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The role of students' higher-order thinking skills in the relationship between academic achievements and machine learning using generative AI chatbots

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Abstract

Students' perspectives on using generative artificial intelligence (AI) chatbots and machine learning are crucial in shaping the design, development, and implementation of their learning projects across various disciplines. Cognitive thinking, a key aspect of AI-related machine learning, aims to replicate human intelligence and behavior. However, the relation between cognitive thinking and knowledge acquisition is often overlooked. This cross-sectional study empirically examines the relationship between academic achievement and students' attitudes toward machine learning, particularly through the use of generative AI chatbots. It specifically focuses on the role of higher-order thinking skills—such as problem-solving, critical thinking, and creativity—as both mediators and moderators in this relationship. A total of four hundred sixteen undergraduate students (n=416) from diverse academic backgrounds voluntarily took part in a project, in which they designed and developed generative AI chatbots in media and information literacy courses. The findings indicate that creativity mediated the relationship between academic achievements and attitudes toward machine learning, but its moderating impact was not significant. Problem-solving and critical thinking did not show significant mediating effects on attitudes toward machine learning, while they showed significant moderating effects in the connection between academic performance and attitudes toward machine learning. This study contributes by elucidating the interrelationships between students' higher-order thinking skills, academic performance, and attitudes on the use of AI and machine learning technologies. By highlighting the mediating role of creativity and the moderating effects of problem-solving and critical thinking, this study offers a deeper understanding of how these skills shape students' perceptions of AI.

Keywords: Artificial intelligence, Academic achievements, Chatbots, Higher-order thinking, Large language models, Machine learning

Introduction

Artificial intelligence (AI) is a rapidly evolving field within computer science dedicated to developing intelligent agents that can mimic human cognitive abilities, such as learning, reasoning, problem-solving, and understanding language (Popenici & Kerr, 2017). It encompasses the development of algorithms, models, and systems that enable machines to learn from experience, adapt to current information, and execute tasks typically associated with human intelligence (Bansal et al., 2024; Chaka, 2022). The emergence of AI conversational agents, such as chatbots, has sparked interdisciplinary discussions extending beyond the realm of technology, reaching into diverse fields like psychology, sociology, programming, and philosophy (Kazanidis & Pellas, 2024). Chatbots, powered by advanced AI architectures like GPT (Generative Pre-trained Transformer), can simulate human-like conversations, enabling users to set up meaningful connections that go beyond mere functionality and navigate the intricacies of human language (Gill et al., 2023). What makes this intersection even more remarkable is the integration of machine learning techniques, allowing generative AI chatbots to continuously enhance users' communication and cognitive intelligence for solving real-world problems through the analysis of vast datasets (Lu et al., 2024). Through machine learning techniques like natural language processing and deep learning, AI chatbots can analyze and interpret the nuances of human communication, including context, intent, and emotion (Kong et al., 2024). This ability to process language at a deeper level lays the foundation for the development of humans' cognitive skills, equipping them to critically reflect on and engage with the ever-evolving landscape of media and information literacy using AI chatbots (Baskoro et al., 2023; Pellas, 2023a).

The use of generative AI conversational chatbots, such as OpenAI's ChatGPT [1], Google's Gemini [2], and Perplexity [3], has the potential to revolutionize the development of higher-order thinking skills. These advanced AI language models are powerful tools for fostering critical thinking, creativity, and problem-solving abilities (Lu et al., 2024; Putra et al., 2023). Through interactive conversations, users who specialize in media and information literacy are encouraged to articulate complex ideas coherently, analyze complex scenarios, and synthesize information from diverse sources (Lee, 2019). For example, this dynamic engagement encourages users to delve into interactive discussions, evaluate multiple perspectives, and engage in thoughtful debates, thereby enhancing their capacity to think critically and make informed decisions (Zhong et al., 2024). By challenging users to communicate effectively with AI that operates at a sophisticated level, generative AI chatbots stimulate cognitive processes that are integral to higher-order thinking skills related to problem-solving, critical thinking, and creativity (Kong & Yang, 2025).

The integration of higher-order thinking skills, machine learning, and generative AI chatbots is transforming human-computer interaction, particularly in higher education. Recent research (e.g., Jia & Tu, 2024; Zhai et al., 2024) highlights AI's potential to revolutionize learning, enhancing critical thinking, self-efficacy, and student engagement. While AI can boost learning effectiveness and support higher-order thinking development, it also raises concerns regarding misuse and its impact on students' learning achievements. Conversely, responsible use of AI, tailored to individual learning styles, can significantly improve educational outcomes. Other professionals and researchers (Hopcan et al., 2024; Lee et al., 2024; Pellas, 2023b) increasingly value skills such as critical thinking, creativity, and problem-solving for higher-order thinking tasks that students need to engage in using AI. They realize that these abilities can enable students to effectively harness AI and machine learning to generate innovative solutions. This evolving perspective emphasizes a mutual relationship between human creativity and machine intelligence. The focus is not solely on replacing human activities but on augmenting human capabilities (Lo, 2023). As a result, the modern workforce is not only adapting to technological changes but also embracing a new era in which higher-order thinking skills, along with a proactive attitude toward continuous learning and knowledge acquisition, are essential for unlocking the full potential of AI and machine learning across diverse industries. Furthermore, students' perspectives on machine learning can be significantly shaped by their experiences with technology (Lee et al., 2024). Those who have met the benefits of technology in their personal and professional lives tend to hold positive opinions about it, viewing it as a tool for enhancing efficiency, productivity, and knowledge acquisition. On the other hand, those who are less familiar with technology might exhibit hesitation or reluctance (Huang et al., 2024).

While previous studies have highlighted the potential mediating role of creativity (Jeon et al., 2023; Jia & Tu, 2024; Kong & Yang, 2025; Zhong et al., 2024), there is a significant research "gap" regarding the moderating effect of creativity in the relationship between academic achievement and attitudes toward AI and machine learning. The limited exploration of this moderating effect, along with the interplay between problem-solving and critical thinking as both mediators and moderators, warrants further investigation (Baskoro et al., 2023; Lu et al., 2024). Additionally, the absence of substantial research on the moderating effects of higher-order thinking skills raises questions about specific contextual factors influencing students' academic achievements using AI and machine learning technologies (Lee et al., 2024; Lo, 2023).

The above research gap motivates the present study, which investigates the mediating and moderating roles of students' higher-order thinking skills (creativity, problem-solving, and critical thinking) in the relationship between academic achievements and attitudes toward AI and machine learning across diverse academic disciplines. Analyzing these mediating and moderating effects will provide a deeper understanding of how students' higher-order thinking skills influence their attitudes toward AI and machine learning in education. Specifically, this study aims to investigate the following hypotheses:

- Hypothesis 1 (H1): Creativity mediates the relationship between academic achievements and attitudes toward AI and machine learning. This means that academic achievement indirectly influences attitudes toward AI and machine learning through its impact on creativity. In other words, higher levels of academic achievement are expected to lead to increased creativity, which in turn positively influences attitudes toward AI and machine learning.
- Hypothesis 2 (H2): Problem-solving and critical thinking moderate the relationship between academic achievements and attitudes toward AI and machine learning. This means that the strength and direction of the relationship between academic achievement and attitudes toward AI and machine learning may vary depending on individuals' levels of problem-solving and critical thinking skills. In essence, students with higher levels of problem-solving and critical thinking may exhibit different patterns in their attitudes toward AI and machine learning compared to those with lower levels of these skills, even when considering their academic achievement.

The present study aims to empirically examine the relationship between academic achievement and students' attitudes toward machine learning, particularly through the use of generative AI chatbots. It specifically focuses on the role of higher-order thinking skills—such as problem-solving, critical thinking, and creativity—as both mediators and moderators in this relationship. By analyzing how these skills influence and potentially alter students' attitudes across diverse academic disciplines, this research seeks to provide deeper insights into the factors that shape students' perceptions of AI and machine learning technologies in educational projects. The cultivation of creativity, problem-solving, and critical thinking can assist students in equipping the necessary mindset to embrace AI as an alternative tool in education.

Literature review

The impact of generative AI chatbots in education

The integration of generative AI chatbots into the discourse on education presents a multifaceted array of opportunities and challenges. AI chatbots can serve as personalized, scalable, and accessible platforms by engaging users in meaningful dialogues around their technological interactions, fostering self-regulation, and delivering tailored strategies for knowledge acquisition (Bansal et al., 2024). These types of chatbots for educational purposes proclaim a new era of personalized, interactive, and accessible learning education

(Gill et al., 2023). Their potential to tailor instruction, stimulate active engagement, and provide instant support has transformative implications for the education landscape as well. As educators and researchers explore further into the realm of AI-driven educational interventions, the combined effect between technology and pedagogy holds the promise of enhancing academic achievements and nurturing individuals prepared to thrive in evolving knowledge acquisition (Lu et al., 2024).

Generative AI chatbots have shown remarkable promise in addressing the diverse learning needs of students within a teaching intervention. Lo (2023) advocated that ChatGPT has variable performance across subjects in education. It can aid instructors and tutor students, but issues include generating incorrect information and bypassing plagiarism detectors as institutions need to update methods, and policies, and provide training to adapt to its impact. These chatbots leverage natural language processing (NLP) to engage learners in real-time conversations, mirroring the achievements of previous teaching interventions (Putra et al., 2023). Nonetheless, their effectiveness varies across subjects, causing further exploration of their potential disruptions and benefits to established learning methods and teacher-student interactions. Powered by advanced NLP algorithms and large language models (LLMs), generative AI chatbots act as sophisticated conversational agents, fueled by the revolutionary GPT architecture. Their ability to grasp and generate human-like text unlocks innovative applications across various fields, including education. Beyond creative domains, generative AI is even transforming traditionally human-driven tasks like report generation and learning material creation.

Unlike "search engines," like Google's search or Microsoft's Bing, generative AI chatbots have emerged as innovative tools capable of interacting with users in a human-like manner, addressing queries, providing information, and even engaging in meaningful conversations. GPT-powered chatbots leverage LLMs to understand and generate coherent text, making them valuable assets in education. For this reason, there are several not only potentials but also drawbacks to delivering personalized support and information tailored to individual users' needs and emotional states, which can support a variety of teaching and learning procedures using AI and machine learning technologies. These are as follows (Huang et al., 2024; Jia & Tu, 2024):

a) Encouraging personalized support: One of the primary advantages of using generative AI chatbots in addressing learning needs is their ability to provide personalized support and information dissemination to a wide range of people without (or with limited) financial cost. These chatbots can engage with students in real time, offering guidance on managing technology-related challenges.

b) Reducing information overload: As students meet vast amounts of digital content, it becomes overwhelming to identify relevant information. Generative AI chatbots can act as filters, sifting through information and presenting users with concise, pertinent details.

c) Promoting self-efficacy and digital competency: By offering guidance and solutions to technological challenges in real time, generative AI chatbots can empower users to develop the skills needed to navigate digital platforms autonomously.

However, concerns exist on the use of generative AI and machine learning technologies, including:

a) Ethical concerns: AI-generated videos, particularly deepfakes, can be used for malicious purposes, such as spreading misinformation, impersonating individuals, and invading privacy.
b) Quality and authenticity challenges: While AI has made remarkable progress, the quality and authenticity of AI-generated content may still fall short of human-created content, especially in terms of emotional depth and nuanced storytelling. AI models trained on biased data may perpetuate stereotypes and biases in the generated content.
c) Depersonalization: The use of virtual influencers and AI-generated characters can sometimes contribute to a sense of depersonalization in media, as audiences interact with non-human entities instead of real individuals.

Higher-order thinking skills in AI-supported education

Higher-order thinking skills, encompassing critical thinking, problem-solving, and creativity, are essential human cognitive thinking abilities and human intelligence (Hwang et al., 2018). Students, especially in tertiary education, are urged to engage in course activities to foster advanced cognitive processes, enhance cognitive thinking skills, and grasp subject-related knowledge. The value of cognitive thinking is for the international literature related to higher-order skills, as several competency frameworks emphasize the following (Huang et al., 2024): a) critical thinking that allows someone to objectively analyze information, thinking logically, and making sound judgments, b) problem-solving that allows someone to identify a problem, gathering and evaluating relevant information to suggest potential solutions, and lastly c) creativity that someone pertains to crafting and generating innovative ideas and approaches by analyzing and appraising existing concepts.

The relationship among higher-order thinking skills, machine learning, and generative AI chatbots point out a transformative combination in the realm of human-computer interaction. An expanding collection of scholarly works delves into the growing connection between generative AI chatbots in higher education, revealing their potential to revolutionize the learning landscape in tertiary education. For example, Baskoro et al. (2023) explored a new method combining peer learning (“peeragogy”) with AI in both teaching and learning shows promise for improving Gen Z's critical thinking skills compared to traditional approaches. AI chatbots like ChatGPT can boost learning effectiveness (back-end) but raise ethical concerns if misused (shortcuts, reduced creativity).

However, AI is a neutral tool, and responsible use (controlled front-end integration) can significantly enhance learning, including higher-order thinking. Huang et al.'s (2024) study revealed that AI-generated content has the potential to enhance student self-efficacy and underlines the importance of customizing teaching strategies to accommodate individual learning styles, crucial for fostering higher-order thinking development. However, limitations inherent to this cross-sectional design and the focus on self-efficacy highlight the need to identify any potential relationship between AI and higher-order thinking measurement. Lee et al. (2024) admitted that generative AI chatbots can significantly enhance students' cognitive and behavioral engagement, self-efficacy, critical thinking, problem-solving, creativity, and knowledge construction. Nevertheless, it did not significantly impact students' intrinsic motivation. The same authors also admitted that the AI chatbots can enhance students' learning experiences and outcomes by providing guidance, fostering self-regulated learning, and developing higher-order thinking skills, while helping them manage autonomy and engage in problem-solving learning tasks. Lastly, Lu et al. (2024) investigated the impact of generative AI-assisted teaching skills training on preservice teachers' self-efficacy and higher-order thinking. Results showed that the experimental group scored significantly higher in both self-efficacy and higher-order thinking, indicating the effectiveness of generative AI in supporting professional development.

To fully realize the potential of generative AI chatbots, it is essential to consider their impact on higher-order thinking skills, which are fundamental to academic success and lifelong learning. While generative AI chatbots can effectively mimic cognitive processes, they often lack the depth of understanding and emotional intelligence inherent in human thought (Ogata et al., 2024; Pellas, 2023a). Consequently, the interaction between human cognition and AI capabilities becomes a critical area of inquiry. Notwithstanding that generative AI chatbots are skilled at imitating enhanced cognition, they often lack understanding and emotional insight as the kind that students' higher-order thinking skills can carry (Kong et al., 2024; Pellas, 2023b). This brings researchers and instructors to investigate how AI technology can assist students' higher-order thinking, exclusively in more complex aspects. Generative AI chatbots are impressive at mimicking cognitive processes but often lack true understanding and emotional depth—qualities that are integral to higher-order thinking. Students, on the other hand, possess these higher-order thinking skills, which include critical thinking, creativity, and problem-solving. Understanding how these skills mediate and moderate the impact of AI on academic achievement and attitudes toward machine learning is crucial for maximizing the benefits of AI in education (Chaka, 2022; Kazanidis & Pellas, 2024).

On the one side, creativity as a higher-order thinking skill is hypothesized to mediate the relationship between academic achievement and attitudes toward AI and machine learning (H1). This means creativity could be the mechanism through which students' academic achievements influence their attitudes toward AI. If we understand this mediation, we can better tailor educational approaches that harness creativity to positively influence students' perceptions and interactions with AI, leading to more effective learning outcomes.

On the other side, problem-solving and critical thinking are examined as potential moderators, meaning they might change the strength or direction of the relationship between academic achievement and attitudes toward AI and machine learning (H2). If students with strong problem-solving and critical thinking skills show a different pattern in how their academic achievements relate to their attitudes toward AI, it suggests that these skills could be key in optimizing the use of this technology in educational contexts. Understanding this moderation helps educators identify which students might benefit more from AI-assisted learning and how to support those who might struggle.

Based on the analysis that was made above in the literature review, there is limited research on how creativity mediates, and problem-solving and critical thinking moderate, the relationship between academic achievement and attitudes toward machine learning. By investigating these roles, the study addresses a significant gap in educational research. This study proposes that creativity mediates the relationship between academic achievement and attitudes toward machine learning. Additionally, problem-solving and critical thinking are explored as potential moderators of this relationship. By investigating these factors, we aim to elucidate how generative AI chatbots can be optimally integrated into educational practices to enhance, rather than replace, higher-order thinking skills. Designing AI-supported educational tools that can be aligned with the cognitive and emotional capacities of students can further foster their deeper learning and more positive attitudes toward this technology. This knowledge can lead to better integration of AI in educational practices, ensuring that it complements and enhances students' higher-order thinking rather than merely imitating it. In essence, understanding these roles helps in designing AI-powered educational tools that are not just effective but also aligned with the cognitive and emotional capacities of students, leading to deeper learning and more positive attitudes toward technology in education.

Method

Research context

The present study employs a cross-sectional research design. This means that data will be collected from a sample of the population at a single point in time. Cross-sectional studies are valuable tools in empirical research, as they gather and analyze real-world data to gain insights into a population or phenomenon at a specific point in time. This approach allows researchers to examine relationships between variables and identify potential trends, but it cannot establish cause-and-effect relationships. It is frequently employed in educational research to identify trends and explore relationships between various factors (Busato et al., 1998). By administering questionnaires or tests, researchers collect data that forms a correlation matrix (Koo & Li, 2016). This matrix serves as the foundation for various statistical analyses, including regression, multivariate analysis, and structural equation modeling (SEM). These analyses allow researchers to test multiple hypotheses, providing a comprehensive understanding of the studied variables (Ma, 2011).

Participants

This study enrolled Greek undergraduate students who utilized generative AI chatbots to design, develop, and implement their learning projects. Participation was voluntary, resulting in a dataset of 416 responses, which was subsequently analyzed. Among the respondents, 184 individuals identified themselves as female, constituting 42% of the total, while 232 individuals identified as male, making up the remaining 58%. The average age of the participants was 21.6 years, with a standard deviation of 2.7, and their ages ranged from 20 to 24 years old. The participants are categorized as follows: 155 were seniors, accounting for 45% of the sample; 122 were juniors, making up 15%; 100 were sophomores, comprising 25%; and thirty-nine were first-year students, representing 15%. All participants pursued a range of academic disciplines, including computer science, language learning, instructional design, chemistry, mathematics, physics, administration, and business. All participants had prior experience with generative AI chatbots from previous projects, focusing on media and information literacy.

Ethical considerations

The main researcher ensured that each participant's welfare was scrupulously considered and protected at all stages of this study, in line with the ethical principles. Stringent ethical considerations encompassed acquiring informed consent, maintaining confidentiality and anonymity, and upholding the participants' well-being and privacy (Onwuegbuzie & Daniel, 2003). These ethical measures were of paramount importance in protecting the rights and welfare of those engaged in the research. Voluntary participation was the sole mode of involvement, and before data collection, all participants provided informed consent. Participants were made clear that they had the right to withdraw from the study at any moment without encountering any negative consequences.

Before the instructional intervention was introduced, a comprehensive elucidation of the study's objectives was furnished to students in both groups. Additionally, they were obligated to endorse a consent document detailing: a) any repercussions linked to the use of assessment platforms. b) the collection and handling of their data aligned with the General Data Protection Regulation (GDPR) stipulations, and c) the unrestricted prerogative of participants to discontinue in this study at any juncture without incurring adverse repercussions.

Lastly, the Internet Protocol (IP) addresses were masked to protect anonymity, and cheaters faced no punitive measures. All individuals received fair compensation, and the online examination featured moderately challenging queries, along with the prospect of a bonus. Nonetheless, cheaters could never achieve a perfect score since the correct answers were not disclosed. To accommodate a delayed debriefing process, the researcher screened participants in advance to confirm their willingness to partake in a study involving deception.

Setting

This study was motivated by the notion that incorporating AI chatbots into the learning process can enrich students' comprehension of machine learning applications in real-world settings, fostering a more holistic understanding of this technology. By engaging with AI chatbots in project development and problem-solving tasks, students can cultivate critical thinking and problem-solving abilities. The participants surveyed were those who used generative AI chatbots: (a) to develop, design, manage, modify, and finally properly apply their learning project creations. For example, these included generating presentations, coding, or artifacts to interface with learning management systems or (online) resources, serving purposes of both formal and informal professional advancement, (b) to employ advanced technological resources and services relevant to the processes of learning, and (c) to participate in various activities aligned with departmental interests, to exchange ideas beyond their existing responsibilities. More specifically, these applications ranged from generating presentations and coding to creating artifacts for interfacing with learning management systems and online resources.

Participants used different AI chatbots for both formal and informal professional advancement, employing advanced technological resources related to learning processes, and participating in activities aligned with departmental interests, following (possible) learning scenarios as described below:

a) Project assistance: Students working on projects, assignments, or coding tasks could utilize AI chatbots for assistance. This aligns with the participants using AI chatbots for project development and modification, fostering a connection between student and professional uses.
b) Learning resource interaction: AI chatbots could help students interact with learning management systems, access online resources, and gather information for their studies. This aligns with the use of chatbots for interfacing with learning resources, emphasizing the integration of technology in the learning process.
c) Professional development: Students can use AI chatbots for informal professional development, seeking guidance on industry-related topics or trends. The use of chatbots for informal professional advancement resonates with students exploring beyond their regular academic responsibilities.

The current study explores undergraduate students' perspectives on the utilization of generative AI chatbots, powered by LLMs, across diverse educational domains. The primary objective of establishing the current research was to bring together a sample of participants that is both representative and chosen randomly from various geographical regions. In the initial phase of the survey, participants' previous encounters were collected, regardless of their specific academic fields. The research subjects were drawn from two prominent email lists extensively employed by instructors and students to exchange ideas, solutions, or experiments/projects involving generative AI chatbots. These lists regularly have given announcements via email. The survey was distributed to a cohort of 456 students situated across different universities in Greece, using email as the distribution method. Among them, 416 valid responses were collected, constituting a robust 91% response rate. To ensure data quality, surveys with missing responses were excluded from the analysis.

The completion of the complete set of questionnaires required no more than 25 minutes. It is noteworthy to emphasize that the design and implementation of the questionnaire deliberately avoided categorizing participants into novice and expert users. This approach was consciously chosen to ensure a holistic understanding of students' experiences using AI chatbots. Accordingly, the survey did not segregate the responses of participants based on their expertise levels following their involvement in university-level courses. This methodology was selected due to the novelty of the survey and the imperative to incorporate the viewpoints and encounters of all participants without differentiation. By this viewpoint, the participants surveyed were those who used generative AI chatbots: (a) to develop, design, manage, modify, and properly apply their learning project creations. For example, these included generating presentations, coding, or artifacts to interface with learning management systems or (online) resources, serving purposes of both formal and informal professional advancement, (b) to employ advanced technological resources and services relevant to the processes of learning, and (c) to participate in various activities aligned with departmental interests, to exchange ideas beyond their existing responsibilities.

Two crucial factors that influenced students' participation reflecting on the schedule were the following: (a) all sessions were aligned with a 20-week university calendar, covering both the winter and spring semesters (from October 2022 to June 2023), within the standard 25-week academic period followed by most universities and (b) any use of generative AI chatbots was adopted as an alternative platform for the completion of their learning projects. The duration of each student session was 45 minutes, and the frequency of these sessions was three times per week.

The research process began by reaching out to instructors or supervisors via email to secure consent for involving students engaged in university courses and allowed students to use AI platforms for their projects. Upon receiving the necessary approvals, recruitment letters and survey links were shared on message boards, with instructors playing an active role in encouraging student engagement. Those students who volunteered took part by completing online consent forms, followed by the survey itself on a designated website.

Measures

The questionnaires were available online and distributed to all participants via email. To ensure cultural appropriateness and linguistic accuracy in assessing students' attitudes toward AI and machine learning, as well as their higher-order skills, the original subscales were translated into Greek. This translation process adhered to the rigorous back-translation method outlined by Behr (2016). Furthermore, a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), was employed to capture the nuances of the students' responses, providing valuable insights into their attitudes toward AI and machine learning technologies.

Academic achievement

An accomplishment examination was employed to gauge the educational achievements of students. To craft the test, an outline aligning objectives with content was devised with input from an external computer science instructor (second evaluator except the main researcher). This evaluative instrument aimed to appraise students' grasp of knowledge, information, materials, underlying principles, concepts, and competencies. This test's content validity was established through the endorsement of three educational science professors and two instructors who specialize in media and information literacy projects. Evaluation of academic achievements was carried out using a rubric developed and validated by Walton (2017) that comprises 13 distinct factors, which include the following: 1. Orientation on research topic, 2. Use of desk research as a research method, 3. Reference list, 4. Quality of primary sources used (books, articles, websites), 5. In-text citations,

6. Creation of new knowledge, 7. Search terms/keywords and 8. Secondary resources used (bibliographic tools, web directories, search engines, etc.).

The instructor of the course performed the assessment. Ratings range from 1 (low) to 5 (highly effective) for each factor, with a total score of 52 points. The rubric's validity coefficient was deemed satisfactory, and it exhibited a strong Cronbach's α value of .813. This indicates that the rubric was a dependable and accurate tool for gauging learning accomplishments. To minimize bias and verify data analysis accuracy, a second rater (computer science instructor) analyzed all data and participated in coding. The primary researcher, alongside an external computer science instructor, evaluated the effectiveness of both content and constructs at each procedural level. The external instructor offered valuable feedback on interpreting results and drawing conclusions from the data analysis. High inter-rater reliability was confirmed through two-way mixed absolute agreement, within-class correlations, and single measures. Any discrepancies were addressed and resolved following the guidelines of Barchard and Pace (2011), resulting in only minimal measurement error.

Machine learning attitude scale

The machine learning attitude scale (MLAS) was employed to elucidate the perspectives held by university students concerning machine learning and underwent validation by Hopcan et al. (2024). The rapid advancement of AI has propelled machine learning technologies to the forefront of technological innovation. Comprehending individuals' perceptions of machine learning is crucial for effectively integrating these tools into various educational settings. To address this need, Lee (2019) developed the Learners' Attitude in Artificial Intelligence Scale (LAIAS), a measurement tool designed to gauge university students' attitudes across diverse academic disciplines. Building upon this work, Hopcan et al. (2021) adapted and validated the LAIAS.

The present study aims to adopt and translate the above questionnaire, ensuring its accuracy and cultural relevance for evaluating university students' attitudes toward machine learning technologies. The scale encompasses thirty-nine items, organized into six distinct sub-dimensions. These items were carefully crafted to elicit insights into participants' attitudes, perspectives, and aspirations related to various aspects of technology, aligning with the specific factors of machine learning attitudes as follows: a) interest in technology (IT): measures participants' innate curiosity and proactive engagement with technology, offering insights into their natural inclination to explore and learn about new advancements (e.g., *"To what extent do you find yourself naturally drawn to exploring and learning about new technological advancements?*"), b) importance and impact of technology (IIT): assess participants' perspectives on the broad societal impacts of technology, this item reveals their awareness of the multifaceted consequences and significance of technological advancements (e.g., *"How would you assess the overall impact of this technology on society, considering aspects such as communication, economy, and education?"*), c) technology-related career paths (TRCP): explores participants' strategic thinking and commitment to meaningful roles within the technology field, providing insights into their long-term career aspirations (e.g., *"Can you describe your long-term career aspirations within the field of technology, and how you envision contributing to advancements in the industry?"*), d) technology and creative activities (TCA): articulates the ways technology intersects with creativity to understand better the symbiotic relationship between technology and creative processes in areas such as art, design, and content creation (e.g., *"In what ways do you believe technology can enhance or influence creative processes in areas such as art, design, or content creation?"*), e) technology and courses (TC): leverages technology in participants' academic pursuits, providing insights into how technology positively impacts their learning experiences (e.g., *"How do you approach integrating technology into your academic pursuits, and how has it positively impacted your learning experiences?"*), and f) gender role of technology (GRT): examines participants' awareness and perspectives on gender dynamics in the technology sector about their critical thinking associated with diversity and their potential contributions (e.g., *"In your opinion, how can we address gender disparities in the technology industry, and what role do you see yourself playing in fostering diversity and inclusion?"*). In terms of reliability, Cronbach's alpha coefficient was computed to be .822, a level deemed acceptable according to the standards provided by Cortina (1993).

Higher-order thinking skills

As conceptualized and validated by Hwang et al. (2018), all questions related to the higher-order thinking scale comprise three core aspects: problem-solving, critical thinking, and creativity. Utilizing the assessment framework, this study employed a questionnaire encompassing eleven items. These items were duly adjusted to align with the specific demands of this research and specifically as follows: a) problem-solving: assess the adeptness to recognize subparts of the main problem, gather pertinent information, and analyze sequentially for its part any proposed solution (e.g., *"I possess the capability to resolve challenges that come my way"*), b) Critical thinking: articulates thoughtful deliberation and rendering of logical judgments (e.g., *"I contemplate various alternatives when confronted with a problem"*), and c) creativity: measures the way that students generate and cultivate ingenious concepts (e.g., *"I am inclined to experiment with new ideas"*). All three dimensions were deemed dependable and valid metrics. The respective Cronbach's alpha (a) coefficients were .833, .842, and .814 for the dimensions of problem-solving, critical thinking, and creativity, respectively.

Reliability and validity

To ascertain the credibility and accuracy of this study's results, both the primary researcher and the computer science instructor utilized multiple data sources to assess the consistency of outcomes obtained from various data collection techniques. To enhance the credibility of data analysis, minimize potential bias, and ensure uniformity and precision in data categorization, an additional evaluator participated in coding and analyzing all the gathered data. This approach adhered to the methodology outlined by Cohen (2013).

Validity and reliability analyses were conducted for each dimension of the questionnaire to assess the suitability of the measurements for this study (Table 1).

Both the main researcher (first evaluator) and an external computer science instructor (second evaluator) meticulously evaluated the efficacy of content and constructs at each phase of the process. The external evaluator, overseeing the experiment, contributed valuable perspectives to interpret the study's outcomes, ensuring the data analysis effectively addressed the research inquiries. To gauge inter-rater reliability, a two-way mixed absolute agreement approach was employed, assessing within-class correlations, and using single measures within a higher range. Any divergences between the assessments of the two evaluators were systematically addressed, with a thorough examination of any instances of data disparities. A slight margin of measurement error was introduced into the coding process to account for potential inconsistencies.

Data collection and analysis

The data that was collected underwent thorough analysis using both SPSS 27.0 and AMOS 24.0 (Jaccard & Turrisi, 2003). The analysis encompassed the application of descriptive statistical measures as well as reliability testing for each variable. Additionally, a comprehensive path analysis was conducted to delve into the potential mediation and moderation effects stemming from higher-order thinking skills related to problem-solving, critical thinking, and creativity. These skills were examined concerning the relationship between academic achievement tests and machine learning. It is worth noting that while the act of performing a path analysis cannot itself establish a causal relationship between variables, it does provide researchers with a means to examine suggested path models,

Table 1 Results of the validity and reliability tests

Variables	Dimensions	Validity	Reliability
Academic achievement	Academic achievement test	.741*	.813
Machine learning attitude scale	MLAS	.712*	.822
Higher-order thinking skills	Problem-solving	.846*	.833
	Critical thinking	.706*	.842
	Creativity	.814*	.814

Note *p<.001.

thereby allowing for the identification of both direct and indirect effects among the variables in question (Streiner, 2005). Furthermore, this study's approach holds significance as it unites the investigation of mediation and moderation effects within a singular analysis, effectively aligning with established theoretical constructs and empirical evidence.

Within the moderation analysis, it is important to highlight that before conducting the assessment, a centering process was applied to all variables to mitigate potential issues related to multicollinearity (Cohen, 2013). Subsequently, through this process, three distinct product terms emerged because of the multiplication between the centered academic achievements score and the centered scores associated with discrete higher-order thinking skills. In terms of estimation, the study opted for a maximum-likelihood approach, supplemented by the utilization of bootstrapping coupled with confidence intervals to assess indirect effects. Throughout the analysis, the designated significance level was set at .05. To examine these overall scores, descriptive statistics (Mean: M; Standard Deviation: SD) were employed.

Results

Descriptive statistics

The statistical details concerning students' academic performance, creativity, problem-solving abilities, critical thinking skills, and attitude toward machine learning attitude are presented in Table 2 to answer H1. It also provides information on the relationships between these variables. The mean score for students' academic achievements was 6.27, signifying a strong perception of academic achievements, whereas problem-solving and critical thinking scores were below 4.00, indicating a lower experience of negative emotions.

To assess multivariate normality, skewness, and kurtosis values were examined. Skewness values ranged from .04 to .41, and kurtosis values ranged from .61 to 1.34. These values were within an acceptable range (skewness < 2.0, kurtosis < 7.0), suggesting no significant concerns regarding multivariate normality (Cohen, 2013). The maximum

Table 2 Descriptive statistics and zero-order correlations of study variables

Variables	M	SD	Skewness	Kurtosis	1	2	3	4
1. Academic achievement test	6.27	.97	.04	-.61	-			
2. MLAS	5.71	2.11	.12	1.34	.34*	-		
3. Problem-solving	3.56	2.04	-.26	1.26	-.37*	-.17	-	
4. Critical thinking	3.62	2.27	-.06	-1.20	-.44	-.77*	.41	-
5. Creativity	4.86	.95	.41	-1.23	.62	.63	-.36	.57*

Note. *p<.05

likelihood estimation method was used for analysis. Positive correlations were observed between students' academic achievements and their attitude toward machine learning (r=.62, p < .01). Furthermore, machine learning attitude correlated positively with problem-solving (r=.63, p<.01), creativity (r=.36, p<.01), and critical thinking (r=.57, p<.01). The researchers examined data for multivariate normality and found no significant concerns. There was a positive correlation between students' academic achievements and their attitude toward machine learning (r=.62, p<.01). A positive attitude toward machine learning was also correlated with problem-solving (r=.63, p<.01), creativity (r=.36, p<.01), and critical thinking (r=.57, p<.01). Overall, this study's results suggest that students who have a positive attitude toward machine learning may be more successful academically and develop stronger problem-solving, creativity, and critical thinking skills.

Path analysis

The suggested model, which accounted for correlations between residuals of mediators and product terms, underwent testing. The decision to permit these correlations was deemed acceptable due to the multiplication of an exogenous variable and mediators. The path model displayed favorable fit indices, excluding x2. Nonetheless, Zheng and Valente (2023) advised the utilization of diverse model fit indicators, such as Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), or Tucker–Lewis Index (TLI), for model assessment, as x2 was overly sensitive to sample size variations. The model fit indices for the path model were x2 (8, n=416) = 28.97, CFI = .97, TLI = .96, RMSEA = .08, indicating satisfactory model fit. The assessed direct path coefficients within the path model were examined (Figure 1).

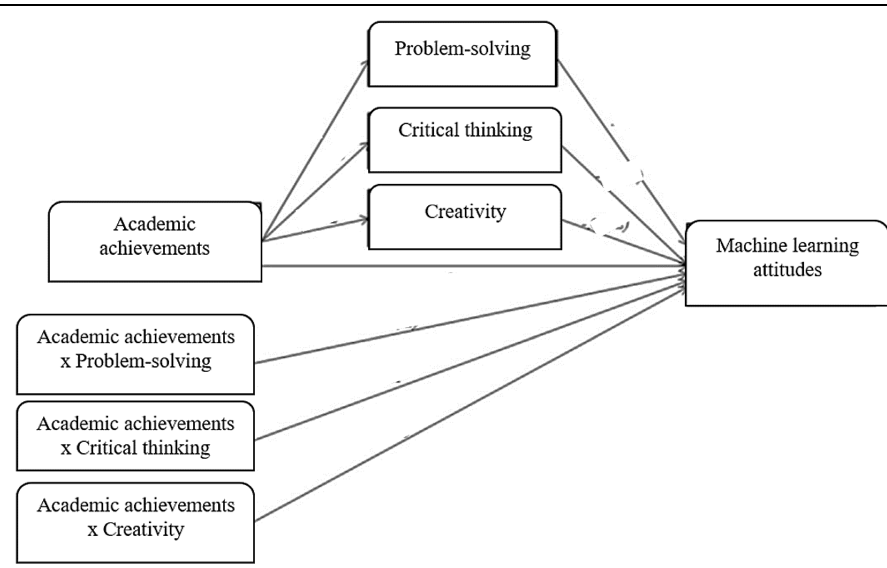

Fig. 1 The proposed path model

Table 3 Path analysis results

Path	B	SE	ß	t
Academic achievements -> Creativity	.38	.06	.33	8.21*
Academic achievements -> Critical thinking	-.48	.08	-.34	-8.19*
Academic achievements -> Problem-solving	-.34	.07	-.28	-8.04*
Academic achievements -> MLAS	.38	.06	.39	9.14*
Creativity -> Machine learning attitude	.29	.07	.33	6.71*
Critical thinking -> MLAS	-.08	.06	-.10	-2.61
Problem-solving -> MLAS	-.08	.06	-.09	-2.71
Academic achievement -> MLAS x Creativity	-.09	.07	-.11	-2.54
Academic achievement -> MLAS x Critical thinking	-.16	.06	-.21	-4.46*
Academic achievement -> MLAS x Problem-solving	-.12	.06	-.13	-3.59*

Note *p<0.001.

As indicated in Table 3, academic achievements positively predicted creativity (B=.38, p<.001) and machine learning (B=.38, p<.001), while negatively predicting critical thinking (B=-.48, p<.001) and problem-solving (B=-.34, p<.001). Furthermore, creativity positively predicted machine learning (B=.29, p<.001), but the association between critical thinking and machine learning lacked significance, as did the link between problem-solving and machine learning attitude.

The interaction of students' academic achievements with critical thinking (B=-.16, p<.001) and academic achievements with problem-solving (B=-.12, p<.05) significantly predicted machine learning. Nevertheless, the interaction of academic achievements with creativity (B=-.09, p=.13) did not reach statistical significance at the .05 level. These findings pointed to the substantial moderating influence of critical thinking and problem-solving in the connection between academic achievements and attitudes toward machine learning (Figure 2).

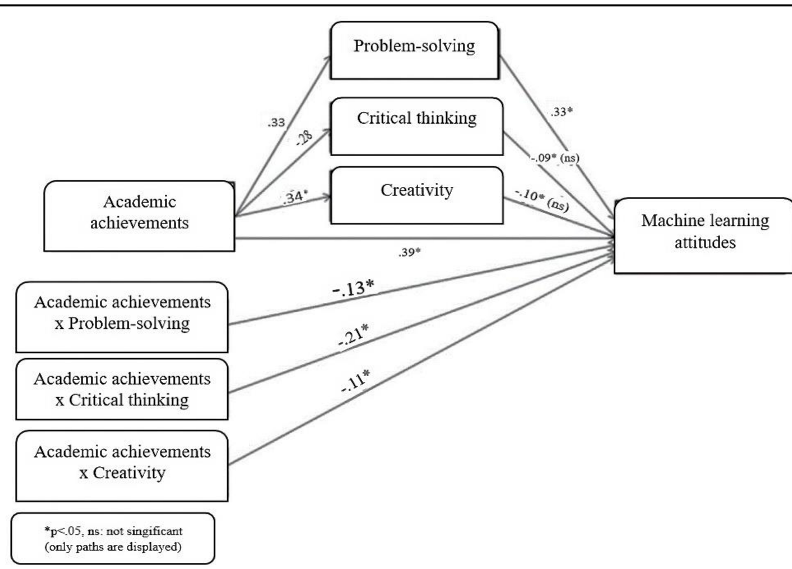

Fig. 2 The direct path coefficients within the path model

The mediating role of higher-order thinking skills was examined by assessing the indirect influence of academic achievements on attitudes toward machine learning to answer H2. Within the path model, academic achievements exhibited both a direct and an indirect impact on attitudes toward machine learning. To estimate and evaluate this indirect effect, a bootstrapping technique was employed, and the resulting bootstrapped 95% confidence interval. The indirect effect of academic achievements on machine learning yielded significance ($B=.16$, $p<.01$), and the 95% confidence interval did not encompass 0 (.12–.24), confirming the substantial nature of the indirect effect. This outcome showed that the academic achievements of students had a notable indirect impact on attitudes toward machine learning, with problem-solving, critical thinking, and creativity serving as mediating factors. Consequently, academic achievements exerted both a direct effect ($B=.38$, ß=.39) and an indirect effect ($B=-.16$, ß=-.21) on attitudes toward machine learning, yielding a cumulative effect size of .50.

Discussion

The present study investigates the role of students' higher-order thinking skills in the relationship between their academic achievements and machine learning attitudes using generative AI chatbots. Academic achievement was significantly and positively associated with machine learning attitude, and students who perceived high academic achievements reported higher degrees of machine learning attitudes than those who perceived lower, even though the relationship between academic achievements and self-regulated learning was moderated by higher-order thinking. This supports the idea that academic achievement is a positive predictor of learners' engagement and performance.

Regarding H1, a significant correlation between academic achievements and higher-order thinking skills can establish a positive relationship between creativity and machine learning. Nevertheless, no substantial connection between critical thinking, problem-solving, and attitude toward machine learning was found. The outcomes of the study draw a heightened focus toward discrete higher-order thinking skills, with creativity revealing a substantial mediating effect and problem-solving, along with critical thinking, emerging as moderators. Academic achievement was significantly and positively associated with machine learning attitudes, and students who perceived high academic achievements reported higher degrees of machine learning attitudes. This stresses the imperative of understanding these specific skills in detail and tailoring implications accordingly. For instance, while both problem-solving and critical thinking are considered pivotal, the guidance for their use in various tasks might diverge. Critical thinking, as another significant skill, can amplify student engagement and involvement in project-based learning when students use generative AI chatbots. Other studies (e.g., Jia & Tu, 2024; Zhai et al., 2024) admitted that students engage in critical thinking not just in the face of excessively challenging tasks but also in scenarios where tasks are not challenging enough. This study's findings revealed that creativity mediated the relationship between academic achievements and attitudes toward machine learning. This implies that students who demonstrate higher levels of creativity tend to have more positive attitudes toward generative AI chatbots (Bansal et al., 2024; Lo, 2023).

The outcomes of this study draw an increased focus toward discrete higher-order thinking skills. With creativity revealing a substantial mediating effect and problem-solving, along with critical thinking, emerging as moderators, it becomes evident that discrete higher-order thinking skills assume distinct roles and effects within the learning process (Baskoro et al., 2023). Although creativity might not have a substantial moderating effect, its robust positive correlation with machine learning cannot be disregarded. This underscores the need for heightened attention to the development of higher-order thinking skills (Baskoro et al., 2023). The indirect effect of academic achievements on machine learning attitudes, mediated by higher-order thinking skills, emerged as significant. Although the study involved three mediators, a separate mediation test was not conducted. Nevertheless, due to the insignificance of the direct paths from critical thinking and problem-solving to machine learning, the results suggest that creativity serves as a crucial mediator. It also suggests a nuanced approach that recognizes the multifaceted nature of these skills and underscores the significance of cultivating them in tandem for a more enriched educational experience.

Regarding H2, the path analysis revealed that critical thinking and problem-solving had a substantial impact on machine learning, while creativity did not wield a noteworthy moderating effect. These findings concurred with previous studies' findings (Chaka, 2022; Jia & Tu, 2024), which indicate that these higher-order aspects restrained the advantages of perceiving high academic control. Additionally, problem-solving, and critical thinking skills did not exhibit mediating effects but showed significant moderating effects in the connection between academic performance and machine learning attitudes. This study's findings are also consistent with Lee et al. (2024), who expressed concerns about potential reductions in cognitive thinking skills due to reliance on generative AI chatbots. The concerns of the same author parallel the findings of this study, indicating that problem-solving and critical thinking do not serve as mediators in shaping attitudes toward machine learning.

However, the findings highlight the moderating effects of higher-order thinking skills on the relationship between academic achievement and attitudes. Creativity assumed a mediating role, while critical thinking and problem-solving adopted a moderating role in the relationship between academic achievements and machine learning attitudes (Jeon et al., 2023). The evidence of these mediating and moderating effects provides a potential explanation for inconclusive relationships observed in previous studies (Lee et al., 2024;

Zhong et al., 2024), highlighting the need for researchers to examine the intertwined dynamics between higher-order thinking and cognition when investigating the impacts of these skills on learning. A crucial point emerges because not only academic achievements but also the various dimensions of higher-order thinking are necessary to foster a positive impact on students' attitudes toward machine learning. Through the lens of moderation analysis, it becomes clear that the relationship between academic achievements and machine learning significantly varies across various levels of critical thinking and problem-solving. Yet, the findings underscore that having a high degree of academic control alone does not suffice to facilitate learning outcomes (Huang et al., 2024; Lee et al., 2024).

Research on the relationship between students' higher-order thinking skills, academic achievements, and attitudes toward machine learning using generative AI chatbots has yielded intriguing findings, shedding light on the nuanced dynamics within this educational landscape. However, a more critical examination is imperative to discern the consequences of these findings in the context of existing literature and to address potential limitations. These are as follows:

- Creativity as a mediator: Existing literature (Jeon et al., 2023; Lee et al., 2024; Putra et al., 2023), raises questions about the generalizability of such mediating effects across diverse student populations and learning environments. Further exploration into the cognitive processes underlying creativity as a mediator is essential for a more comprehensive understanding. The revelation that creativity plays a mediating role in the relationship between academic achievements and attitudes toward machine learning introduces a novel perspective. While this aligns with Lee et al. (2024) concerns about potential reductions in cognitive thinking skills due to reliance on AI chatbots, the current study does not delve into the specifics of how creativity operates as a mediator.
- Moderating effects of critical thinking and problem-solving: The assertion that critical thinking and problem-solving skills exhibit significant moderating effects in the connection between academic performance and machine learning attitudes offers valuable insights. However, the study falls short of providing a deeper exploration of the contextual factors influencing these moderating effects. Contrary to Lu et al.'s (2024) findings, which suggest a constraining role of higher-order aspects on academic control, the current study emphasizes the positive impact of critical thinking and problem-solving. This discrepancy necessitates a critical examination of the contextual factors that may contribute to varying outcomes across studies.
- Distinct roles of higher-order thinking skills: Related literature (Lee et al., 2024; Putra et al., 2023) argued that a comprehensive approach to education requires an understanding of the interplay between different cognitive skills. An exploration

of how these skills complement or conflict with each other could provide a more nuanced understanding of their collective impact on students' machine learning attitudes. The distinct roles for creativity as a mediator and problem-solving and critical thinking as moderators based on this study's findings underscore the multifaceted nature of higher-order thinking skills. Nevertheless, this study does not explicitly address potential interactions or interdependencies among these skills.

- Importance of academic achievements: While the positive association between academic achievements and machine learning attitudes exist, this study could benefit from a critical examination of the potential biases associated with equating academic success with machine learning proficiency. This study recognizes the positive predictive value of academic achievements but falls short of addressing whether these achievements necessarily translate into practical skills in machine learning. Incorporating insights from previous works (Baskoro et al., 2023; Hopcan et al., 2021; Putra et al., 2023) that explored the practical implications of academic success in machine learning contexts could strengthen the discussion.

The results of the present study align with those of prior research (Hopcan et al., 2024; Jeon et al., 2023; Zhai et al., 2024) pertaining to the features of AI chatbots. Specifically, by elucidating their advancements and potentials, these features can influence students' perceptions and higher-order thinking skills, as well as their attitudes toward machine learning and AI technologies. Consistent with prior works (Kong & Yang, 2025; Ogata et al., 2024), the incorporation of interactive AI features not only engages students but also prompts them to think critically about the subject matter. Problem-solving comes into play as they navigate and interact with the content, fostering a creative approach to understanding machine learning concepts.

- Enhanced learning tasks: Improved interactivity encourages inquiry-based or problem-based learning, where students ask questions, investigate, and draw conclusions. This process involves critical thinking, requiring students to analyze information, solve problems, and think creatively to explore and understand complex concepts using machine learning and AI technologies.
- Development of critical thinking: Interaction with AI chatbots promotes the development of critical thinking. Students are challenged to evaluate information, make connections, and draw meaningful conclusions, fostering higher-order cognitive processes essential for both problem-solving and creativity.
- Machine learning and AI-generated learning practices: The practical examples and real-time demonstrations provided by advanced AI chatbots encourage critical thinking. Students need to grasp abstract concepts, solve problems, and

think creatively to understand and apply machine learning principles, demystifying the subject through active cognitive engagement.

- Increased confidence in using AI technologies: Confidence in using technologies arises from the ability to problem-solve and think critically when interacting with advanced AI chatbots. Understanding machine learning algorithms enhances creativity in navigating and utilizing technology effectively, reflecting higher-order cognitive processes.

Conclusion

This cross-sectional study empirically examines how higher-order thinking skills—such as problem-solving, critical thinking, and creativity—mediate and moderate the relationship between academic achievement and students' attitudes toward machine learning, particularly through the use of generative AI chatbots. The findings contribute to a comprehensive insight of how specific cognitive skills influence learning outcomes in the context of advanced technological tools. Previous research (Jia & Tu, 2024; Zhai et al., 2024) has often emphasized the importance of critical thinking and problem-solving in educational success, whereas this study uniquely highlights creativity as a crucial mediator in shaping positive attitudes toward machine learning. This study's finding aligns with Hopcan et al. (2024) and Lu et al. (2024), who also recognized creativity's importance in AI-supported education. Moreover, this study also extends the work of Baskoro et al. (2023) by demonstrating how distinct higher-order thinking skills contribute differently to learning outcomes.

Unlike Putra et al. (2023), who suggested higher-order aspects might constrain academic control, this research stresses their enhancing role, particularly in fostering positive machine learning attitudes. Specifically, path analysis, addressing H1, revealed a significant positive correlation between academic achievement and higher-order thinking skills. Notably, creativity emerged as a mediator, meaning it strengthens the connection between academic achievement and positive attitudes toward machine learning. Conversely, critical thinking and problem-solving skills acted as moderators, influencing the strength of this relationship. This aligns with the idea that academic achievement is a positive predictor of student engagement and performance in machine learning tasks. The results demonstrated that creativity acts as a substantial mediator. In other words, students with higher levels of creativity tend to have more positive attitudes toward machine learning and the use of AI chatbots. Interestingly, critical thinking and problem-solving skills, while not directly mediating the relationship, exhibited significant moderating effects. This suggests that these skills are crucial for enhancing the positive association between academic achievement and attitudes toward machine learning.

Finally, in response to H2, the study further examined the distinct roles of these skills. The findings confirmed the robust mediating effect of creativity and the moderating effects of critical thinking and problem-solving on the relationship between academic achievement and machine learning attitudes. By examining the mediating and moderating roles of higher-order thinking skills in the relationship between academic achievements and machine learning attitudes, this study provides a valuable perspective that complements the existing literature's focus on potential benefits and challenges.

Implications

The implications of this study's findings extend to different instructional settings, suggesting ways in which fostering higher-order cognitive skills can enhance students' attitudes toward AI and machine learning technologies. First, the crucial role of creative thinking in bridging academic achievements and the acceptance of machine learning technologies is crucial. Encouraging creative exploration can positively impact students' attitudes toward these technologies. Second, the distinct moderating effects of problem-solving and critical thinking accentuate their potential in shaping how academic achievements translate into attitudes toward machine learning. The discussion of this study's findings could delve deeper into the implications of the results. More details on the theoretical and practical implications in education are as follows:

A. Theoretical implications:

- Identifying the distinct roles of higher-order thinking skills: The study highlights the distinct roles that creativity, critical thinking, and problem-solving play in the learning process. This differentiation adds depth to cognitive theory in education, suggesting that these skills interact with academic achievements and attitudes toward technology in unique ways.
- Incorporating mediating and moderating effects: The findings support the refinement of existing educational models to account for the mediating role of creativity and the moderating effects of critical thinking and problem-solving. This nuanced understanding can help develop more effective educational interventions and assessment tools.

B. Practical implications:

- Integration of creativity: The findings suggest that fostering creativity can enhance students' attitudes toward machine learning and generative AI chatbots. Educational programs should incorporate activities that stimulate creative thinking, such as project-based learning and open-ended assignments, to maximize student engagement and positive perceptions of technology. This personalized approach can cater to diverse learning needs, enhancing overall educational outcomes.

- Targeted skill development: While creativity emerged as a significant mediator, critical thinking, and problem-solving played crucial moderating roles. Educators should design curricula that specifically target these skills, integrating AI chatbots as tools to challenge students' problem-solving and critical thinking abilities through real-time feedback and complex scenario simulations. AI chatbots can be used to create personalized learning environments that adapt to individual students' creative, critical thinking, and problem-solving strengths and weaknesses.

Additionally, the potential reasons behind the non-significant findings for problem-solving and critical thinking as mediators should be discussed more thoroughly, considering contextual or methodological factors below.

1. Contextual factors:
    - Task complexity: The nature and complexity of tasks assigned during this study may have influenced the results. For instance, if the tasks were not sufficiently challenging, students might not have had the opportunity to fully utilize their problem-solving and critical thinking skills. Future research should consider varying task difficulty to better capture the influence of these skills.
    - Learning environment: The AI-supported learning environment and context, such as the availability of resources, instructor support, and peer interactions, might have affected the students' ability to engage in problem-solving and critical thinking. Differences in these contextual factors could explain the non-significant mediating effects observed.
2. Methodological factors:
    - Measurement tools: The tools and methods used to assess problem-solving and critical thinking might not have been sensitive enough to detect their mediating effects. Ensuring the use of validated and reliable instruments in future studies could provide more accurate insights.
    - Duration and frequency of interactions: The duration and frequency of students' interactions with AI chatbots may not have been sufficient to develop and measure the full extent of their problem-solving and critical thinking skills. Longer-term studies with more frequent interactions could yield different results.

Despite this study highlights the significant role of creativity in mediating the relationship between academic achievements and attitudes toward machine learning, it also points to the need for a deeper exploration of the non-significant findings for problem-solving and critical thinking. This expanded understanding will be crucial for developing more effective educational strategies and technologies that harness the full potential of these cognitive skills.

Limitations and future research directions

This study has several limitations. It focuses on Greek undergraduate students, limiting generalizability to other groups. The reliance on self-reported data may introduce response bias, and the cross-sectional design restricts causal inferences. This study is limited by the fact that all participants had prior experience with generative AI chatbots from previous projects, potentially introducing bias. Additionally, the mediating and moderating effects observed, whereas noteworthy, could be influenced by unaccounted contextual or individual variables. While efforts were made to control external variables, unexplored factors could still influence the observed relationships. Lastly, this study's findings might be sensitive to the specific instructional settings, which may impact the transferability of the results to different educational environments.

This study's limitations suggest several pathways for future research. Longitudinal studies could track how student attitudes toward machine learning evolve over time. Qualitative methods like interviews or focus groups could delve deeper into students' cognitive processes and motivations. Finally, research on AI-supported interventions targeting higher-order thinking skills could offer practical strategies for online and blended learning environments.

Abbreviations

AI: Artificial Intelligence; CFI: Comparative Fit Index; GDPR: General Data Protection Regulation; GPT: Generative Pre-trained Transformer; H1: Hypothesis1; H2: Hypothesis2; IP: Internet Protocol; LAIAS: Learners' Attitude in Artificial Intelligence Scale; MLAS: Machine Learning Attitude Scale; NLP: Natural Language Processing; LLMs: Large Language Models; RMSEA: Root Mean Square Error of Approximation; SEM: Structural Equation Modeling; TLI: Tucker–Lewis Index.

Endnotes

[1] OpenAI's ChatGPT: https://chat.openai.com/auth/login

[2] Google's Gemini: https://gemini.google.com/app

[3] Perplexity: https://www.perplexity.ai/

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Author's contributions

The author is responsible for the whole manuscript. The author read and approved the final manuscript.

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Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests
The author declares no competing interests.

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