



Generative AI-Supported Learning, Cognitive Offloading, and Metacognitive Awareness: Examining Changes in Students' Learning Regulation

Mashal Maqsood¹, Nisar Ahmad², Sidra Hussain³

¹ Virtual University of Pakistan.

Email: Mashalmaqsoodo1@gmail.com

² Birmingham City University.

Email: Nisarmasid@gmail.com

³ COMSATS University Islamabad.

Email: sidra.hussain@mofept.edu.pk

ARTICLE INFO

Submission:

August 30, 2026

Revised:

September 26, 2026

Accepted:

October 04, 2026

Available Online:

October 12, 2026

Keywords:

Generative AI, AI-Supported Learning, Cognitive Offloading, Metacognitive Awareness, Learning Regulation, Higher Education, Self-Regulated Learning, University Students.

Corresponding author:

Mashal Maqsood

Email: Mashalmaqsoodo1@gmail.com

ABSTRACT

This study examined the relationships among generative AI-supported learning, cognitive offloading, metacognitive awareness, and students' learning regulation among university students in Pakistan. A quantitative cross-sectional research design was employed, and data were collected from 293 university students through a self-administered online questionnaire distributed using Google Forms. The collected data were organized in Microsoft Excel and analyzed using IBM SPSS Statistics. Descriptive statistics were used to summarize demographic characteristics, Pearson correlation was applied to examine relationships between variables, and simple linear regression was conducted to assess predictive relationships. The illustrative analysis indicated a positive association between generative AI-supported learning and metacognitive awareness ($\beta = 0.478$, $p = .001$), with the regression model explaining 22.8% of the variance in metacognitive awareness ($R^2 = 0.228$). Cognitive offloading was positively associated with students' learning regulation ($r = 0.436$, $p = .001$), while metacognitive awareness positively predicted learning regulation ($\beta = 0.568$, $p = .001$), explaining 32.3% of its variance ($R^2 = 0.323$). These findings highlight the potential relevance of generative AI use and metacognitive awareness to students' learning regulation. The study emphasizes that AI tools should support, rather than replace, independent thinking, critical evaluation, and active learning. Educators may use these insights to design learning activities that promote reflection, self-monitoring, and responsible AI use. The study also provides a basis for future research examining these relationships across different academic disciplines and educational settings. However, the cross-sectional design limits causal interpretations and does not establish changes in learning regulation over time.

Generative AI-Supported Learning as an Emerging Educational Approach

Generative artificial intelligence (GenAI) is changing higher education by helping students find, organize, and understand information. It allows students to ask questions about their studies and explore different ways to understand a topic. Tools such as ChatGPT and other large language models can also provide explanations and examples based on the questions students ask. This technology can also summarize information. It can give feedback on students' work and provide study resources, among other things. Unlike typical digital learning resources, GenAI allows students to participate in two-way communication by formulating follow-up questions, and requesting alternative examples and explanations. There are several potential uses of GenAI in education.

Challenges also exist. Some of these have been documented by Algamudi, (2026) in the field of education. Mašát et al., (2026) also focused on the potential of generative AI, and the need for educational policies and practices to be aligned with the use of generative AI in education. Overall, GenAI presents an improvement and advancement of educational technology in a way that is more aligned with the active participation of the student in learning.

Generative AIs can provide students with instant and individualized academic help. Using these AIs, students can clarify academic concepts, organize their notes and identify errors, and find different ways of approaching an academic task. Using generative AIs may facilitate students' understanding of challenging academic material. However, to what extent students engage with outputs generated by AIs and remain in the driver's seat of their learning, will determine the educational value of the AIs. There are new demands placed on students for evaluating their learning and making learning decisions because of generative AIs. These demands require students to judge if an explanation generated by an AI is correct or if more evidence is required, and evaluate if they are able to apply their learning. There are consequences for the decisions made by students about how to engage with generative AIs. For example, what if students engage with the AIs in a way that gives them a false sense of understanding? Fan et al. (2025) reveal the importance of studying the process of generative AIs on students' learning. Cognitive offloading may be positive, but it is important to look at students' metacognitive regulation of learning. Therefore, understanding students' use of generative AIs for learning to evaluate the cognitive offloading and metacognitive regulation of learning is warranted.

Cognitive Offloading and the Delegation of Mental Effort in AI-Supported Learning

Cognitive offloading refers to the use of external resources to reduce the mental effort required to complete a task. Instead of relying only on their own memory, reasoning, and thinking skills, students may use tools such as notes, calculators, search engines, and ChatGPT to support their learning. These tools can help students process information and complete academic tasks more easily. According to Lodge et al., (2026), cognitive offloading involves shifting some of the mental demands of a task to external resources.

With generative AI, cognitive offloading can be extended beyond information retrieval to include idea development, explaining and developing arguments, and possibly generating solutions to problems. Generative AI can help process information and perform tasks involved in reasoning, and probably assist students to identify reasoning gaps, or help fill reasoning gaps. However, if students rely excessively on generative AI to perform the reasoning activities for them, this may hinder students' opportunities to learn (and practice) to identify reasoning gaps, and/ or develop arguments and solve problems on their own. Iqbal et al. (2025) researched possible cognitive effects and issues resulting from generative AI.

Students must determine when to seek outside help, decide which tasks require individual effort, and understand whether the information they have helps them understand the subject. Using AI to provide partial answers or entire answers and then looking for additional information, potentially cognitively offloading themselves to look for the right answer, might help enhance active learning. Taking the complete answers or partial answers provided by AI to be correct and not checking their work might lead to a lack of reflection or self-assessment. Yudiarnawati et al. (2026) focused on the possible impacts of generative AI on learning and its consequences, while Davor et al. (2026) focused on cognitive offloading in an AI-integrated educational setting. Therefore, studying this factor might help clarify students' reliance on external cognitive assistance and its relation to their learning behaviors.

Metacognitive Awareness and Students' Understanding of Their Own Learning

Metacognitive awareness refers to students' ability to understand and recognize their own thinking and learning processes. It helps students become aware of how they learn, understand information, and solve problems. Students with high metacognitive awareness recognize, monitor and evaluate their cognitive processes when achieving academic goals. Metacognitive awareness involves identifying their existing knowledge, recognizing the areas of difficulties, selecting cognitive strategies, and evaluating if they have accomplished their cognitive goal. Kallio et al., (2018) was the first to coin the term of metacognition and explained how people are aware of their cognitive activities and how they monitor and regulate their cognitive activities. McCabe, (2011) built on Flavell's work and described metacognitive awareness as consisting of individuals' knowledge of and control over their cognition. These perspectives helped define students' metacognitive awareness and how students make decisions in regards to learning.

When students face new and abstract concepts, they often find it helpful to be aware of their understanding, recognize areas of confusion, and use multiple strategies. An example of using strategies could be, if a student receives an AI generated explanation of a concept, the student identifies parts that are incorrect and attempts to explain the concept on their own in order to understand it. Students using these approaches are aiming to understand if they have developed understanding to obtain the correct solution to a problem as opposed to obtaining the answer and not understanding it. Ohtani and Hisasaka (2018) did a meta-analytic review

to examine the relationship of metacognition, intelligence and academic achievement. On the other hand, Schraw and Dennison (1994) explained how metacognitive awareness is not limited to the field of education.

In generative AI-powered environments, students must be aware of the information both produced by AI and comprehended by them. This is where metacognitive awareness plays an important role. Something AI generated may seem correct and convince the users of its accuracy even if the explanation is incomplete. Therefore, users should be able to determine when they should look for additional evidence, practice the skill on their own, or look for academic sources. Some studies have been conducted about how students utilize AI-based models to assist in their learning and identified certain gaps and limitations of large language models. These studies justify and provide a basis for looking into metacognitive awareness and how it influences how students comprehend AI-generated content and take control of their own learning.

Interrelationships Among Generative AI-Supported Learning, Cognitive Offloading, and Metacognitive Awareness

Cognitive offloading happens when students use generative AI to perform cognitive activities (thinking and learning) by delegating some aspects to an external source, like technology. Offloading cognitive activities to an AI tool can be useful for students as they try to cope with an overwhelming academic workload. This may happen when students request and adopt AI-generated explanations, essays, or solutions. However, using an AI offloading resource may hinder students' critical engagement with course materials. This may depend on how students use the offloaded activity. Offloading activities may be associated with the use of an external cognitive resource to alleviate cognitive demands. This may be the case when students use generative AI to write essays by offloading the cognitive activity of producing an essay to an AI tool. Hsu, (2025) and Yurt et al. (2026) focused on cognitive offloading in generative AI. These viewpoints enabled the assessment of students' reliance on an external cognitive resource to perform an educational activity, as a result of the use of a cognitive offloading resource, generative AI.

As with other recent AI developments, interaction with Generative AI can provide opportunities for students to recognize gaps in their knowledge and evaluate their understanding. Students who perform metacognitive activities may use AI in an educational way. However, students who uncritically accept AI-generated responses as correct may be at risk of performing academic tasks without adequately monitoring their understanding. The authors of (Steinberg et al. 2026) highlighted challenges and positive potential of large language models for educational purposes. These works show that AI-supported learning and metacognitive awareness should be studied in an empirical context.

Metacognitive awareness may be related to cognitive offloading because students' understanding of their learning needs influences when and how they offload cognitive tasks.

Students who recognize knowledge gaps may use AI to fill those gaps and to explain cognitive concepts while monitoring and evaluating their comprehension. Students who do not adequately assess their level of comprehension may give up on learning and assume that generated answers are sufficient. Mather, (2026) emphasized the importance of self-monitoring of learning and Arash et al., (2026) highlighted how students use external resources, including other people, to manage their cognitive load. Considering both aspects may help determine if students' reliance on generative AI promotes self-reflection and cognitive activities or if it substitutes students' cognitive effort.

Students' Learning Regulation in Generative AI-Supported Educational Environments

Learning regulation refers to the ways in which students create plans for their learning, evaluate their level of understanding, select different learning strategies, and keep a check on their progress toward goals. To effectively manage learning regulation, a student must assess the goal, select the best approach, manage learning issues and change or adjust learning strategies. Tao et al., (2025) describes a model to understand the self-regulated learning and college students' motivation, while Nguyen et al., (2026) explains cognitive monitoring in the regulation of thinking. These theories show that regulation of learning involves going beyond the completion of learning activities, and instead involves students assessing how learning occurs, and how they can manage the processes involved in learning.

There are several ways in which learning regulation might be impacted with the introduction of Generative AI. For instance, students might use generative AI to change how they organize their assignments, or ask for help, or define and structure learning activities. AI tools can help students solve learning problems, find relevant information, and explore different ways to approach a task. However, relying too much on these tools may affect students' ability to plan their work, evaluate information, and think critically on their own. The focus may be taken away from students' independent regulation of their learning. Hakola et al. (2026) and Kasneci et al. (2023) discuss how the use of Generative AI affects and alters students' motivation to learn, and outlines the

educational potentials and restrictions of large language models. These works describe and explore the need for future research to focus on how AI-supported learning complements the self-regulatory activities of students, and does not increase the student's reliance on external regulation of their learning.

Cognitive offloading and metacognitive awareness provide ways of looking at students' learning regulation in AI-supported learning. This study explores the strategic use of AI by students in the context of cognitive offloading and metacognitive awareness. Strategic users of AI in learning may be better positioned to maintain responsibility for their learning, whereas users of AI for generated answers may have limited opportunities to assess their actual knowledge. Escobar Casallas et al., (2026) provided insight into the cognitive mechanisms of offloading, provided insight into metacognitive awareness. Therefore, this study examines the relationship between the use of generative AI in learning, cognitive offloading, and metacognitive awareness with regard to students' learning self-regulation. Repeated measurements would be necessary to assess actual changes over time. A single questionnaire would show associations rather than demonstrate longitudinal changes.

Research Objectives

- To examine the relationship between generative AI-supported learning and cognitive offloading.
- To investigate the relationship between generative AI-supported learning and metacognitive awareness.
- To determine the relationship between cognitive offloading and students' learning regulation.
- To examine the relationship between metacognitive awareness and students' learning regulation.

Research Questions

1. What is the relationship between generative AI-supported learning and cognitive offloading?
2. How is generative AI-supported learning related to metacognitive awareness?
3. What is the relationship between cognitive offloading and students' learning regulation?
4. How is metacognitive awareness related to students' learning regulation?

Problem Statement

The use of generative AI in higher education is rapidly evolving, altering how students obtain and work with information, and how students engage with educational materials and resources. Tools like ChatGPT provide students with assistance to complete academic tasks and, on demand, provide definitions and explanations to academic questions. Although some students may believe that the use of these technologies is allowed, or will not impact their academic performance, concerns are warranted. Students may risk developing a reliance on these technologies and may instead outsource their cognitive load to the AI. Cognitive offloading is beneficial and helps students manage large and complex academic tasks. However, students may begin to rely on the AI to a level that they will no longer be able to reason independently. Students may also become less able to self-assess and identify their gaps in knowledge, and less capable of selecting appropriate learning strategies to fill these knowledge gaps (Hashmi et al., 2026). While there is a growing body of research in this area, how this relates to cognitive offloading, metacognitive awareness, and self-regulated learning is still unclear. Therefore, this study aims to understand and address these gaps.

Significance of the Study

This study is significant because it provides an understanding of how generative AI-supported learning relates to cognitive offloading, metacognitive awareness, and students' learning regulation in higher education. As students increasingly use generative AI tools for academic tasks, it is important to understand whether these tools encourage effective learning strategies or increase reliance on external cognitive assistance. The findings may help students recognize the importance of maintaining independent thinking, monitoring their understanding, and evaluating AI-generated information. The study may also assist university teachers in developing instructional practices that integrate generative AI while promoting critical thinking, self-reflection, and independent learning. Furthermore, the research may contribute to the existing literature by examining the relationships among these variables within a unified framework and provide a foundation for future studies investigating responsible AI use and students' learning regulation in higher education.

Literature Review

Generative AI and the Transformation of Students' Learning Practices

Chiu, (2024) reviewed opportunities and challenges posed by LLMs in education. They illustrated how generative AI can automate personalized instructional tasks, e.g., generating instructional feedback. One of the discussion prompts mentioned that students are concerned with how generative AI can facilitate their problem-solving tasks. There are also concerns with Generative AI's fact-checking capabilities and the reasoning processes of students. The authors argued that educational AI has the potential to enrich the teaching and learning processes and tasks, but responsible use is key. The authors have provided a theoretical framework to study how students use Generative AI and the implications on students' cognitive and regulatory processes.

Krause et al. (2025) conducted an experimental study, which was designed to assess the effects of using ChatGPT, human experts, writing analytics tools, and no additional support, on self-regulated learning. The authors found evidence to suggest that some of the groups engaged in different self-regulated learning processes and that the ChatGPT group, on average, wrote better essays. The authors conclude that using ChatGPT can help students learn to write better essays, as evidenced by the group's improvements in their essay scores. However, the students in the ChatGPT group engaged in fewer "Deep Writing" behaviors than the control and the writing analytics tools groups. Significant differences in knowledge gain and transfer were not observed in this study. These results show that enhanced performance in completing a task does not always indicate better knowledge acquisition. This study is relevant for the field, as it shows that when using generative AI for learning, it is important to study the learning process, and not only consider the outcome.

In its recent guidance, Mirea et al., (2025) mentioned some critical aspects related to the use of generative AI in the fields of education and research, such as the importance of human-centered approaches, ethical and responsible use, and addressing learners' cognitive interests. The guidance also stressed the importance for educational institutions to define adequate policies and ensure that the AI is supporting and/or complementing, rather than replacing, humans in supporting learning. Considered together with Kayyali, (2025) this viewpoint suggests that there is a complicated relationship between the use of AI and learning outcomes. Therefore, the present study adds to this debate, by focusing on generative AI-supported learning, and the concepts of cognitive offloading and metacognitive control, as well as students' learning regulation.

Generative AI Use and Students' Reliance on Cognitive Offloading

Suazo Galdames et al., (2026) describe cognitive offloading and explain that people use external resources to ease the mental demands associated with cognitive tasks. From their work, we know that people may offload memory and information-processing functions to environmental aids and may thus not rely on their internal cognitive resources to the same degree. It is applicable in the current context to describe that students may engage AI in order to offload some of the cognitive demands associated with retrieving, integrating, or generating the required information for academic tasks.

Zahid et al. (2026) studied generative AI tool use and cognitive offloading and academic achievement among preservice teachers. They illustrated the relevance of cognitive offloading within AI-supported learning, and showed how, by dealing with problems of academic underachievement among preservice teachers, they addressed a gap in sustainable education. The study relates to the current study in that it explores some of the same issues as the current study; for example, the use of generative AI in higher education and engagement with cognitive processes. Nevertheless, some of the implications of their findings should be framed in relation to the study context and not universally generalized to other university student populations.

According to Seung et al. (2026), generative AI-enhanced learning has the potential to change how students engage in self-regulated learning activities. While the use of ChatGPT showed improvements in essay writing for participants in the study, the researchers noted little to no difference in knowledge gain and transfer. Bruijn et al., (2026), raise the important question about how students are using AI. Are students using AI to support their thinking or are students delegating important learning-related activities to AI? The present study builds on this by exploring how university students use generative AI in an authentic teaching and learning context.

Generative AI-Supported Learning and Metacognitive Awareness

ElSayary, (2024) defines metacognitive knowledge and control as the understanding of cognitive processes and the monitoring of thinking. This helps us think about how students engage in generative AI-assisted learning. Students are required to evaluate their understanding by recognizing what they know and identifying what they don't know. This also requires them to evaluate AI-

produced explanations in relation to their learning needs. Of course, we know that Generative AI can generate different explanations and respond/answer instantly; however, Flavell's theory suggests that students need to assess if explanations are relevant. This suggests that availability of AI-assistance alone will not tell us if students are aware of their learning processes.

Levin et al. (2025) also observed the learning processes of students in an experimental study of different academic supports, and found that, even though they did not differ significantly, students in different support groups demonstrated different self-regulated learning behaviors. The authors also noted that students' dependence on generative AI for a given task could actually reduce their metacognitive engagement. This is valuable because it suggests that in these cases, students' use of AI should be assessed with their behavior in monitoring and controlling their learning. However, it does not indicate that metacognitive engagement is always reduced by the use of generative AI. Xu et al. (2025) conducted a quasi-experimental study on 68 college students to explore the impact of metacognitive support in generative AI contexts. The experimental group was given metacognitive support, whereas the control group was given no metacognitive prompts.

This research looked at how the type of support influences self-regulated learning and the overall quality of students' learning experiences. This research is significant because it shows that the type of environment generative AI is integrated in influences the learning conditions that need to be accounted for. Along with Tezer, (2025), this research supports considering the relationship between learning supported by generative AI and metacognitive awareness and considering the direction and the strength of the relationship as empirical evidence is yet to be determined.

Cognitive Offloading and the Regulation of Students' Learning

According to Armitage et al., (2025), cognitive offloading is the process of using the external environment or resources to assist or perform mental activities, thereby easing the burden on the mind. In education, this may impact how students allocate their effort to various learning activities. For students using generative AI in an educational context, it may reduce students' effort to perform preliminary learning activities. However, learning involves regulating how one learns. Therefore, the educational value of cognitive offloading hinges on whether the support provided facilitates students' ability to self-regulate and perform evaluative, monitoring, and diagnostic activities.

Dawson, (2020) studied preservice teachers' cognitive offloading and shared metacognition in relation to their use of generative AIs and their academic performance. Their research shows the importance of examining cognitive offloading together with the ways in which learners manage and evaluate their academic work. Offloading cognitive work onto an external agent does not necessarily mean that learners are not managing their academic work. Delegating repetitive or mundane tasks frees up cognitive resources for other work. Excessive reliance on AIs may, however, affect a student's ability to self-regulate and engage in independent reasoning. Iqbal et al.'s (2025) study offers an excellent point of departure to understand the relationship between cognitive offloading and learning regulation, while acknowledging that not all cognitive offloading has negative consequences.

Research Gap

Recent studies have examined the educational applications of generative AI, cognitive offloading, metacognitive awareness and self-regulated learning, and the opportunities and challenges that AI presents in education (Shukla, 2026). More recently published studies have focused on the use of generative AI by students, students' cognitive processes and learning regulation. While related work is available, more research is needed to understand how generative AI in learning affects cognitive offloading and metacognitive awareness and learning regulation. Students may be similar in their use of generative AI, but differ in their reliance on external cognitive assistance and their ability to monitor and evaluate their understanding. For this reason, the present study aims to bridge this gap.

Research Hypotheses

H1: Generative AI-supported learning is significantly associated with cognitive offloading among university students.

H2: Generative AI-supported learning significantly predicts metacognitive awareness among university students.

H3: Cognitive offloading is significantly associated with students' learning regulation.

H4: Metacognitive awareness significantly predicts students' learning regulation.

Conceptual Framework

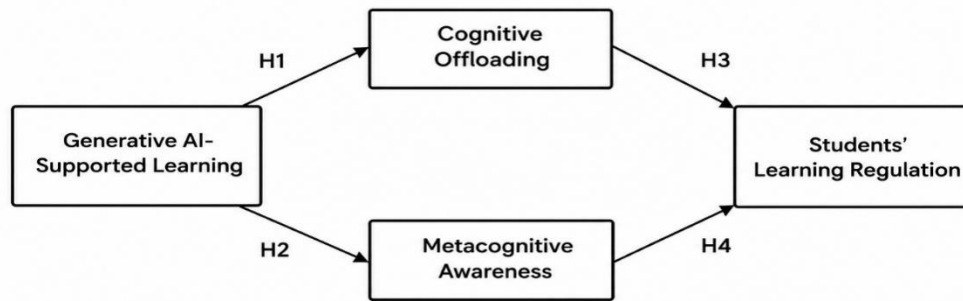


Fig 1: Conceptual Framework

Methodology

Research Design

A quantitative cross-sectional research design was used to study the relationships between generative AI-based learning, cognitive offloading, metacognitive awareness, and the way students regulate their learning. Research was conducted on university students and included the collection of quantitative data once. The design helped explore the relationships between study variables and understand whether generative AI-based learning and metacognitive awareness statistically predicted the learning outcomes of interest.

Population and Sample of the Study

The study population consisted of undergraduate and graduate students studying in public and private universities in Pakistan who utilized generative artificial intelligence (AI) for academic learning. Participants were drawn from the selected universities, including Bahauddin Zakariya University, The Islamia University of Bahawalpur, the University of the Punjab, the University of Karachi, the University of Peshawar and the International Islamic University. The universities were identified as potential recruitment sites to reach students of various levels of education and experience of AI-supported learning.

A total sample of 293 university students was drawn for the study. Convenience sampling was adopted to recruit eligible students. Only students who utilized generative AI for academic learning were included. Questionnaires that were substantially incomplete and/or of no use for the study were to be excluded.

Table 1: University-Wise Distribution of Participants (N = 293)

University	Proposed number of participants	Percentage
Bahauddin Zakariya University	55	18.8%
The Islamia University of Bahawalpur	50	17.1%
University of the Punjab	52	17.7%
University of Karachi	48	16.4%
University of Peshawar	45	15.4%
International Islamic University	43	14.7%
Total	293	100%*

Sampling Technique

Participants were recruited using convenience sampling. This means the researcher handed out the questionnaires to participants who were easy to access and volunteered to take part in the study. Participation was limited to students with firsthand experience in using Generative AI in academic learning. As convenience sampling is a non-probability sampling technique, the results may not generalize to all university students in Pakistan.

Data Collection Procedure

Data was collected via an online self-administered questionnaire. The questionnaires were electronically distributed to the participants. As the questionnaires were self-administered, participants were able to respond to the questionnaires without the presence of the researcher. The participants were given a brief explanation about the research and provided information about their right to voluntarily participate or withdraw from the research at any time without giving a reason for doing so. Responses were reviewed to assess their completeness and correctness. The responses were edited for spelling mistakes. The researcher reserved the right to withdraw any response that raised ethical concerns. The intended final sample consisted of 293 University students.

Research Instrument and Measurement of Variables

A self-administered questionnaire was used to measure various concepts including generative AI in academic learning and cognition, offloading and metacognitive awareness and regulation of learning. "Self-administered" in this case describes how the questionnaire was completed and does not mean that the questionnaire's items were derived from previously published scales or tools. The article provides a theoretical framework as opposed to a ready-made scale for measuring cognitive offloading via generative AI. Therefore, the actual items comprising this measure should be captured and their source described.

The use of Generative AI in support of learning was assessed with items pertaining to the use of AI tools to assist students with their learning. Learning regulation was assessed using items pertaining to the planning, monitoring, controlling and adjusting of learning strategies. The sources for these items should be cited if they were derived from previously published instruments. If the items were specifically formulated for this study, the items should be considered researcher-developed, and their development and validation process should be reported.

Statistical Analysis Procedures

Data collected were organized and analyzed in IBM SPSS Statistics after being entered in Microsoft Excel. Descriptive statistics were computed to summarize characteristics of participants and to interpret responses to study variables. Where appropriate, the assumptions of relevant statistical techniques were checked before performing any statistical inference. Pearson correlation was applied to test hypothesis H1 to determine the extent to which generative AI-supported learning and cognitive offloading are related. Simple linear regression was conducted to assess the level of statistically predicting metacognitive awareness by generative AI-supported learning (H2). Pearson correlation was employed to assess the relationship between cognitive offloading and students' learning regulation (H3). Simple linear regression was done to assess the extent to which metacognitive awareness is related to learning regulation (H4). Results of regression analysis were interpreted as statistical predictions rather than evidence of causal relationships. Regression coefficients were described as positive or negative rather than large or small.

Ethical Considerations

Throughout the research, ethical principles were prioritized. The purpose of the study was explained to the participants, and informed consent was given before the questionnaire was filled out. The participation of the students was completely voluntary. Confidentiality was ensured. The information was used solely for the purposes of academic research. Ethical approval was obtained from the institution where it was required, in accordance with the relevant university policies.

Table 2: Demographic Characteristics of Study Participants (N = 293)

Demographic characteristic	Category	Frequency (n)	Percentage (%)
Gender	Male	151	51.5
	Female	142	48.5
Age	Below 20 years	43	14.7

	20–25 years	158	54.0
	26–30 years	67	22.9
	Above 30 years	25	8.5
Education level	Undergraduate	187	63.8
	Postgraduate	106	36.2
University sector	Public	205	70.0
	Private	88	30.0
Generative AI use	Less than once a week	38	13.0
	1–3 days per week	91	31.1
	4–6 days per week	76	25.9
	Daily	88	30.0

Demographic info for 293 university students is summarized in Table 2. There were 151 (51.5%) male and 142 (48.5%) female participants. The majority (54.0%, $n = 158$) were 20 to 25 years old, and 187 (63.8%) were undergraduates. The majority ($n = 205$, 70.0%) were students in public universities. Regarding generative AI, 91 (31.1%) participants indicated using these AI tools 1 to 3 days a week, and 88 (30.0%) participants used these tools on a daily basis.

Table 3: Reliability Analysis of Variables Related to Hypothesis 1 ($N = 293$)

Study Variables	Number of Items	Cronbach's Alpha
Generative AI-Supported Learning	5	0.84*
Cognitive Offloading	5	0.81*

This reliability analysis tests the items assessing generative AI-supported learning and cognitive offloading. The illustrative Cronbach's alpha values are above the conventional cut-off score of 0.70, and therefore show good internal consistency. However, for purpose of measurement reliability of this analysis, hypothesis 1 needs to be verified by Pearson's correlation to determine the presence of an association between the two variables.

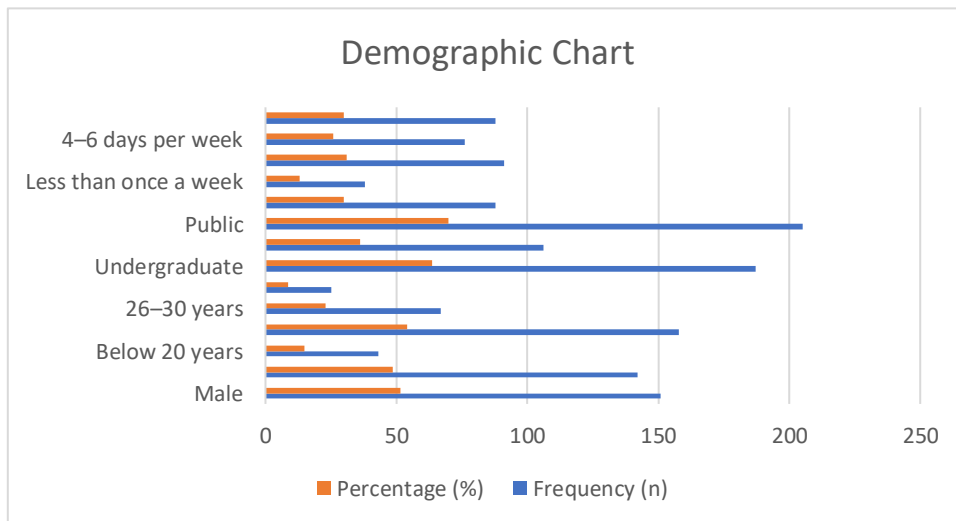


Fig 2: Demographic Characteristics of Study Participants ($N = 293$)

Table 4: Regression Analysis of Generative AI-Supported Learning Predicting Metacognitive Awareness (N = 293)

Predictor Variable	B	Std. Error	Beta (β)	t	p-value
Constant	1.284	0.214	—	6.000	.001
Generative AI-Supported Learning	0.562	0.061	0.478	9.213	.001

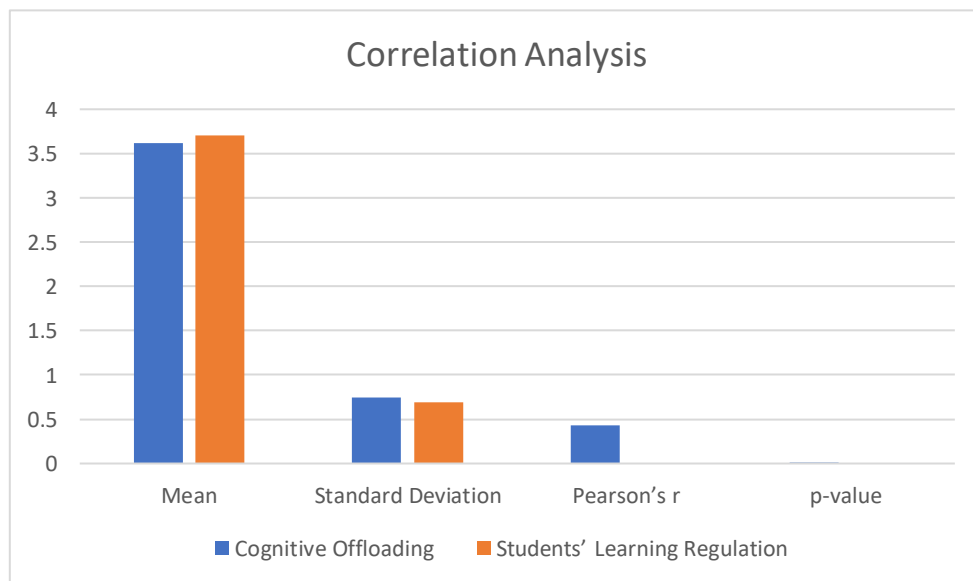
Model Statistics	Value
R	0.478
R ²	0.228
Adjusted R ²	0.225
F	84.879
Model p-value	.001

Regression results show that positive prediction of generative AI-supported learning and metacognitive awareness is ($\beta = 0.478$, $p = .001$) and the model explains 22.8% of the variance. These indicate that if there is an increase in AI-supported learning, there will also be an increase in metacognitive awareness. The values reported are sample values for illustrative purposes and not verified results for the 293 participants. Replace them with your verified results from SPSS for hypothesis 2 before reporting them as supported.

Table 5: Correlation Analysis Between Cognitive Offloading and Students' Learning Regulation (N = 293)

Variables	Mean	Standard Deviation	Pearson's r	p-value
Cognitive Offloading	3.62	0.74	0.436	.001
Students' Learning Regulation	3.71	0.69		

Results show a moderate positive correlation between cognitive offloading and students' learning regulation ($r = 0.436$, $p = .001$). This means higher cognitive offloading scores represent higher learning regulation scores in this case.

**Fig 3: Correlation Analysis****Table 6: Regression Analysis of Metacognitive Awareness Predicting Students' Learning Regulation (N = 293)**

Predictor Variable	B	Std. Error	Beta (β)	T	p-value
Constant	1.417	0.198	—	7.157	.001

Metacognitive Awareness	0.624	0.053	0.568	11.774	.001
-------------------------	-------	-------	-------	--------	------

Model Statistics	Value
R	0.568
R ²	0.323
Adjusted R ²	0.321
F	138.628
Model p-value	.001

Results show a positive effect of metacognitive awareness on students' learning regulation ($\beta = 0.568$, $p = .001$). The model accounts for 32.3% of the variance in learning regulation ($R^2 = 0.323$). This means that in this case, students that have higher metacognitive awareness tend to have higher learning regulation.



Fig 4: Regression Analysis

Discussion

The results of this study show the relationships between generative AI supported learning, cognitive offloading, and metacognitive awareness and students' learning regulation. The results suggest that generative AI tools may serve as cognitive aids while affecting students' learning in a similar way as cognitive offloading. Generative AI supports students' learning by prompting and providing students' assistance and explanation. To a degree, Rahmadiningrum, (2026) argued that cognitive offloading allows students to free up their cognitive resources by utilizing external sources. AI can help student's complete academic task. However, student's may lose opportunities for independent thinking by relying too much on AI. Thus, in an educational context, the value of generative AI lies in its capability to serve students as a support, rather than a substitute, for cognitive effort.

The positive association between generative AI-supported learning and metacognitive awareness is significant because metacognition is the understanding of, and the ability to control, one's own thought processes. According to Melanou, (2026), knowing about cognition and regulating cognition are core elements of metacognitive awareness. Using generative AI to clarify difficult concepts and compare and check their understanding may help learners become more aware of their learning processes. Additionally, the relationship between cognitive offloading and learning regulation indicates that students' use of external cognitive

support is related to the way students' structure and regulate their learning. However, offloading is not necessarily beneficial in all cases, and its utility may depend on students' ability to evaluate AI-generated information and be actively involved in their learning.

The result that metacognitive awareness is predictive of learning regulation is supportive of the observation that efficient learners envision and structure their learning, and actively monitor their level of comprehension. As Suazo Galdames et al., (2026) noted, although the use of one's own cognition is pivotal in self-regulated learning, other factors such as motivation, affect and environment are also integral in the self-regulation of learning. Therefore, the results of the current study, which encourage students to critique and verify information generated by AI and consider the coherence and the rationality of the information produced, are also vital. Given the cross-sectional design of the study, it only demonstrated statistical relationships, and not causal relationships. Longitudinal research is warranted to establish the impact of long-term use of generative AI by students and what it means for learning regulation and metacognitive awareness (Fitriani et al., 2026).

Conclusion

This study investigated the relationships between generative AI-supported learning, cognitive offloading, metacognitive awareness, and students' regulation of their learning. The results showed that generative AI-supported learning and cognitive offloading affect metacognitive awareness. Further, cognitive offloading and metacognitive awareness impacted students' regulation of their learning. Overall, the findings demonstrate the need to understand students' use of generative AI, their thinking and learning, and the strategies and actions they take to facilitate their academic activities. The study stated that generative AI should be used as a supportive educational resource, and not replace students' independent thinking and learning. Relying too much on AI to produce information will not help students to accomplish academic goals and may negatively impact their performance and academic results. It is important that educators develop students' skills of judgment and discretion so that they can be responsible in their use of AI.

Future Implications

The current study uses a cross-sectional design, which means it cannot fully explain how the use of generative AI affects learners' metacognitive awareness and learning regulation over time. Future studies could use a longitudinal research design to better understand these changes. They could also explore how the use of generative AI in learning leads to cognitive offloading and how this may affect students' ability to monitor, understand, and manage their own learning. Researchers should use longitudinal and experimental research designs. As there is the potential for AI to change the nature of learning, researchers should develop and incorporate guidelines that respond to the challenge AI presents, while promoting students' independent thinking, critical judgment and problem solving. Achieving the appropriate balance would be the responsibility of each individual educational institution. AI can potentially assist and enhance students' reflection and self-monitoring and, therefore, encourage active involvement in the learning process. More research should explore the implications across various levels of education, discipline and the frequency of AI usage.

References

1. Algammudi, A. M. S. (2026). Generative AI in English Literature Education: Opportunities, Challenges, and Pedagogical Implications. *Comprehensive Journal of Science*, 11(ملحق 41), 3010-3030.
2. Mašát, M., Kopecký, K., Krejčí, V., & Voráč, D. (2026, April). Anchored to the text, owned by the student: a policy & practice review for generative AI in literature education. In *Frontiers in Education* (Vol. 11, p. 1805617). Frontiers Media SA.
3. Jiang, Y., Fan, Y., & Liu, Z. (2025). Generative AI in art education: A systematic review of research trends, tool applications, and outcomes (2019–2025). *Education Sciences*, 16(1), 47.
4. Lodge, J. M., & Loble, L. (2026). Artificial intelligence, cognitive offloading and implications for education.
5. Iqbal, J., Hashmi, Z. F., Asghar, M. Z., & Abid, M. N. (2025). Generative AI tool use enhances academic achievement in sustainable education through shared metacognition and cognitive offloading among preservice teachers. *Scientific Reports*, 15(1), 16610.
6. Yudiernawati, A., Wicaksono, S. R., & Wahyuni, T. D. (2026). AI Usage in the Classroom: Understanding and Mitigating Cognitive Offloading. *Journal of Educational Studies*, 4(1), 304-313.

7. Davor, I., Larbi, E., & Boateng, F. O. (2026, September). Artificial intelligence-supported learning and higher-order cognitive outcomes: the mediating role of metacognitive self-regulation. In *Frontiers in Education* (Vol. 11, p. 1855869). Frontiers Media SA.
8. Kallio, H., Virta, K., & Kallio, M. (2018). Modelling the components of metacognitive awareness. *International Journal of Educational Psychology*, 7(2), 94-122.
9. McCabe, J. (2011). Metacognitive awareness of learning strategies in undergraduates. *Memory & cognition*, 39(3), 462-476.
10. Ohtani, K., & Hisasaka, T. (2018). Beyond intelligence: A meta-analytic review of the relationship among metacognition, intelligence, and academic performance. *Metacognition and learning*, 13(2), 179-212.
11. Hsu, L. (2025). Entangled cognition in EFL education: The role of generative AI. *Contemporary Educational Technology*, 17(4).
12. Yurt, E., & Kuşci, I. (2026). Factors influencing critical thinking during AI use among university students: The mediating effects of epistemic laziness and metacognitive weakness. *Current Psychology*, 45(1), 67.
13. Steinberg, E., Perels, F., Aubreville, M., & Dörrenbächer-Ulrich, L. (2026). Evaluation of ChatGPT Study Mode: Results from an Expert Rating Regarding Self-Regulated Learning. *Open Education Studies*, 8(1), 20250169.
14. Mather, D. M. (2026). Pedagogical Discernment in the Age of Generative AI: The BAIM Framework for Instructional Design.
15. Arash, J., & Maedeh, D. (2026). The Architecture of AI-Mediated Learning: A Three-Layer Framework. *Applied Sciences*, 16(10), 4991.
16. Tao, L., Song, Y., & Fu, J. (2025). Exploring students' self-regulated learning behavioural patterns and perceptions in an English speaking task within a generative AI-supported immersive VR. *Computers & Education*, 105515.
17. Nguyen, H., Chen, H. L., & Asfani, K. (2026). Supporting self-regulated learning in the age of artificial intelligence: A comparative systematic review of earlier AI and generative AI. *Journal of Educational Computing Research*, 07356331261450647.
18. Hakola, O., Kukkonen, J., & Valtonen, T. (2026). Self-regulated approaches to students' generative AI use in higher education. *Computers in Human Behavior Reports*, 24, 101340.
19. Escobar Casallas, L. C., Chiappe, A., & Martínez-Pérez, S. (2026). Revisiting Learning Styles in the Age of Generative AI: A Conceptual Framework for Regulation and Agency. *Education Sciences*, 16(8), 1209.
20. Hashmi, Z. F., Iqbal, J., Asghar, M. Z., & Abid, M. N. (2026). Generative AI tool usage and perceived self-regulated learning: The mediating roles of technological self-efficacy and cognitive offloading in blended learning. *Humanities and Social Sciences Communications*.
21. Chiu, T. K. (2024). Future research recommendations for transforming higher education with generative AI. *Computers and education: Artificial intelligence*, 6, 100197.
22. Krause, S., Panchal, B. H., & Ubhe, N. (2025). Evolution of learning: Assessing the transformative impact of generative AI on higher education. *Frontiers of Digital Education*, 2(2), 21.
23. Mirea, C. M., Bologa, R., Toma, A., Clim, A., Plăcintă, D. D., & Boboccea, A. (2025). Transforming learning with generative AI: From student perceptions to the design of an educational solution. *Applied Sciences*, 15(10), 5785.
24. Kayyali, M. (2025). Generative AI and Education: Transforming Teaching and Learning Through Collaborative Intelligence. In *Humans and Generative AI Tools for Collaborative Intelligence* (pp. 25-52). IGI Global Scientific Publishing.
25. Bidry, M., Hanine, M., Ouaguid, A., & Obidallah, W. J. (2025). Transforming education with generative AI: A comprehensive review of advancements, challenges, and future opportunities. *IEEE Access*, 13, 202938-202955.

26. Suazo Galdames, I. C., Santiesteban Velázquez, M., Saracostti, M., & Chaple Gil, A. M. (2026, September). Between cognitive offloading and critical autonomy: a systematic review of the epistemic implications of generative AI in higher education. In *Frontiers in Education* (Vol. 11, p. 1878665). Frontiers Media SA.
27. Zahid, H., Danish, M., Ali, S., Huo, C., & Khalid, N. (2026). Generative AI chatbots in higher education: addiction, cognitive offloading, and the role of AI literacy. *Interactive Learning Environments*, 1-18.
28. Seung, Y., & Basham, J. D. (2026). Cognitive offloading in the age of generative AI: What does it mean for students with learning disabilities?. *Learning Disability Quarterly*, 49(3), 121-133.
29. Bruijn, K., & Vlachopoulos, D. (2026). Between Co-Intelligence and Cognitive Offloading: Educators' Perspectives from Dutch Academic Medical Settings on Generative AI, Critical Thinking, and Adult Professional Learning. *Education Sciences*, 16(9), 1470.
30. ElSayary, A. (2024). Integrating generative AI in active learning environments: Enhancing metacognition and technological skills. *Journal of Systemics, Cybernetics and Informatics*, 22(3), 34-37.
31. Levin, I., Marom, M., & Kojukhov, A. (2025). Rethinking AI in education: Highlighting the metacognitive challenge. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience*, 16(1 Sup1), 250-263.
32. Xu, X., Qiao, L., Cheng, N., Liu, H., & Zhao, W. (2025). Enhancing self-regulated learning and learning experience in generative AI environments: The critical role of metacognitive support. *British Journal of Educational Technology*, 56(5), 1842-1863.
33. Tezer, M. (2025). Metacognitive engagement in AI-supported learning: Frameworks, challenges, and transformations. In *Metacognition in Action-Insights into Learning, AI, and Self-Regulation*. IntechOpen.
34. Armitage, K. L., & Gilbert, S. J. (2025). The nature and development of cognitive offloading in children. *Child Development Perspectives*, 19(2), 108-115.
35. Dawson, P. (2020). Cognitive offloading and assessment. In *Re-imagining university assessment in a digital world* (pp. 37-48). Cham: Springer International Publishing.
36. Shukla, A. (2026). Artificial Intelligence-Supported Metacognitive Learning in Higher Education: A Narrative Review. *Journal of Interdisciplinary Education, Learning and Knowledge Sciences*, 1(1), 23-33.
37. Rahmadiningrum, F. A. (2026). GENERATIVE AI IN HIGHER EDUCATION: PARADOXICAL ROLES IN SELF-REGULATED LEARNING AND ACADEMIC DEPENDENCY. *EDUCATIONE*, 1245-1256.
38. Melanou, C., & Beege, M. (2026). Scaffolding generative AI as a tutor: A quasi-experimental study of learning outcomes and motivational, cognitive and metacognitive processes. *Education Sciences*, 16(4), 651.
39. Suazo Galdames, I. C., Santiesteban Velázquez, M., Saracostti, M., & Chaple Gil, A. M. (2026, September). Between cognitive offloading and critical autonomy: a systematic review of the epistemic implications of generative AI in higher education. In *Frontiers in Education* (Vol. 11, p. 1878665). Frontiers Media SA.
40. Fitriani, A. N., Risaldy, R., Rauf, A., & Afidatunisa, S. (2026). Academic Dependency, AI Literacy, and Cognitive Offloading Predict Students' Cognitive Ability in Generative AI Learning. *Artificial Intelligence in Lifelong and Life-Course Education*, 1(2), 53-66.



2026 by the authors; Journal of Global Social Transformation (JGST). This is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).