generated analogies exhibit better learning outcomes, including enhanced understanding, efficiency, self-efficacy, and retention, than those exposed to plain explanation. The combination of quantitative and qualitative analyses provides a comprehensive evaluation of the effectiveness of personalized analogies in AI education.

4.2 Impact on Learner Experience

4.2.1 Quantitative Analysis

The analysis used ANOVA to test the differences between the control and experimental groups across various metrics such as engagement, cognitive load, learning enjoyment, and satisfaction. The results indicated significant differences in several key areas, which suggest that the personalized AI-generated analogies had a notable impact on the learning experience.

Figure 6 showed that there was a significant difference in how enjoyable participants found the learning process ($F(1, 35) = 30.93$, $p < 0.001$), with the experimental group reporting higher levels of enjoyment. Satisfaction with the learning material also differed significantly between the groups ($F(1, 35) = 22.14$, $p < 0.001$), again with higher satisfaction in the experimental group. The material was more effective at sparking interest in the experimental group ($F(1, 35) = 10.68$, $p = 0.002$).

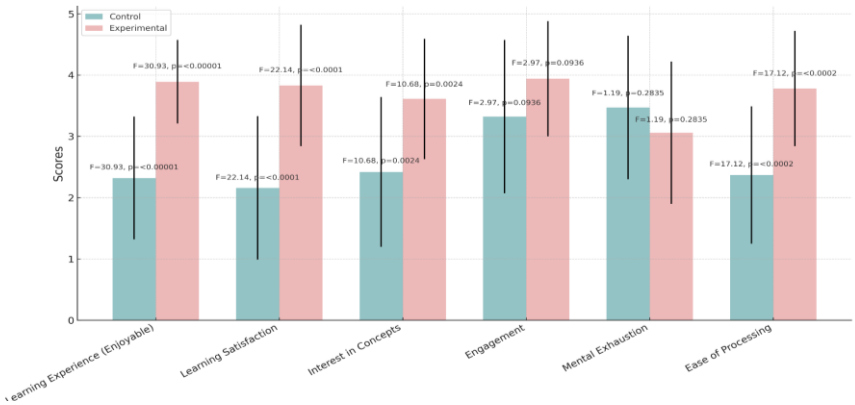

Figure 6. Significant Differences in Enjoyment, Satisfaction, and Interest Between Experimental and Control Groups

However, some metrics, such as full engagement and mental exhaustion, did not show significant differences, which could suggest that the nature of the content and its complexity might equally affect both groups regardless of the analogy used.

4.2.2 Qualitative Analysis

The thematic analysis of open-ended responses provided deeper insights into the specific elements of the learning material that participants found beneficial or needing improvement.

Theme 1: Need for More Examples and Visual Aids
While the feedback on AI-generated analogies was largely positive, some participants suggested including more examples and visual aids to complement the analogies. They believed this would further enhance understanding and retention. One suggestion was, "*I think it would be helpful to have more visual aids alongside the analogies to see the concepts in action.*" Another participant said, "*Including additional examples would improve the material. Sometimes, one analogy isn't enough to cover all aspects.*"

Some learners in the control group preferred plain explanations' straightforward and concise nature. They found these traditional methods efficient for quickly understanding the material. One learner noted, "*I liked the plain explanations because they got straight to the point without any extra fluff.*" Another remarked, "*The direct approach of the plain explanations helped me focus on the key concepts without getting distracted.*"

Theme 2: Mixed Feelings on Depth of Analogies
A few participants noted that while analogies were helpful, they occasionally felt oversimplified or lacked depth. These learners suggested balancing analogies with more detailed technical explanations. One participant mentioned, "The analogies were great, but sometimes they felt too simplistic. I would appreciate a bit more depth." Another learner added, "I enjoyed the analogies, but there were moments where I wanted more detailed information alongside them."

The thematic analysis of open-ended survey responses indicates that some learners suggested incorporating more visual aids and examples to enhance the effectiveness of the analogies further. Additionally, while plain explanations were appreciated for their conciseness, a balance between analogies and detailed technical content could cater to a broader range of learning preferences.

5. Conclusion

This study contributes to AI education by demonstrating the efficacy of personalized analogies generated by AI models in facilitating learning among adult novices. We demonstrate the practical application of AI in education by using GPT-4 to craft analogies specifically tailored to individual learners' backgrounds and needs. By incorporating continuous feedback from experts in various fields, our study ensures that the generated analogies are both technically sound and pedagogically effective. This iterative process helps refine the analogies further, ensuring they meet high educational standards and are more likely to aid learning. Additionally, addressing the absence of systematic metrics for evaluating analogies, our research introduces robust evaluation frameworks grounded in educational, psychological, and cognitive theories. These frameworks assess the technical accuracy of the analogies and evaluate their impact on learning outcomes, providing a more reliable and consistent method to measure their educational effectiveness. This personalized approach helps mitigate the challenge of generic content that does not address individual learning backgrounds and preferences, making learning more accessible and engaging for adult novices. Finally, using mixed methods, our study thoroughly analyzes the impact of AI-generated analogies on learning outcomes such as understanding, retention, engagement, and motivation. This

comprehensive approach offers actionable insights for educators and AI developers alike. The study highlights the potential of personalized learning approaches to promote inclusivity and accessibility in education by tailoring educational content to individual learners' backgrounds and preferences.

While the study provides valuable insights, several limitations should be considered. Firstly, the generalizability of the findings may be limited by factors such as the sample size, participant demographics, and the specific AI concepts covered. Future research could aim to replicate the study with larger and more diverse samples to enhance the generalizability of the findings across different populations and educational contexts. Secondly, the scope of AI concepts covered in the study was limited to foundational topics such as linear regression and convolutional neural networks (CNNs). Exploring a broader range of AI topics could provide a more comprehensive understanding of the impact of personalized analogies across different domains within AI education. Thirdly, methodological considerations, such as using a learner-sourced methodology and online data collection, may introduce biases and limitations associated with self-selection and participant engagement. Complementing this approach with traditional classroom-based studies could validate the findings in different learning environments.

To address these limitations and further advance the field, future research directions could focus on several areas. There is a need to refine the process of generating personalized analogies to optimize their effectiveness. This may involve exploring different AI models, fine-tuning the analogy generation algorithms, and incorporating feedback mechanisms to improve the quality and relevance of the analogies iteratively. Besides, integrating multimedia elements into educational materials could enhance engagement and facilitate a deeper understanding of AI concepts, including interactive simulations, animations, and real-world examples to complement the personalized analogies. Moreover, longitudinal studies could assess the long-term impact of personalized analogies on learning outcomes and retention. By tracking participants' progress over an extended period, researchers can evaluate the durability of learning gains and identify any potential fade-out effects or need for reinforcement strategies. Additionally, cross-cultural investigations could explore variations in the effectiveness of personalized analogies across different cultural contexts. Comparative studies could show how cultural factors influence learners' responses to personalized learning approaches and inform culturally responsive educational practices. Addressing these considerations and pursuing these future research directions will continue to advance our understanding of personalized learning approaches in AI education and contribute to the ongoing efforts to promote inclusive, equitable, and effective educational practices in the digital age.

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