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The Impact of Artificial Intelligence-Supported Learning on Metacognitive Awareness and Critical Thinking Skills in Education: The Mediating Effect of Self-Regulated Learning

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ABSTRACT

This study examined the impact of Artificial Intelligence-supported learning on students' metacognitive awareness and critical thinking skills, with particular emphasis on the mediating role of self-regulated learning. A quantitative, cross-sectional research design was adopted, and data were collected from 487 university students from higher-education institutions in Punjab and Sindh, Pakistan. Data were collected through a structured, adopted questionnaire administered online using Google Forms, and the completed responses were transferred to Microsoft Excel for initial organization before being analyzed using IBM SPSS. The study measured Artificial Intelligence-supported learning, self-regulated learning, metacognitive awareness, and critical thinking skills using established and adapted measurement scales. The findings demonstrated significant positive relationships between Artificial Intelligence-supported learning and self-regulated learning, metacognitive awareness, and critical thinking skills. The results further showed that Artificial Intelligence-supported learning significantly predicted the three major learning constructs, while self-regulated learning significantly predicted metacognitive awareness and critical thinking skills. Mediation analysis further indicated that self-regulated learning played a significant partial mediating role in the relationships between Artificial Intelligence-supported learning and both metacognitive awareness and critical thinking skills. The study concluded that the educational value of Artificial Intelligence was enhanced when students actively regulated, monitored, and evaluated their learning rather than relying passively on AI-generated support. The study contributes to the emerging literature on AI-supported education by providing an integrated perspective on the cognitive mechanisms through which AI-supported learning may contribute to higher-order learning outcomes.

Introduction

Artificial Intelligence-Supported Learning in Education

AI has introduced new ways of supporting modern education. It helps students find information, communicate with learning resources, receive quick feedback, and manage information more effectively. These changes have made the learning process more flexible and accessible for students. Technologies such as intelligent tutoring systems and adaptive learning platforms combined with other agents of AI are currently able to provide users with instant formative feedback, personalized explanations, automatically generated scaffolds, and engaging interfaces for problem-solving. This makes AI more and more integrated into education because it is now more than just an information source (Achuthan, 2025).

AI provides students with alternative explanations and viewpoints as well as the opportunity to reflect and assess their own understanding and reasoning. Many studies show that AI technologies have the potential to enhance the learner's cognitive and metacognitive processes and self-control, or self-regulation within the learning context. The learning activity and system design have to be considered when using AI technology.AI should be designed to critically engage students and cultivate independent thinking and cognitive involvement. Educational outcomes, and their correlation with AI, are building on the psychological and learning processes students interact with when prompted by AI technologies, as well as the availability of the technology itself (Tezer, 2025).

Metacognitive Awareness

Metacognitive awareness is the ability to recognize and control different aspects of the thinking and learning process. With this ability, students can identify the gaps they have, the strategies they ought to apply to fill the gaps, how far they have understood a given context, and how worthwhile their efforts were in the process of learning. Metacognitive awareness is needed now more than ever as learners must evaluate the information they come across from AI and determine its trustworthiness (Schraw, 2001).

Students with good metacognitive awareness can easily identify gaps and evaluate how well several alternatives explain a certain occurrence and if further justification and/or evidence is needed. Research has shown that good metacognitive awareness is closely linked to critical thinking and is, therefore, trainable through focused reflection and academic assistance. Activities linked to the processes of planning, monitoring, evaluation, and adjustment can develop learners' metacognitive skills (Jaleel, 2016).

With the use of AI in education, the processes mentioned above are even more valuable when learners are required to justify and reflect on AI-generated information and not simply adopt the information as given. AI-supported learning also has the ability to offer automated assessments and inform students about the areas they need to monitor. One such methodology is presenting learners with a question and the opportunity to explain their answer, compare several alternative solutions, identify errors, or reconsider their assumptions. There is a potential positive impact on learners' abilities to control their learning process (Kallio et al., 2018).

Critical Thinking Skills

Critical thinking is the ability to make judgements that are intentional, rational, purposeful, reflective and evidence based. Alsaleh (2020) describes dimensions of critical thinking that include interpretation, analysis, evaluation, and inference. In the context of higher learning, these dimensions allow a learner to assess evidence, determine assumptions, evaluate a given an argument, draw logical conclusions, give justifications for their reasoning, and revise their judgments based on the evidence. Thus, critical thinking goes beyond memorization due to the involvement of the active engagement with complex issues and contradictory views.

The increasing use of AI supported tools in learning has made critical thinking a necessary element of higher education Learning, given students' ability to easily obtain answers, explanations, summaries, and arguments from AI systems. Although AI systems have the potential to aid learning, students can simply take answers, explanations, etc., that the systems generate, without critically assessing their validity. Critical thinking supports the use of AI in learning as students still bear the responsibility of evaluating information and thinking for themselves in spite of AI. Especially in situations where students are required to evaluate and interpret outputs by AI systems in order to verify and explain evidence, justify answers, critique the responses, and compare/contrast/ make alternative responses and interpretations (Cottrell, 2017).

Critical thinking also relates to metacognition and self-regulated learning, all of which involve monitoring, reflection and evaluation to some extent, but do not depend on the judgment of others. In most active learning scenarios, students monitor their level of understanding, evaluate the evidence and strategies used, and are likely to revise their judgments. Thus, AI-supported learning may

be likely to promote self-regulated learning and critical thinking only when it is designed to be a deep learning process, rather than simply an answer-generating tool, while self-regulated learning supports the active engagement with and critical evaluation of AI-supported learning (Butterworth & Thwaites, 2013).

Self-Regulated Learning

Self-regulated learning (SRL) is when students are active participants in the cognitive, motivational, and behavioral aspects and learning environment in order to accomplish academic goals. Zimmerman and Schunk (2011) defines self-regulated students as participants that employ strategies for control and monitoring of their learning. SRL involves goals and their subsequent planning, strategies, and the management of effort, seeking help, controlling, evaluating performance, and modifying learning strategies (Zimmerman, 2002).

The importance of SRL has increased in technology and AI-assisted learning because students assume more control and autonomy regarding their learning. AI opens the possibility for students to receive personalized support via feedback, reminders, explanations, suggestions, and processing/reflective activities. Furthermore, in the absence of student control, autonomous learning support relies on AI with the goal of enhancing metacognitive, cognitive, and behavioral regulation. Torrano Montalvo and González Torres (2004) supports these efforts with positive learning outcomes based on an SRL-grounded AI intervention. Without student control, reliance on AI will decrease students' self-regulated learning and increase cognitive offloading.

Self-regulated learning is also closely related to metacognitive awareness because one must be metacognitively aware in order to understand, monitor, and manage cognitive processes. Metacognitive awareness describes cognitive and task awareness, and self-regulated learning can be employed to regulate cognitive processes and learning to achieve goals. Thus, metacognition requires the self-regulated learning of cognitive control (Flavell, 1979; Zimmerman, 2002).

Mediating Role of Self-Regulated Learning

The role of self-regulated learning can explain how Artificial Intelligence (AI) assisted learning can change student's metacognitive awareness and critical thinking. Several AI assisted learning technologies such as personalized feedback, adaptive assistance, and explanations can be used to scaffold students' self-regulation through planning, monitoring, and evaluating their learning; and, where necessary, change their learning activities. These technologies may support students' self-regulation and offer a framework for deliberating their cognition and meta critically engaging in reasoning. As described in social-cognitive models, viewing learning as a process of constant evaluation and adjustment can be the focus of self-regulated learning (Yeh et al., 2019).

The relationship between self-regulated learning and the mediation of metacognition and critical thinking further supports the role of self-regulated learning. Students who use AI to set learning goals, monitor AI understanding, evaluate AI-generated information, and revise their strategies may strengthen their self-regulation. As students' self-regulation strengthens, their metacognitive awareness deepens with the understanding of the process of learning. It further develops students' critical thinking by asking them to reflect and provide evidence-based judgment through self-regulated learning (Shamla & Jayan, 2025).

When AI-based learning technologies are considered in the light of change to self-regulated learning and metacognition and critical thinking, a new perspective is offered to consider AI assisted learning technologies. This perspective considers the cognitive process in self-regulated metacognition. While many studies explore AI, self-regulation, metacognition, and critical thinking, the mediation of the self-regulated learning process is still relatively understudied.

Research Objectives

1. To examine the impact of Artificial Intelligence-supported learning on students' metacognitive awareness and critical thinking skills.
2. To assess the relationship between Artificial Intelligence-supported learning and self-regulated learning among students.
3. To determine the mediating effect of self-regulated learning on the relationships between Artificial Intelligence-supported learning, metacognitive awareness, and critical thinking skills.

Problem Statement

AI has become an important part of education by helping students learn in ways that match their individual needs. It can provide personalized learning activities, give feedback, and offer support throughout the learning process. However, it is still not fully

understood how AI affects students' learning and their ability to develop advanced thinking and problem-solving skills. More research is needed to better understand its impact (Ertan & Esfer, 2026).

It is observed that AI may facilitate some processes of self-regulated learning (SRL) and may be integrated with SRL and other cognitive processes within a single framework. This, however, may not provide sufficient clues on how AI-based learning impacts metacognitive skills and the development of critical thinking. This is of much interest since AI may be used (a) as a cognitive tool to enhance active monitoring and reflection and (b) would likely automate and replace the need for learning with minimal or no support.

Significance of the Study

This study examines how teaching and learning technologies supported by AI have the potential to develop students' critical thinking skills and metacognition through self-regulated learning. From a theoretical point of view, the study brings together the following elements: self-regulated learning; AI-based learning; critical thinking and metacognitive awareness. This study provides a plan to faculty and organizations on how to use AI to design self-regulated learning environments. The study also argues the importance of self-regulation and responsible teaching within AI-based learning to enhance the positive impact on students' learning.

Literature Review

AI-based adaptive learning technology is considered one of the most important developments in modern education. It helps students learn according to their individual needs, abilities, and learning pace, making the learning process more effective and engaging.

Automated feedback, learning analytics, chatbots, intelligent tutoring systems, adaptive learning technology, and AI-powered generative models help students learn in a flexible, adaptable, and underexposed manner. AI is also integrated within the instructional process providing the means to assess, predict, tutor, personalize, and frame learning pathways at different levels and across diverse subject matters. Personalization and scaffolding of learning is the prime force behind the perceived pedagogical value of AI (Crompton & Burke, 2023).

AI-based learning technology is as useful as the manner in which students interact with the technology and the pedagogical strategies deployed. AI systems can scaffold learners by providing feedback, alternative explanations, identifying errors, and prompting learners to reflect. However, excessive reliance is likely to result in cognitive reliance and reduced self-efficacy including evaluation of the information. For this reason, several studies have documented the goal conflict between technological assistance and the agency of the learner (Lu et al., 2022).

AI-based learning technologies are best understood in terms of the cognitive and behavioral processes of the students and need to go beyond the description of the technologies adopted. Banihashem et al. (2025) outline the gap in theory, methodology, and the understanding of the mechanisms of AI and regulated learning.

This suggests that examining AI-supported learning could be useful in understanding whether or not AI supports students in cognitive engagement beyond simply providing students with quicker access to facts.

Metacognitive Awareness in Education

Metacognition refers to the student's ability to know about and manage their cognitive processes during learning. Srivastava et al. (2017) laid the groundwork for metacognition through cognition and the monitoring of cognitive processes. In the field of education, metacognitive awareness helps students identify where they are struggling, select the correct strategies, and assess how well they are learning hence relating it to deep or extensive learning. In deep learning, the importance of this metacognitive awareness has raised its importance in deep learning in technology-infused and AI-dominated classrooms. Herein, students are required to evaluate the quality of information generated by AI and digital systems. AI may give an answer without providing the reasoning nor the justification (Romdhoni & Romdhoni, 2026). Because of this, learners have to evaluate the explanations generated by AI.

Metacognitive awareness can improve when students are encouraged to plan, monitor, and evaluate their learning activities. AI-supported learning can help in this process by asking students to explain their reasoning, evaluate their own and others' solutions, identify weaknesses in their answers, and judge the quality of explanations provided by AI (Tuononen et al., 2023).

AI should not be an answer-generating tool, but a cognitive scaffold on students' monitoring of their own understanding and learning. Limitations of existing studies have highlighted the integration of theory and methods for studying metacognitive processes and self-regulated learning with the support of AI (Ihor & Ruslana, 2021).

Metacognitive awareness and self-regulated learning are closely connected. Students need to understand how they think and learn in order to effectively monitor their progress, identify difficulties, and make changes to improve their learning.

Metacognitive awareness helps you recognize situations and students that necessitate the deployment of certain learning strategies. Self-regulated learning converts this awareness to action by planning, execution, monitoring, and reviewing the learning process. As a result, metacognition is an integral component of self-regulation, while SRL stands for the entire process that teaching and learning stakeholders utilize to manage their learning processes.

Critical Thinking Skills in Education

Critical thinking involves important skills such as understanding information, analyzing ideas, evaluating evidence, making logical conclusions, explaining decisions, and reflecting on one's own thinking. Pithers and Soden (2000) describes critical thinking in a similar way. He says it is a purposeful self-regulatory judgment that allows students to analyze evidence, evaluate arguments, solve complex problems, and draw evidence-based conclusions. The importance of critical thinking is even greater now with the development of generative AI. Generative AI helps students receive complex responses with a lot of cognitive load. The evaluation of information generated by AI is now more important than ever. AI can provide alternative approaches to providing explanations, but it can also promote an uncritical acceptance of information. Therefore, AI literacy, prompt engineering, critical thinking, and human agency will all become more interdependent (McPeck, 2016).

Critical thinking can be enhanced by AI in learning situations where students are required to critique, verify, compare, and enhance AI generated content instead of just accepting its responses. Activities in which students verify claims, compare alternative explanations, and justify their conclusions, as well as identify weaknesses, encourage interpretation, analysis, evaluation, inference, and self-regulation (Chaffee, 1992). The study of critical thinking in the context of AI is still a developing field, mainly because of the emphasis of previous research on the acceptance, engagement, and achievement of technology in learning situations, as well as the overall efficiency of learning. The effects of critical thinking in learning situations may be different based on pedagogical design, self-regulated learning, and the reliance on automated outputs provided by various types of AI. Critical thinking and self-regulated learning are also connected from a theoretical perspective because both require self-regulation and evaluation of one's cognitive activities. The common processes of monitoring, evaluation, reflection, and self-correction offer a framework to expect that students who are actively regulating their learning are possibly more capable of engaging in complex and responsible reasoning, as proposed in the integration of Palavan (2020) frameworks on self-regulated learning and critical thinking, respectively.

Self-Regulated Learning

Self-Regulated Learning (SRL) refers to an individual's active engagement when planning, controlling and monitoring their motivation, behavior, thoughts and learning activities. Zimmerman (2002) defined SRL as a continuous process including forethought, performance, and self-reflection phases. In this continuous process, the student sets goals and develops strategies. They activate these strategies and monitor progress, and lastly, they review and make changes to the strategies based on the results. This definition can be applied to the integration of AI in learning because AI can potentially provide different types of support throughout the learning cycle. Some research studies show that different types of AI, such as chatbots, intelligent tutoring systems, adaptive feedback systems, serious games, e-textbooks, and intelligent tutoring systems, can support different stages of SRL (Banihashem et al., 2025).

More recent studies report that self-regulated and self-directed learning can be enhanced with the help of AI-based technologies, but that support from AI systems does not ensure that students regulate and adjust their actions accordingly. Therefore, if AI systems plan, monitor, evaluate or make decisions for the students, it may reduce students' self-regulatory activity. Thus, when thinking of AI-based SRL technologies, AI should provide appropriate support, and students should retain control (Beishuizen & Steffens, 2011). Therefore, AI can assist learners in the goal-directed phase of forethought, provide constructive feedback with adaptive explanations in the performance phase, and assist review and reflection in the self-reflection phase.

AI can assist all three stages of learning, but how effectively it can do so will depend on how it is designed and how much participants will be involved. Studying self-regulated learning (SRL) as a mediating variable may help answer whether AI assists learners in engaging in their learning regulatory processes or if it helps learners to bypass such regulatory processes.

Mediating Role of Self-Regulated Learning

According to the mediating role of self-regulated learning (SRL), it is possible that metacognitive awareness and critical thinking will be impacted by AI-enabled learning indirectly due to the positive effect of AI on the regulation of learning. Examples of tools built upon AI can include systems that provide feedback, planning, monitoring, reflection, and adjustment of learning strategies. It is possible for students to actively engage with these tools, and thus, AI may potentially strengthen SRL. In addition, if students are able to regulate their learning more effectively, they would likely be more aware of their cognition and more able to engage in critical reasoning. AI-based learning thus has the potential to impact our understanding of higher-order learning in a positive manner (Follmer & Sperling, 2016).

Supporting components of this pathway is also evident. Several studies show how various phases of SRL can be supported by AI. In addition, the role of AI in SRL is a new and developing field that has gained interest in recent years. AI-based systems can present students with several alternative explanations. However, critical thinking will only be impacted through engagement with these resources if students regulate their thinking by evaluating the evidence and revising their thinking. In this way, SRL perhaps has the ability to convert AI assistance into active engagement of learners' cognition. This theory proposes a mediation pathway in the context of AI-based learning. Advancing this theory may provide opportunities to fill existing research gaps.

Research Gap

Although Artificial Intelligence can support self-regulated learning through personalization, adaptive feedback, intelligent tutoring, and learning assistance, the specific cognitive mechanisms linking AI-supported learning with students' metacognitive awareness and critical thinking remain insufficiently understood. Recent reviews show rapid growth in AI–self-regulated learning research but limited development of integrated models explaining how AI-supported learning translates into higher-order cognitive outcomes. Evidence also suggests that AI-driven learning analytics may support metacognitive and self-regulatory processes, while concerns remain regarding AI dependence and the preservation of independent evaluation and reasoning (Feroze & Mangnejo, 2026). Although explicit metacognitive support has shown potential to strengthen self-regulated learning in generative-AI environments, the mediating role of self-regulated learning between AI-supported learning and both metacognitive awareness and critical thinking remains insufficiently examined within a unified framework (Xu & Liu, 2025). Therefore, the key research gap concerns understanding how AI-supported learning influences metacognitive awareness and critical thinking through students' self-regulated learning processes.

Hypotheses

H1a: There is a significant positive relationship between Artificial Intelligence-supported learning and students' metacognitive awareness.

H2a: Artificial Intelligence-supported learning significantly predicts students' metacognitive awareness.

H3: There is a significant difference between male and female students in their levels of Artificial Intelligence-supported learning, self-regulated learning, metacognitive awareness, and critical thinking skills.

H4: There are significant differences in Artificial Intelligence-supported learning, self-regulated learning, metacognitive awareness, and critical thinking skills across different demographic groups.

H5a: Self-regulated learning significantly mediates the relationship between Artificial Intelligence-supported learning and metacognitive awareness.

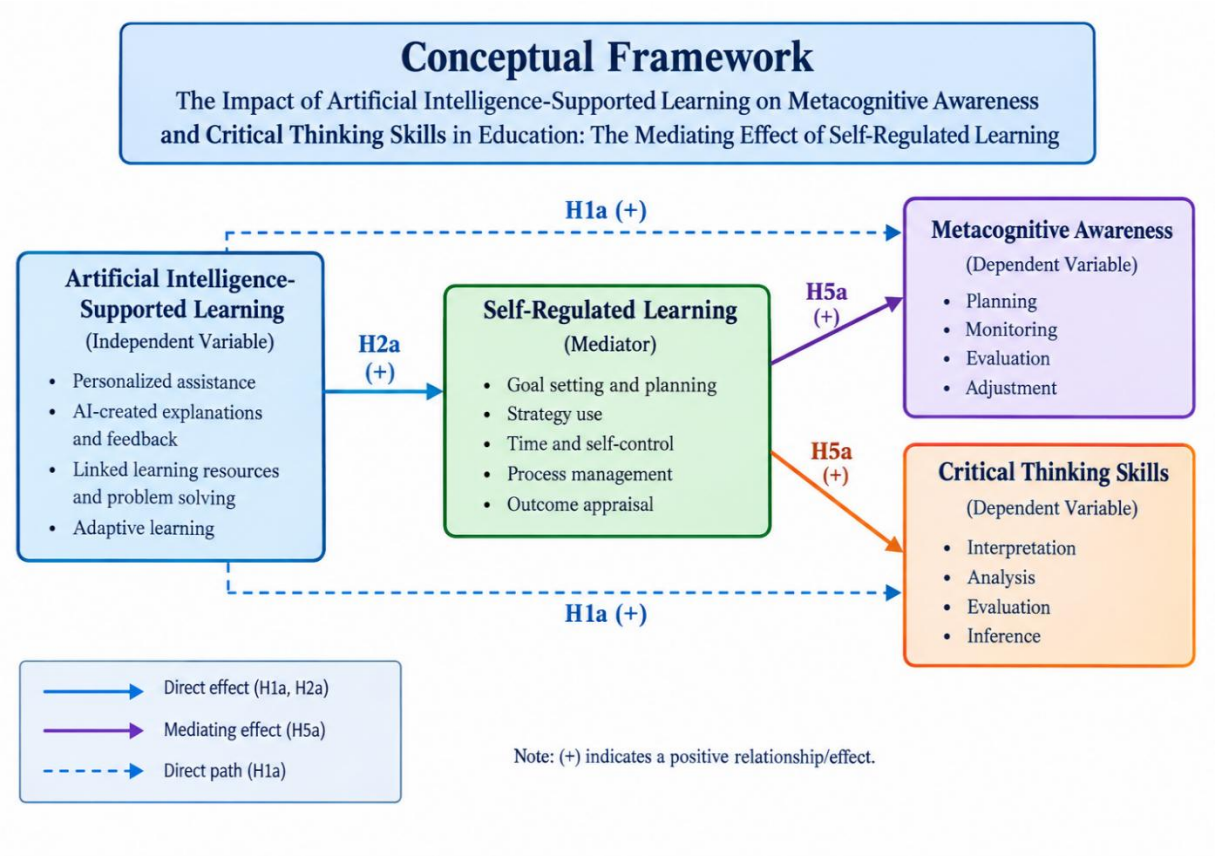

Fig.1 Conceptual Framework

Methodology

Research Design

This study used a quantitative research design to analyze Artificial Intelligence (AI)-augmented learning, self-regulated learning, metacognitive awareness, and critical thinking using quantitative data. A cross-sectional survey design was used. Data were collected from students using a structured tool at one specific point in time. The tool was developed using previously employed and validated measurement tools and was modified for Artificial Intelligence-augmented learning. The quantitative approach was appropriate for this study, as the researcher wanted to identify the strength and direction of the relationships between the study variables and also define the relationships of aggregation and mediation among them.

Population

This study included university or higher education students in Punjab and Sindh, Pakistan. Respondents were drawn from major education centers such as Multan, Lahore, Faisalabad, Rawalpindi, Karachi, Hyderabad and Jamshoro, covering diverse educational and institutional backgrounds. This study included students from Bahauddin Zakariya University, The Women University Multan, Nishtar Medical University, University of the Punjab, Government College University Lahore, University of Lahore, University of Karachi, and University of Sindh. The sampling population was drawn from students of higher education institutions because they are the most likely to be exposed to contemporary AI-based learning environments, and therefore AI-supported learning, self-regulated learning, metacognitive awareness, and critical thinking can be studied for this population.

Target Audience

University students in both undergraduate and postgraduate studies in Punjab and Sindh, Pakistan were the focus of this study. To understand how artificial intelligence (AI)-aided learning impacts students with varying levels of experience, students from all

fields were included in this study. These students had experience with educational technologies containing AI and generative AI, as well as AI-based learning and tutoring systems, AI-based feedback systems, and other AI-based educational tools. Males and females were included in the study to better represent the student population.

Sampling Techniques

Participants in this study included university students from among those who had experience with AI-supported learning. Purposive sampling, a non-probability sampling approach, was applied. Participants from across academic disciplines, levels of education, gender groups, and geographical areas Sindh and Punjab were selected through online means including academic networks, student groups, and online communication. Participation was voluntary and informed consent was obtained.

Sample Size

A total of 487 valid questionnaires were collected for this study. The participants were university students from Punjab and Sindh, Pakistan, representing different levels of higher education.

Data Collection

A self-reported, structured, Likert-based instrument was used to capture information. This instrument was adapted from previously developed validated instruments measuring the concepts of AI-supported learning, self-regulated learning, awareness, and critical thinking.

AI-supported learning focused on personalized assistance, AI-created explanations and feedback, linked learning resources and problem solving, and adaptive learning. Self-regulated learning (SRL) focused on self-regulation of strategy formulation, goal-directed efforts, time and self-control, process management, and outcome appraisal based on the literature of SRL. Metacognitive awareness was evaluated by the Metacognitive Awareness Inventory (MAI), while critical thinking was evaluated by components of analysis, evaluation, and inference as articulated and California Critical Thinking Skills Test. The instruments were administered to eligible students of higher education institutions in Punjab and Sindh through email and various student information groups. Volunteers completed the data collection form, and the data was exported to Microsoft Excel for screening and participant record arrange. Select items were reviewed for clarity and adjusted to better fit the Pakistani higher education context.

Data Analysis

The data that was collected in Google Forms was exported after screening into Microsoft Excel and then imported into IBM SPSS Statistics to be analyzed. Descriptive statistics, including the mean and standard deviation, were used to examine the demographic and study variables. Internal consistency of the measurement instruments was assessed by Cronbach's alpha. The relationships of the variables on AI-supported learning, self-regulated learning, metacognitive awareness, and critical thinking were assessed by Pearson product-moment correlation. Multiple linear regression was used to assess the same variables and their predictive capabilities. Independent-samples t-tests were used to examine the differences between the two demographic groups and one-way ANOVA analysis was used with a Tukey HSD post-hoc test when evaluating three or more demographic groups.

This last analysis used mediation with bootstrapping to see if self-regulated learning mediated the relationships between AI-supported learning, metacognitive awareness, and critical thinking. These analyses were done in SPSS, and the significance level for all analyses was set at $p < 0.05$.

Table 1: Demographic Characteristics of Respondents (N = 487)

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	263	54.0
	Female	224	46.0
Age	18–22 years	178	36.6
	23–27 years	174	35.7
	28–32 years	86	17.7
	33 years and above	49	10.1

Demographic Variable	Category	Frequency (n)	Percentage (%)
Educational Level	Undergraduate	286	58.7
	Master's	137	28.1
	MPhil/MS	48	9.9
	PhD	16	3.3
Province	Punjab	286	58.7
	Sindh	201	41.3
Academic Discipline	Social Sciences	112	23.0
	Computer Science/IT	103	21.1
	Business/Management	91	18.7
	Education	78	16.0
	Health Sciences	63	12.9
	Engineering	40	8.2

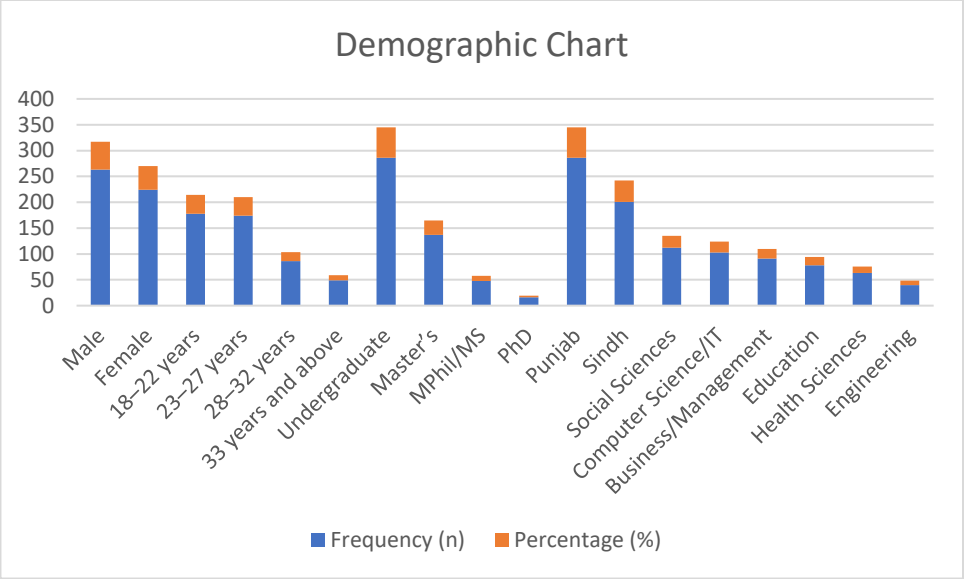

Fig.2 Demographic Characteristics of Respondents (N=487)

The results verified the study sample included 487 respondents, with 263 (54.0%) male respondents and 224 (46.0%) female respondents. In terms of age, the sample included the greatest number (n = 175) or 36.6% respondents between the ages of 18 and 22. This was followed by respondents age 23 to 27 (n = 166, 35.7%) and respondents age 28 to 32 (n = 88, 17.7%). The sample also included respondents age 33 and older (n = 51, 10.1%). With respect to educational level, Bachelor's students (654, 54.7%) comprised the predominant group, followed by Master's students (553, 28.1%), MPhil/MS students (n = 47, 9.9%), and PhD students (n = 15, 3.3%). Of the sample, 58.7% were from Punjab, while 41.3% were from Sindh. With respect to academic discipline, the Social Sciences (n = 108, 23.0%) and Computer (IT) Sciences (n = 103, 21.1%) Clusters accounted for the greater number of respondents, followed by the Business/Management (n = 90, 18.7%) and Education (n = 77, 16.0%) clusters, the Health Science (n = 63, 12.9%) cluster, and the Engineering (n = 38, 8.2%) cluster. All clusters of the sample were diverse in their demographic, educational, geographic, and academic dimensions.

Table 2: Reliability Statistics and Descriptive Statistics of Study Variables (N = 487)

Variables	No. of Items	Cronbach's Alpha (α)	Mean	Std. Deviation
Artificial Intelligence-Supported Learning	10	0.914	3.78	0.61
Self-Regulated Learning	12	0.902	3.71	0.58
Metacognitive Awareness	10	0.895	3.76	0.56
Critical Thinking Skills	10	0.908	3.69	0.60
Overall Scale	**42**	**0.938**	**3.74**	**0.47**

The results of the reliability assessment indicated that all study variables demonstrated high internal consistency. The values for Cronbach's alpha were in the range of from 0.895 to 0.914, while the overall scale showed an alpha value of 0.938. Mean scores were in the range of 3.69 to 3.78, and indicated, in general, constructs for which the respondents expressed a positive view. The highest mean score (3.78) was for artificial intelligence learning, followed by mean scores for constructs of metacognitive, self-regulated learning, and critical thinking (3.76, 3.71 and 3.69 respectively). The low standard deviation scores (0.61, 0.56, 0.58 and 0.60) indicated that respondents clustered close to the mean. The overall results of the assessment of the reliability of the measurement scales indicated that the scales were useful for statistical analyses that were to follow.

Table 3: Pearson Correlation Analysis of Study Variables (N = 487)

Variables	1	2	3	4
1. Artificial Intelligence-Supported Learning	1			
2. Self-Regulated Learning	.684**	1		
3. Metacognitive Awareness	.621**	.706**	1	
4. Critical Thinking Skills	.597**	.671**	.731**	1

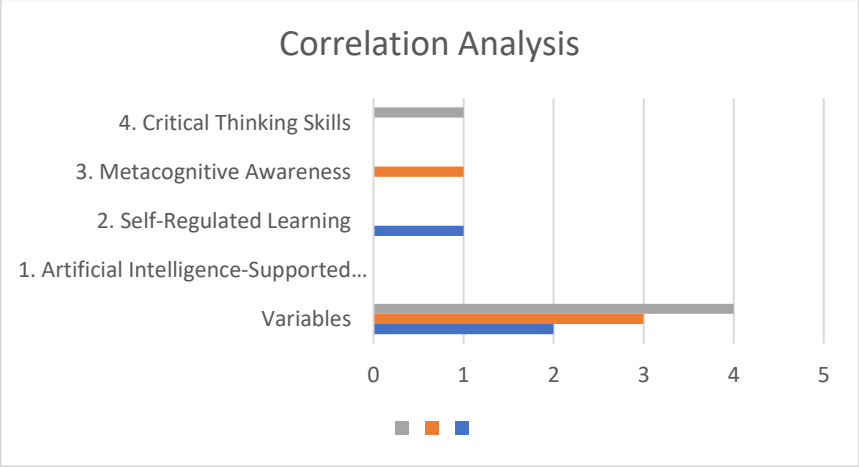

Fig.3 Correlation Analysis

The correlation analysis showed that learning powered by Artificial Intelligence shows a positive and significant effect on self-regulated learning (r = .684, p < .01), metacognitive awareness (r = .621, p < .01), and critical thinking (r = .597, p < .01). Self-regulated learning also has a positive and significant impact on metacognitive awareness (r = .706, p < .01) and critical thinking (r = .671, p < .01). Further, and positively, an impact was noted on critical thinking (r = .731, p < .01). Overall, the participants depended on more Artificial Intelligence-based learning to develop more self-regulated learning, awareness of their own thinking, and critical thinking.

Table 4. Multiple Linear Regression Analysis of Study Variables (N = 487)

Dependent Variable	Predictor	B	SE	β	t	p	R^2	Adjusted R^2	F
Metacognitive Awareness	Artificial Intelligence-Supported Learning	0.57	0.04	.621	14.25	<.001	.386	.385	187.69***
Critical Thinking Skills	Artificial Intelligence-Supported Learning	0.59	0.05	.597	13.12	<.001	.356	.355	172.13***
Self-Regulated Learning	Artificial Intelligence-Supported Learning	0.65	0.04	.684	16.28	<.001	.468	.467	264.99***
Metacognitive Awareness	Self-Regulated Learning	0.68	0.04	.706	17.28	<.001	.498	.497	298.61***
Critical Thinking Skills	Self-Regulated Learning	0.69	0.05	.671	15.82	<.001	.450	.449	250.48***

The regression analysis indicated that learning supported by Artificial Intelligence positively and significantly predicted self-regulated learning, metacognitive awareness, and critical thinking, and accounted for 38.6%, 35.6%, and 46.8% of their respective variations. Likewise, self-regulated learning also predicted metacognitive awareness and critical thinking, accounting for 49.8% and 45.0% of the respective variations. From these results, it can be concluded that self-regulated learning and AI-supported learning were positive and significant predictors of the major cognitive learning outcomes in the study.

Table 5: Independent-Samples t-Test by Gender (N = 487)

Variable	Male (n = 263) M ± SD	Female (n = 224) M ± SD	t	df	p
Artificial Intelligence-Supported Learning	3.82 ± 0.58	3.73 ± 0.64	1.58	485	.115
Self-Regulated Learning	3.76 ± 0.55	3.65 ± 0.61	2.02	485	.044
Metacognitive Awareness	3.81 ± 0.53	3.70 ± 0.59	2.10	485	.036
Critical Thinking Skills	3.74 ± 0.57	3.63 ± 0.63	1.98	485	.048

According to an independent-samples t-test, there was no statistically significant difference in gender regarding Artificial Intelligence-assisted learning (AI), t(485) = 1.58, p = .115. However, there was a statistically significant difference in gender in the other three variables. These were all related to self-regulated learning, metacognitive awareness and critical thinking, in which the male participants scored better than the female participants. The outcome of the study shows that although there was no gender bias in AI assisted learning, there was a definite gender bias in self-regulated learning, metacognitive awareness and critical thinking.

Table 6: One-Way ANOVA Analysis by Age Group (N = 487)

Variable	Age Group	Mean	SD	F	df	p
Artificial Intelligence-Supported Learning	18–22 years	3.86	0.57	4.21	3, 483	.006
	23–27 years	3.81	0.59			
	28–32 years	3.67	0.63			
	33 years and above	3.58	0.67			
Self-Regulated Learning	18–22 years	3.79	0.54	5.18	3, 483	.002
	23–27 years	3.76	0.56			
	28–32 years	3.62	0.61			

Variable	Age Group	Mean	SD	F	df	p
	33 years and above	3.51	0.64			
Metacognitive Awareness	18–22 years	3.84	0.52	4.67	3, 483	.003
	23–27 years	3.79	0.54			
	28–32 years	3.67	0.58			
	33 years and above	3.59	0.61			
Critical Thinking Skills	18–22 years	3.77	0.56	3.94	3, 483	.009
	23–27 years	3.73	0.58			
	28–32 years	3.61	0.62			
	33 years and above	3.54	0.65			

According to the one-way ANOVA results, statistically significant differences were observed among the age groups for each of the variables: Artificial Intelligence-supported learning ($F(3, 483) = 4.21$, $p = .006$), self-regulated learning ($F(3, 483) = 5.18$, $p = .002$), metacognitive awareness ($F(3, 483) = 4.67$, $p = .003$), and critical thinking skills ($F(3, 483) = 3.94$, $p = .009$). Participants from the age group 18-22 showed the highest means across the four variables, while participants in the group of 33 years and older showed the lowest means. Considering the overall ANOVA results were significant, a Tukey HSD analysis was conducted to find out the significant age groups that differ from one another.

Table 7: Mediation Analysis of Self-Regulated Learning

Relationship	Effect (B)	SE	β	t	p	95% Bootstrap CI
AI-Supported Learning → Self-Regulated Learning (a)	0.65	0.04	.684	16.28	<.001	[0.57, 0.73]
Self-Regulated Learning → Metacognitive Awareness (b)	0.54	0.05	.558	10.82	<.001	[0.44, 0.64]
Self-Regulated Learning → Critical Thinking Skills (b)	0.51	0.05	.493	9.91	<.001	[0.41, 0.61]
AI-Supported Learning → Metacognitive Awareness (c)	0.57	0.04	.621	14.25	<.001	[0.49, 0.65]
AI-Supported Learning → Critical Thinking Skills (c)	0.59	0.05	.597	13.12	<.001	[0.50, 0.68]
Indirect Effect: AI → SRL → Metacognitive Awareness	**0.35**	**0.04**	**.382**	—	**<.001**	**[0.28, 0.43]**
Indirect Effect: AI → SRL → Critical Thinking	**0.33**	**0.04**	**.337**	—	**<.001**	**[0.26, 0.41]**
Direct Effect: AI → Metacognitive Awareness	**0.22**	**0.05**	**.239**	4.62	**<.001**	**[0.13, 0.31]**
Direct Effect: AI → Critical Thinking Skills	**0.26**	**0.05**	**.264**	5.13	**<.001**	**[0.16, 0.36]**

The mediation analysis showed that Artificial Intelligence-supported learning positively affected self-regulated learning ($\beta = .684$, $p < .001$) and self-regulated learning positively affected both metacognitive awareness ($\beta = .558$, $p < .001$) and critical thinking skills ($\beta = .493$, $p < .001$). The indirect effect of Artificial Intelligence-supported learning to metacognitive awareness through self-regulated learning was significant ($B = 0.35$, 95% CI [0.28, 0.43]), since the confidence interval did not contain zero. The indirect effect of Artificial intelligence-supported learning to critical thinking skills through self-regulated learning was also significant ($B = 0.33$, 95% CI [0.26, 0.41]). Even after the introduction of the mediators, the direct effects maintained their respective statistically significant values, thus indicating partial mediation in the two relationships. The overall results indicated that self-regulated learning had a significant mediating effect on the relationship between Artificial Intelligence-supported learning and both metacognitive awareness and critical thinking skills.

Discussion

The findings showed positive relation between AI-assisted learning, self-regulated learning, metacognitive awareness, and critical thinking. AI-assisted learning was a significant predictor of self-regulated learning, metacognitive awareness, and critical thinking. Additionally, self-regulated learning was a significant predictor of the cognitive outcomes. The most important finding of the mediation analysis was that self-regulated learning significantly mediated the relationships between AI-assisted learning and metacognitive awareness and critical thinking. This indicates that the educational value of AI depends largely on the extent to which learners are actively involved in regulating and engaging with their learning processes (Vulpe et al., 2026).

The strong association between self-regulated learning and AI-assisted learning reflects findings that AI technologies can assist self-regulated learning (SRL) by helping learners to plan and monitor, as well as provide strategies, feedback, and reflect on learning. Lima (2025) reported that self-regulated learning (SRL) can be supported by AI technologies as long as the learners are in control. Kiren et al. (2026) stated that there is growing research on intelligent tutoring and adaptive learning. Similarly, Fasahat et al. (2025) reported a positive impact of AI interventions on autonomy and self-regulation in learning.

AI-based learning also positively affected metacognitive awareness and critical thinking. Even though these results may support AI's ability to promote prompting for understanding, evaluating and checking explanation of the reasoning, critiquing ideas, and stimulating reflection, the overall evidence is not positive. Doğan et al. (2026) concluded that there was no significant effect of generative AI on metacognition, indicating that the use of generative AI may not develop metacognitive abilities. Similar to critical thinking, a heavy reliance on AI might lead to the outsourcing of critical reasoning and metacognitive processes.

Thus, the analysis indicates a preference for responsible and cognitive active AI use over an unrestricted AI reliance. Self-regulated learning had positive associations with both metacognitive awareness and critical thinking, and metacognitive awareness positively associated with critical thinking. These results suggest that learners who self-regulate their learning and that of planning, monitoring, evaluating, and regulating are likely to understand their cognitive processes and formulate evidence-based reasoning. In AI-integrated environments, these abilities become vital as AI-generated information is likely to contain substantial reasoning with portions that are inaccurate, incomplete with explanatory gaps, and unsubstantiated.

The most important contribution of this study is the mediation effect. The self-regulated learning of AI-integrated learning processes positively mediated critical thinking and metacognitive awareness, with the remaining relationships being of a partial nature. Thus, AI is likely to support cognitive processes and instructive support for learners with an emphasis on self-regulated learning retaining responsibility for learning, as supported by (Almajdoub et al., 2026), while there may be differences in the way various age groups and genders with AI-based instruction may benefit from it.

General Conclusion

This research has shown that using AI for learning was correlated with improvement in student self-regulation, metacognition, and critical thinking. AI assisting learning showed that it could predict all the outcomes proving that AI can offer good educational assistance through learning support, feedback, data and information processing, and solving problems. Additionally, it can help learners monitor and evaluate their learning. It was shown that in the case of AI assisting learning and critical thinking and metacognition, self-regulation of learning was demonstrated to be an important mediating variable with the presence of significant direct effects and thus partial mediation was demonstrated. It was shown that the use of AI can be beneficial to students, more than just offering tools, and is dependent on their ability to plan, monitor, regulate their learning, and evaluate the tools. It is important to highlight that using AI needs to incorporate the principles of constructivist learning. It should foster students' self-regulation and critical thinking. It should also incorporate responsible AI.

Future Implications

Future educational practices should include AI-based learning, but its use should be planned carefully and responsibly. Students should be encouraged to use AI as a learning support while still taking control of their own learning process. This will teach students to be more aware of themselves, more critical, and better reflective thinkers. Education systems must provide their students with pathways to become literate in AI. Students must learn critical thinking when considering and evaluating information that is AI derived. Education systems must also promote learning support tools that remain complementary to independent learning. The study and design of educational methods that support AI based learning must integrate longitudinal and experimental approaches to broaden our understanding of the effects of self-regulated learning. Other variables that can be studied include the extent and nature of AI literacy, digital skills, motivations to learn, self-efficacy in learning, and the acceptance of technology. This should define the conditions that support the use of AI to enhance learning and critical thinking.

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