DOI: 10.71317/jgst.2.8(s).2026.483
Journal of Global Social Transformation
Journal homepage: https://rjsaonline.org/index.php/JGST

Cognitive Agility, Generative AI-Assisted Learning, and Problem-Solving Effectiveness among University Students: The Mediating Effect of Metacognitive Competence

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ARTICLE INFO	ABSTRACT

Submission:
July 08, 2026
Revised:
July 24, 2026
Accepted:
August 11, 2026
Available Online:
August 25, 2026

Keywords:

Cognitive Agility, Generative Artificial Intelligence, AI-Assisted Learning, Metacognitive Competence, Problem-Solving Effectiveness, Higher Education, University Students, AI Literacy.

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The rapid integration of Generative Artificial Intelligence (GenAI) into higher education is transforming how university students access information, engage with learning tasks, and approach complex academic problems, making it increasingly important to understand the cognitive mechanisms that support effective AI-assisted learning. The effects of cognitive agility, Generative AI-assisted learning, metacognitive competence, and problem solving with an emphasis on the mediating role of metacognitive competence on university students in Punjab and Sindh, Pakistan were analyzed. A quantitative, cross-sectional research design was utilized. 397 students were selected from universities using an adopted structured questionnaire filled in using the online Google Forms. Data was collected and analyzed in SPSS after being organized and screened in Microsoft Excel. Among the study variables, cognitive agility and Generative AI learning had a positive correlation which was statistically significant and explained metacognitive competence and problem solving. In terms of predictors, cognitive agility, Generative AI learning, and metacognitive competence had a positive correlation which was statistically significant and explained problem solving, with metacognitive competence having a more significant contribution. According to the mediation analysis, metacognitive competence was a significant mediator of the relation between cognitive agility and problem solving and between Generative AI learning and problem solving. This means that in terms of flexible thinking and learning enhanced by AI, planning, monitoring, evaluating and controlling one's cognitive processes is a crucial factor in the effective resolution of problems. This study indicates that describing Generative AI as a teaching tool would not be enough. Teaching flexible thinking and planning, monitoring and controlling through metacognition is of equal importance. These findings can help higher education professionals, curriculum developers, and policy creators build responsible, reflective, and cognitively empowering AI-enabled learning environments in universities.

Introduction

Complexifying information and knowledge can change rapidly. Different academic problems cannot be solved by rote memorization. In this changing situation, problem-solving effectiveness is an important higher-order cognitive skill. This skill defines the ability to identify problems. It also includes interpreting information and generating alternatives, evaluating and interpreting evidence, and selecting the most adequate solution. This requires students to change the way they think in the face of the changing and odd. This requires cognitive agility, which is the ability to simultaneously possess multiple perspectives, change cognitive strategies, integrate new knowledge, and respond flexibly to changes, all of which are important to contemporary higher education. Cognitive flexibility is an important attribute for students to perform complex tasks associated with academia and shift strategies when customary approaches fail (Almasri, 2024; Yusuf et al., 2024).

Cognitive agility is more important than ever due to the rapid inclusion of Generative Artificial Intelligence (GenAI) into higher education. Examples of GenAI such as ChatGPT are able to respond to requests and provide additional information, explain ideas and concepts, offer alternative solutions, summarize information, and give feedback. These offerings and features may certainly aid students in several steps of the process of problem solving. However, students cannot rely on AI for effective learning and independent reasoning. In fact, new research shows that GenAI facilitates higher-order thinking and problem-solving skills of students, but may create chronic cognitive offloading, unwavering assistance, and incomplete vetting of AI outputs (Urban et al., 2024; Chen & Cheung, 2025). As a result, students must cultivate cognitive agility more than ever to interpret the output of AI, offer and justify alternative perspectives, and adapt to the challenges of differentiated academic situations.

In this new learning context, metacognition is a critical self-regulation component, connecting flexible thinking with AI-based learning to solve problems. With metacognition, learners plan, monitor, evaluate, and adapt. This control is needed when students use GenAI to assess if AI-produced responses are accurate, relevant, appropriate, and sufficiently justified for the case being addressed. It is clear that students must possess the correct level of metacognition to control their reliance on AI to develop cognitive responses. Recent studies affirm that metacognition positively impacts students' control of AI-guided learning, while the absence of such self-regulation increases the negative impacts of such technologies on learners' cognitive engagement (Yoo & Ahn, 2024). Therefore, considering the cognitive, generative AI, learning and problem solving paradigms, and their relationships with metacognition, can better describe how university students can use newly developed AI systems to control their cognitive processes.

Generative AI-Assisted Learning and Students' Cognitive Development

Generative AI (GenAI) is reshaping how university students learn and how they access, analyze, evaluate, and synthesize information. Large language models enable students to generate explanations, construct examples, structure and develop outlines, outline draft texts, offer alternative suggestions, synthesize complex till structures, and generate writing and coding suggestions, as well as provide instant evaluative feedback for academic tasks. Rather than a replacement for information-seeking technology, these resources are posited to be valuable learning aids. Empirical and review-based studies show that when incorporating GenAI into the instructional design, they can facilitate achievement of learning goals and enhance engagement, analytical, thinking, and problem-solving competencies through the provision of flexible and tailored cognitive resources to the learners. In a study reviewing 158 published studies, Daniel et al. (2025) documented the potential of GenAI to support the development of advanced cognitive skills including analytical abilities, problem-solving, critical thinking, and self-reflection. Similarly, Yao et al. (2024) reported the growing tendency to use GenAI for learning aids, feedback, teaching, and learning adjusted to the needs and preferences of individual learners, indicating that the effectiveness of these iterations primarily depends on the AI-generated content and the extent to which learners engage with the technology.

Even with its benefits, there are concerns about the educational costs of GenAI. AI systems may simplify the task of answering questions by producing responses that are too advanced for the learner, and students may become too dependent on provided answers to the point of avoiding the thinking and engagement necessary for analysis, reasoning, and problem-solving. Cognitive offloading may limit students' ability to assess and interpret data, identify errors, evaluate disparate opinions, and construct their own arguments. Zhai et al. (2024) highlight the importance of examining the implications of over-reliance on AI in educational settings. This is particularly problematic when assessing the efficacy of AI in problem-solving, as successful AI-enabled problem-solving may only deliver correct answers to a user.

The end result may be assessment-centered GenAI usage. Therefore, this technology may be most rewarding when students use it to explore and verify possible solutions. When students use GenAI in such a way, it may support learning. In contrast, uncritical acceptance of AI-generated solutions results in students becoming passive learners. This may be the case in AI-enabled learning environments. Hence, the impact of GenAI on cognitive development within the higher education sector needs to be studied in the context of cognitive flexibility, metacognition, and problem-solving.

Metacognitive Competence as a Mechanism of Effective AI-Supported Learning

In this uncertain realm of education, metacognitive competence offers an important theoretical mechanism for understanding why students may produce different outputs after working with GenAI. Metacognition encompasses the student's understanding and control of their own cognitive processes. Such cognitive processes involve understanding how to initiate a task, monitoring comprehension, assessing the state of progress, and formulating a strategy if the original chosen strategy is ineffective. These cognitive processes gain significance in GenAI assisted learning because information processed and generated by AI may seem credible, and yet, such information may be erroneous, incomplete, biased, or may lack context to fit the requirements of a given academic context. Therefore, it is imperative for students to determine what information they already have, to discern the information they need to supply, to craft accurate prompts, to review the AI responses for quality, to validate critical information, and determine whether the information generated addresses the problem. Within this framework, metacognitive competence invites students to be actively cognizant of their cognitive involvement in the process and to not abdicate their responsibility for learning to the technology. Xu (2025) has also pointed out the significance of explicit metacognitive scaffolding for GenAI learning, noting that such metacognitive scaffolding encourages students to engage in self-regulated learning.

Metacognition helps explain why GenAI use likely aids student learning. One recent study is Rao, S (2025). This study examined university students' GenAI-based education and its influence on academic self-efficacy and problem-solving and metacognition. More generally, this study reflects the trend of looking at the interplay between cognitive processes aided by technology and students' interior cognitive processes. This study implies that the utility of GenAI in an educational setting may provide students with a framework to engage in planning, monitoring, and evaluating their academic problem-solving within an acceptable range. Additionally, recent studies show that the utility of GenAI is likely to be optimized when students interrogate, critically assess, and improve the output, rather than simply using the first response generated by the AI. Therefore, whether GenAI is used as a replacement for cognitive work or as a tool to facilitate enhanced and reflective learning is dependent on the user's metacognitive skills.

From this perspective, the bridge that integrates cognitive agility and the effectiveness of problem solving may include metacognitive competence. The strength of students' cognitive agility for generating alternatives and transforming strategies may be complemented by students' self-regulating efficacy of determining when the best alternative has been identified and when the most appropriate strategy has been implemented. The same stands for GenAI-based learning; even though GenAI may quickly suggest a multitude of possible solutions, students still must assess the alternatives and embed the most relevant among them in their line of reasoning. Thus, the metacognitive ability may be critical for integrating flexible thinking and the inclusion of Generative AI in learning towards the solving of problems effectively. This mediation is worth the effort because most existing studies have looked at Generative AI and metacognition, or metacognition and problem solving, respectively, while comparatively little focus has been placed on formulating an integrated model that combines cognitive agility, Generative AI in learning, metacognition and problem solving effectiveness, specifically at the university level.

Research Objectives

- To examine the relationship between cognitive agility and problem-solving effectiveness among university students.
- To determine the relationship between Generative AI-assisted learning and problem-solving effectiveness among university students.
- To examine the mediating effect of metacognitive competence in the relationships of cognitive agility and Generative AI-assisted learning with problem-solving effectiveness among university students.

Research Questions

- What is the relationship between cognitive agility and problem-solving effectiveness among university students?
- What is the relationship between Generative AI-assisted learning and problem-solving effectiveness among university students?
- Does metacognitive competence mediate the relationships of cognitive agility and Generative AI-assisted learning with problem-solving effectiveness among university students?

Problem Statement

The inclusion of Generative AI in higher education is causing a major concern in education as students ALLOW Generative AI to solve complex problems FOR them, rather than challenging Generative AI as they MASTER cognitive “higher thinking” and problem-solving skills. As previously reported, the consensus is that using Generative AI adversely impacts student cognitive autonomy and analytical thinking. Despite this, positive strides in cognitive and higher-order academic skills have been noted. ChatGPT has revolutionized the way students (intelligently) think of a solution to a problem, and has created a cognitive barrier for students to accurately assess their own performance, indicating that using AI does not guarantee self-regulation. Generative AI may improve the learning outcomes of university students, but may not develop the metacognition of the students. The gap in cognitive agility, coupled with the mere use of Generative AI in the classroom, could allow and inspire students to pursue avenues of "unregulated" self-guided problem-solving, dominated by technology, through metacognitive reasoning. The exact mechanism through which cognitive agility and Generative AI-assisted learning promote problem-solving among university students is still unknown, and more integrated empirical research on cognitive agility, Generative AI-assisted learning, metacognitive competence, and problem-solving effectiveness is needed to adequately explain and understand this phenomenon.

Significance of the Study

This study is unique because it is addressing a new challenge in education regarding how University level students use Generative AI in their cognitive learning while maintaining their critical thinking, flexibility, and strong problem-solving skills.From what is currently known, Generative AI may even enhance higher-order skills like problem-solving, but its educational value will be subject to how the students direct and manage AI-enabled learning. Recent meta-analytic studies show that Generative AI may positively influence University level students’ learning outcomes, while the effects of Generative AI on metacognition are not as clear. This emphasized the need to study cognitive processes in AI-assisted learning that are effective. Thus, this study is significant as its aim is to integrate cognitive agility with Generative AI, metacognition and problem-solving in one framework. The results from this study may fill a gap in the existing literature by providing a theoretical basis to understand how students’ cognitive flexibility, metacognition, and problem-solving are interrelated, and how metacognition may play a role in moving students from cognitive flexibility to effective problem-solving. From a practical perspective, it may provide evidence to University instructors and other institutional stakeholders on how to construct AI-assisted learning designs that will motivate students to go beyond searching for AI-generated answers, to evaluate, monitor and adjust their use of AI generated content in a critical and adaptive manner. This study may also help academics construct pedagogical frameworks that utilize Generative AI in the classroom knowing that there is a risk of losing cognitive and metacognitive functions if it is used to excess (Qian, 2025).

Literature Review

Cognitive agility is vital at the university level because students need to go beyond memorizing and applying knowledge to cope with increasingly complex academic tasks that incorporate skills of flexible reasoning, strategic adaptation, and effective decision-making. Cognitive agility involves the ability to switch between views, change an interpretation, incorporate new information, and adapt cognitive strategies as circumstances or task requirements change. Problem-solving and cognitive agility are closely related because problem-solving rarely follows one fixed path. In such a case, students have to identify the type of problem, assess the information available, consider and develop alternative answers, and abandon ineffective problem-solving approaches and change the strands of their thinking. Cognitive flexibility is the foundation of agile thinking. Abidin, R et al. (2025) conceptualized cognitive flexibility as the ability to rapidly shift from one problem-solving approach to another approach that is optimal under the given circumstances and demonstrated that cognitive flexibility and performance are related. Directly referring to higher education, Mehmood, S et al. (2025) described cognitive agility of university students and illustrated its importance to students' academic functioning. Cognitive agility is, therefore, especially important for university students due to the nature of academic environments, which requires students to respond to a variety of demands and to new and unfamiliar problems, different and competing information, and/or rapidly changing learning situations and intellectually challenging problems.

Adaptive strategy selection is another aspect of cognitive agility that illustrates the relationship between cognitive agility and problem-solving effectiveness. Cognitive agility generates the ability to identify a previously successful approach that is now inappropriate, therefore warranting a change of strategy. This is particularly important in academic problems with multiple potential explanations and/or multiple potential solutions. Some research has shown that when a problem is flexibly solved, a problem-solver must have the ability to reshape their existing knowledge based on the given task requirements (Bobrowicz 2024). Cognitive processes that are required for planning, flexibility and problem-solving, etc, are interrelated and have a positive impact on problem-solving as shown by computational thinking research (Moșoi, A. et al., 2025). Related university studies show that cognitive flexibility was relatively high among the participants of the study, including the assessment of critical thinking (Karakuş 2024). Overall, this research suggests that cognitive agility helps a problem solver to evaluate one's assumptions and other possible alternatives while remaining open to changing the direction of one's line of reasoning when the initial answer fails to solve the problem.

Evidence from university education supports the claim that broader cognitive skills positively impact students' ability to cope with academic demands. Qu, X et al., (2025) found that university students' cognitive ability and academic achievement have a proven positive relationship, and identified reasoning, comprehension, problem-solving, and rapid thinking as cognitive dimensions of interest. From a few related studies, students who possess a higher level of cognitive flexibility have been found to possess a higher level of metacognition compared to their peers of a lower level of cognitive flexibility. This literature further supports the theoretical framework as effective problem-solving relies on a chronic evaluation of the existing system, and whether the problem-solving system needs to be adjusted. This notion is further supported by new metacognition research indicating that students' level of metacognition is positively correlated with their critical thinking after controlling for working memory (2024). Consequently, cognitive agility may facilitate problem-solving effectiveness by more than rapid thinking, but by adaptive and reflective cognitive responses to the changing state of the problem.

Generative AI-Assisted Learning and Problem-Solving Effectiveness in Higher Education

In recent years, one of the most significant developments involving the use of technology in higher education has been the appearance of ChatGPT and other similar programs. These programs are examples of generative artificial intelligence (GenAI). One of the most popular features of ChatGPT and programs like it are the fact that they can explain concepts, offer examples, give alternative strategies for solving problems, give feedback, and provide many other services for students. In this age of GenAI, technologies that assist learning become less passive and more interactive, where students have the opportunity to engage in dialogue with artificial intelligence while they work on their assignments. In a review of 158 studies published between 2021 and 2024, Cong-Lem et al. (2026) reported considerable evidence that GenAI can strengthen and develop cognitive abilities such as critical thinking and problem-solving, as well as analytic thinking and metacognition. The authors highlighted the importance of personalized learning and instant feedback in developing these skill. Likewise, Abbosh et al. (2025) in a systematic review and meta-analysis of 57 studies, found a positive, and relatively large, overall effect of GenAI on university students' learning outcomes, especially on higher-order thinking. This data is indicative that GenAI, when integrated in learning frameworks, is able to provide students with cognitive tools that help them progress beyond simple knowledge retrieval, and facilitate the evaluation, generation, and improvement of solutions.

The effectiveness of GenAI-enhanced learning in problem-solving is clear when students work in tandem with adaptive AI and cognitive resources, instead of using them to replace their thinking. Miao (2026) provided empirical evidence when he analyzed the complex creative problem solving task that university students were assigned. Students using ChatGPT reported higher self-efficacy, lower perceived mental effort, and produced more elaborative and original solutions. Using ChatGPT to help with tasks provided an improvement in student performance. Complex problem-solving tasks in higher education will benefit greatly from the advancement of GenAI technology. ChatGPT helps students perform better at complex tasks; however, students are having difficulty in determining the overall quality of their solutions. High task performance without the ability to regulate one's own judgement and make informed decisions about the sufficiency of related information is counterproductive because the aim of higher education is not just to provide a correct answer. It is about evaluating multiple solutions, understanding the implications, and judging the quality of information within an appropriate context.

Additional systemic studies show that educational outcomes from GenAI are positive, but they depend on how GenAI is integrated into educational activities. Positive educational outcomes will depend on the pedagogical strategies used along with GenAI. Abbas, Z et al., (2026) conducted a meta-analysis that showed that GenAI positively influenced outcomes like academic achievement, higher-order thinking, and affective-motivational outcomes. However, the meta-analysis did not show a significant "metacognition" outcome. This lack of positive influence on metacognition suggests that giving students access to GenAI will not lead to the development of cognitive skills needed for reflective and independent problem-solving. Similar to Abbas et al., Nie, X et al., (2025) argued that GenAI positively impacts learning outcomes and increases learning efficiency and learning creativity and critical thinking and encourages learner autonomy, but over-reliance on AI encourages the outsourcing of critical cognitive and metacognitive functions. In this light, the effectiveness of GenAI-based learning (or any technology-mediated learning) is dependent on the nature of the students' interaction with the technology. If students interrogate AI responses, decide among alternative explanations, verify AI-generated information, and use AI responses as stimuli for further thinking, the technology may enhance problem-solving skills. On the other hand, if students simply take AI responses as answers, the technology may reduce opportunities for students to be actively engaged in problem-solving.

Metacognitive Competence and Students' Problem-Solving Effectiveness

Metacognition is the cognitive skill that enables learners to think and reflect on their own cognitive processes and evaluate the effectiveness of their problem-solving strategies in order to change their strategies when the goal is not achieved. In higher education, problem-solving tasks tend to contain information that students have never encountered before, multiple strategies that students must select from, and cases in which students must decide for themselves whether their reasoning is valid. Knowledge on its own cannot guarantee that students will be successful in problem solving. Students must also know how to apply that knowledge. According to Halmo et al. (2024), the metacognitive component of problem solving requires students to continually assess their level of understanding and the strategic decisions that they make, and self-coaching can assist students in addressing the sticking points that they encounter while attempting to solve complex problems. Their research on first-year students at university confirmed that self-regulated and self-determined learners were able to address challenging problem-solving tasks. This perspective posits that students who have developed their metacognitive abilities move past the simple act of attempting to solve problems, to a more critical evaluation of their problem-solving strategies and whether such strategies are justified. They are also able to make intentional strategic adjustments.

Empirical University Student Research Clearly Illustrates The Relationship Between Metacognition And Problem Solving. Song et. al. (2012) performed a study on problem solving and metacognition with 107 occupational therapy students. They created a regression model and determined that metacognition explained 54.7% of the problem solving ability. They found that cognitive knowledge and cognitive control both made important contributions, and it was therefore determined that the ability to understand and regulate thinking processes is useful in problem solving. Similar research on problem solving disposition of university students, found that metacognition, in combination with critical thinking, predicted problem solving, confirming that the metacognitive processes are significantly important when formulating problem solving approaches. The research studies provide evidence that metacognition is one of the higher cognitive order processes, as demonstrated in a study 3 years ago where middle school and university students were both researched, and the influence of metacognition on critical thinking was found, even after considering working memory. Students that have the ability to control and adjust their thinking will likely be more successful in finding appropriate solutions to the various complex problems they may face in an academic setting.

The significance of metacognitive competence is evident in situations where students have to resolve issues that cannot be fixed by the memorization of facts or the step by step execution of known procedures. In their study of first-year students pursuing a degree in chemistry at the university, Vo et al. (2024) pointed out that the application of metacognitive scaffolding stimulated the development of structured techniques of solving problems over an academic semester. The focus was on planning, monitoring, and evaluating procedures and reflecting on the same. Students developed a range of flexible and creative techniques of approaching problems, although they pointed out that challenges remained in the comprehending and evaluating of concepts. It was noted that the development of metacognition was insufficient without sufficient knowledge and the opportunity for reflective practice. This is an important finding as it confirms that the application of metacognition should not be limited to a range of study techniques, but rather should be employed to regulate the student's existing knowledge to match the nature of the problem to be solved. Recent studies in Complex Problem Solving have described the role of metacognition and the regulation of cognition in the presence of demanding tasks and highlight the importance of monitoring and regulating cognition as the complexity of tasks increases.

The Mediating Role of Metacognitive Competence in the Relationships Between Cognitive Agility, Generative AI-Assisted Learning, and Problem-Solving Effectiveness

It is evident from the new literature that the application of metacognitive competence is necessary to convert students' cognitive resources and learning supported by technology into successful problem solving. Cognitive agility enables students to develop the flexibility to cultivate new perspectives and shift priorities. Despite this, simply being flexible does not guarantee students will select or properly regulate the strategies they apply. Metacognitive ability adds this capability. Metacognitive ability allows students to plan, self check, evaluate, and improve the solutions they develop. It also enables students to apply and regulate the strategies they apply. Research involving university students has described this relationship well. For instance, as recently as next year, it has been shown through research that the level of metacognition a student possesses directly correlates to how effectively the student can solve problems (2024). In other words, students who are cognitively agile, are likely to be able to develop different alternative approaches, but whether they actually succeed in using such approaches would depend on their ability to assess the effectiveness of the approaches and regulate their subsequent behavior. In this context, the ability to self regulate is the difference between being flexible and achieving effective and purposeful problem solving.

Generative AI assistants may challenge the role of metacognitive thinking within learning environments. GenAI can provide learners with multiple explanations, alternative solutions, examples, feedback, and prompts expanding the resources learners may use to solve problems. More cognitive resources are not enough for a learner to make progress on a task. They must evaluate the AI generated resources and determine the accuracy and relevance for their specific problem. Pellas, N (2025), for one, reported that the use of Generative AI in educational tasks enhanced university students' metacognitive process and improved some problem-solving skills, especially the development of alternative solutions. The use of Generative AI in the intervention, however, did not lead to improvements in all the parameters of problem-solving, illustrating that even heavy exposure to AI may not lead to advances in holistic problem-solving. Likewise, ChatGPT was demonstrated by Lee, C et al. (2025) to improve the quality, elaboration, and originality of the solutions, yet students struggled to accurately assess their own performance. There is a need for this model to incorporate such findings given they illustrate that the attainment of optimum learning outcomes from AI use is likely contingent on a learner's ability to assess their own performance involving monitoring and evaluating rather than just answering the questions. Therefore, GenAI provides relevant resources to solve a problem. Yet, the metacognitive capability precisely defines how the resources are interpreted and evaluated to aid the problem-solving process for a user.

New studies continue to illuminate the role of self-regulation and metacognition in explaining the cognitive effects of AI assistance. For instance, Wang et al. (2025) studied 223 college students to show the impact of Generative AI on their self-regulation. In addition, self-regulation was shown to help build students' critical thinking and solve their problems. In addition, a mediation analysis showed the presence of the relationship between the ease of use of GenAI and more complex thinking, but the learning value and perceived GenAI usefulness did not show a similar indirect effect. Since self-regulation, in principle, is inclusive of metacognitive skills, these findings provide empirical evidence for the proposition that the cognitive effects of AI use are mostly likely to be brought about by the students' internal regulatory systems. Alongside this work, Alghamdi (2025) found that the GenAI learning environment, when combined with explicit metacognitive support, enhanced university students' self-regulated learning, especially self-task regulation and self-evaluation, while students lacking such support exhibited declining self-regulation. In addition, Contel and Cusi (2025) argued that students can use GPT-4 to assist and regulate metacognition during problem-solving activities. In sum, the educational impact of GenAI appears to be far from merely adding more technology. Rather, how students cognitively regulate AI interactions is probably the most relevant factor.

Research Gap

This research identifies gaps in current research regarding the cognitive mechanisms underlying the positive impacts of Generative AI on university students' higher-order thinking and problem-solving. One of the recent systematic reviews was conducted by Daniel et al. (2025) on 158 studies. They reported an improvement in cognitive variables, including problem-solving and metacognition, in most of the studies. However, literature on the effects on learning and the mechanisms through which they occur is largely disparate. Chen and Cheung (2025), in their meta-analysis on 57 studies, found positive effects of Generative AI on university students' learning and higher-order thinking. However, they did not find any positive effects on metacognition. Other research, such as the research by Al-Qaisi and Saleh (2024), studied less about the cognitive effects of GenAI. In their study, they focused on the cognitive effects of GenAI on the cognitive agility of university students in relation to their academic performance, rather than cognitive effects on problem-solving. More recent findings suggest that the cognitive effects of GenAI are conditional. Alubthane (2026) synthesized 89 studies, and reported that the positive effects of GenAI were accompanied by the negative effects of over-reliance on GenAI, reduced analytical autonomy, and cognitive offloading, in the absence of sufficient research in this field. Consequently, the author has identified a specific research gap in studying the cognitive effects of Generative AI on problem-solving and cognitive agility in the university students' metacognitive cognition. Closing this gap will enable scholars to move beyond analyzing the direct educational effects of GenAI and begin to identify the cognitive mechanisms through which students develop adaptive thinking and AI-integrated learning that facilitates effective problem solving.

Research Hypotheses

- **H1:** There will be a significant positive relationship between cognitive agility, Generative AI-assisted learning, metacognitive competence, and problem-solving effectiveness among university students.
- **H2:** Cognitive agility, Generative AI-assisted learning, and metacognitive competence will significantly predict problem-solving effectiveness among university students.

- **H3:** There will be significant differences in cognitive agility, Generative AI-assisted learning, metacognitive competence, and problem-solving effectiveness among university students based on selected demographic characteristics.
- **H4:** Metacognitive competence will significantly mediate the relationships between cognitive agility and problem-solving effectiveness and between Generative AI-assisted learning and problem-solving effectiveness among university students.

Methodology

Research Design

This study employed a quantitative, cross-sectional survey research design. The main research tool in this case was a structured tool used to collect numerical data on cognitive agility, Generative AI-assisted learning, metacognitive skills, and effective problem solving among the undergraduate learners within a university setting. I opted to use the quantitative approach because it provides the opportunity to evaluate the relationships that exist among the study variables in a statistical sense, and also to evaluate the relationships of both predicting and mediating in the research model that I have constructed. The cross-sectional design was adopted because the data were collected from the respondents at one point in time, as opposed to collecting data numerous times over a prolonged period of time. Similar recent studies that examined GenAI-assisted learning in the higher education context also employed a cross-sectional survey design to examine learning-oriented AI use and the cognitive and learning processes of the students (Zhang et al., 2026).

Population

This study's population included university students in higher education institutions in the provinces of Punjab and Sindh in Pakistan. When determining the extent of coverage, the goal was to capture students across different levels and settings of academia in the two provinces. For Punjab, data were collected from students associated with the following institutions: Bahauddin Zakariya University, Multan; The Women University Multan; Muhammad Nawaz Sharif University of Agriculture, Multan; Nishtar Medical University, Multan; University of Education, Multan Campus; Government College University Faisalabad; University of Sargodha; University of the Punjab, Lahore; and University of Lahore. For Sindh, respondents were collected from the following institutions: University of Karachi, Karachi; Jinnah Sindh Medical University, Karachi; Dow University of Health Sciences, Karachi; University of Sindh, Jamshoro; and Shah Abdul Latif University, Khairpur. Collecting data from a set of institutions in Punjab and a set of institutions in Sindh was done with the aim of getting a wider representation from students in different disciplinary and institutional environments, as opposed to just limiting the study to one university.

Target Audience

The target population consisted of undergraduate and graduate students from higher education institutions in Punjab and Sindh, Pakistan. Students from different academic disciplines were considered as potential participants because cognitive agility, AI-assisted learning, metacognitive skills, and problem-solving are relevant to various fields of study. Participants were required to be university students with a reasonable amount of experience using digital learning environments to answer the questions pertaining to Generative AI-assisted learning. Individuals who were not university students or who had significantly incomplete questionnaires were not included in the final data set.

Sampling Technique

The sampling technique used for this research was purposively done. The main inclusion criteria were being a current university student and having prior experience with digital learning as part of contemporary learning environments. The sample was collected from online academic networks and institutional contacts spread across Punjab and Sindh using the convenience sampling method. As the survey was conducted online, people from different institutions were able to participate irrespective of their access to a research site. This method also sought to provide a large sample of participants from various universities and a wide range of backgrounds to provide enough and varied examples of the participants' experiences relating to Generative AI and higher education learning.

Sample Size

The analysis was completed using 397 valid published responses of university students. The sample was considered adequate for the planned correlational and regression analyses. The dataset was therefore composed of 397 participants employed in higher education in Punjab and Sindh, Pakistan.

Data Collection Procedure

The data were collected using an online structured tool in Google Forms. The survey was shared through academic and student networks, and participants were able to complete the survey using direct online communication. Before completing the survey, people were informed about the focus of the study, the voluntary nature of the participation, and the protection of response confidentiality and participants' right to withdraw from the study at any time.

After the collection period was complete, I exported the responses from Google Forms into an Excel file. Before conducting the statistical analysis, I corrected the dataset by checking for incomplete responses and inconsistencies. After the dataset was cleaned and ready to be analyzed, the data was exported from Excel to SPSS for the analysis.

Research Instrument and Measurement Scales

The questionnaire was designed as an adopted and contextually adapted instrument. Items were sourced from established measurement tools and recent higher education studies, and were appropriated to apply to the context of Pakistani university students from Punjab and Sindh. The survey's main constructs utilized a five-point Likert response format ranging from 1 = strongly disagree to 5 = strongly agree. The use of Likert-based measurement is in line with recently published GenAI studies within the scope of higher education, where the use of learning-oriented GenAI has been assessed through the use of five-point response types. One example of this is Zhang et al. (2026) who employed a six-item learning-oriented GenAI-use scale of a five-point Likert response format covering the use of GenAI to support academic requirements to assist in understanding difficult concepts, arrange and organize learning materials, plan and organize academic activities, and receive feedback.

An adapted version of the cognitive agility scale was used to measure cognitive agility. The version used was adapted from Al-Qaisi and Saleh (2024), who studied cognitive agility in the context of university students and used a specific measure of cognitive agility on a sample of 400 students. Their study reported reliable cognitive agility with a Cronbach's alpha of .85 and test–retest reliability of .88. The present items of the questionnaire were adapted to emphasize students' ability to shift between multiple viewpoints and maintain flexibility of thought as well as the ability to consider other approaches to address different kinds of shifting and changing academic problems.

The items used to capture students' academic use of Generative AI as a learning-support resource were adapted from General AI-assisted Learning. The focus is on learning-related uses rather than General AI-related attitudes. Generative AI is used to understand difficult concepts, synthesize and organize learning materials, plan tasks and activities, and generate feedback to support the learning process. This is aligned to Zhang et al. (2026), who conceptualized learning-related GenAI use as generative AI supporting the understanding, organization, planning, and feedback of tasks and learning activities. Recent research has also focused on the development of measures specific to GAI-assisted learning in higher education, as well as adapting these measures to the context of university-related learning (2026).

To assess metacognitive skills, a modified version of the Metacognitive Awareness Inventory (MAI) was used. Schraw and Dennison (1994) constructed their original 52-item version to evaluate levels of metacognition related to the knowledge and regulation of cognitive processes. Schraw and Dennison (1994) reported strong internal reliability of the principal factors of the inventory, which they developed based on undergraduate student samples. Items included in the inventory were modified to reflect the learning and problem solving context of the university to evaluate students' awareness and regulation of their cognitive processes while learning and problem solving.

The Problem Solving Inventory (PSI) was adapted for this research to assess problem-solving effectiveness. This version was based on the work of Heppner and Petersen (1982), and it is comprised of the confidence dimension of problem-solving, style of approach and avoidance, and personal control. The original instrument had 32 items and used a 6 point scale with good internal consistency and temporal stability. Like the other measures included in the study, the response format of this measure was also standardized. The inventory was used to assess students' perceptions of their problem-solving effectiveness, control, and the strategies they use to solve complex problems.

Instrument Adaptation and Reliability

Prior to primary data collection, contextual clarity of adopted scales was evaluated. Items were modified and based on specific references to the university students' understanding across academic learning, Generative AI, and problem-solving. The modified questionnaire underwent assessment towards redundancy and clarity prior to administration. After data collection, internal consistency of the study scales was assessed using Cronbach's alpha. Reliability assessment for cognitive agility, Generative AI-based learning, metacognitive ability, and problem solving was performed separately. Satisfactory internal consistency of constructs was evaluated based on the outcome of the reliability assessments. This enabled researchers to proceed with the principal inferential analyses.

Ethical Considerations

The study conformed to the initial ethical standards in research involving human participants. Participants were able to decide not to participate. Before the participants completed the questionnaire, they were informed about the purpose and the general nature of the research. Informed consent was done by a click and participants proceeded to the survey without providing personally identifiable information. Participants were given confidentiality and the response data were kept for the sole purpose of scholarly research in a manner that restricted access of data to unauthorized persons. Participants were informed they could choose to not participate in the research without any consequence being imposed. The study adhered to the principles of respect for voluntary participation, confidentiality, and privacy.

Data Analysis

Response data from the Google Form surveys were exported to the Microsoft Excel platform, where data was organized, coded, and analyzed for missing and/or inconsistent data and for screening. Following the cleaning process, the dataset was uploaded to SPPS for analysis and calculation of descriptive statistics. Descriptive statistics were calculated for the main survey data and the demographic data. Continuous data was analyzed for mean and standard deviation, and for categorical data, frequency and percentages were analyzed.

The internal structure of the measurement tools used was assessed using Cronbach's alpha. Using Pearson's correlation measurement, the relative and absolute strength for the relationships among cognitive agility, Generative AI-assisted learning, metacognitive competence and problem-solving capability was evaluated. To address the main research question, the relationships among cognitive agility, Generative AI-assisted learning, and metacognitive competence and problem-solving capability were assessed using multiple linear regression analysis. The analysis included standardized regression coefficients, the coefficient of determination (R^2) and the adjusted R^2, the F value, and the significance level, and appropriate confidence intervals.

For the study variables under comparison where two demographic groups were defined, an independent-samples t-test was conducted to evaluate statistically significant differences. When the demographic groups defined had three or more categories, one-way analysis of variance (ANOVA) was utilized to evaluate the differences among group means. When a statistically significant F value (overall) was obtained, the post-hoc analysis was limited to Tukey's HSD to establish the means between groups where statistically significant differences were noted.

In conclusion, a mediation analysis using bootstrapping was conducted to determine if metacognitive competence mediates the associations between cognitive agility and problem-solving effectiveness, and between Generative AI-assisted learning and problem-solving effectiveness. Bootstrapped confidence intervals were used to examine indirect effects. The mediation effect was considered significant if the confidence interval for the indirect effect excluded zero. The process was chosen because of the growing scholarship on Generative AI and its indirect cognitive and learning mechanisms, which have mainly relied on mediation models and bootstrapped indirect effects. As an example, Zhang et al. (2026) used bootstrapped mediation analysis to study the indirect pathway of learning-oriented Generative AI use and learning outcomes.

The analysis of the data was conducted at a 0.05 significance level (.05). This means effects were considered to be statistically significant if the p- value was less than .05. The overall analysis therefore included data screening, description statistics, reliability analysis, Pearson correlations, multiple linear regression, independent samples t-tests, one-way ANOVAs with subsequent Tukey HSD post hoc analysis, and bootstrapped mediation analysis. The order of the analyses was designed in a way that would allow a thorough analysis of the associations between cognitive agility, Generative AI-based learning, competence of metacognition, and problem-solving effectiveness.

Table 1: Demographic Characteristics of University Students (N = 397)

Demographic Variable	Category	Frequency (f)	Percentage (%)
Gender	Male	207	52.1
	Female	190	47.9
Age	18–21 years	145	36.5
	22–25 years	171	43.1
	26–29 years	56	14.1
	30 years and above	25	6.3
Academic Level	Undergraduate	243	61.2
	Master’s	103	26.0
	MPhil/MS	38	9.6
	PhD	13	3.3
Province	Punjab	247	62.2
	Sindh	150	37.8
Academic Discipline	Social Sciences	89	22.4
	Business/Management	72	18.1
	Computer Science/IT	76	19.1
	Medical/Health Sciences	68	17.1
	Natural Sciences	51	12.8
	Engineering	41	10.3
Total	—	397	100.0

According to the demographic study, 207 (52.1%) participants were male and 190 (47.9%) were female. This balance between males and females demonstrates a relatively even distribution. Regarding age, the majority of respondents were 22 through 25 years (43.1%) and 18 through 21 years (36.5%). Meanwhile, 14.1% of respondents were between 26 and 29 years and 6.3% of respondents were 30 years and older. With respect to the academic level, 61.2% of the respondents were undergraduate students and 26.0 % were Master’s students. Furthermore, 9.6% of the participants were enrolled in MPhil/MS and other postgraduate studies and 3.3% were PhD students. Of the participants, 62.2% were from Punjab and 37.8 % were from Sindh, thus representing the two study regions. With respect to academic disciplines, participants from the Social Sciences (22.4%) were the largest group, followed by participants from the Computer Sciences (19.1%), followed by participants from the Business and Management (18.1%) and participants from the Medical and Health Sciences (17.1%). Additionally, participants from the Natural Sciences (12.8%) and participants from the Engineering (10.3%) comprised the participants. Overall, based on the given demographic information the study includes university students across multiple age groups, levels of academic study, regional Location, and disciplines.

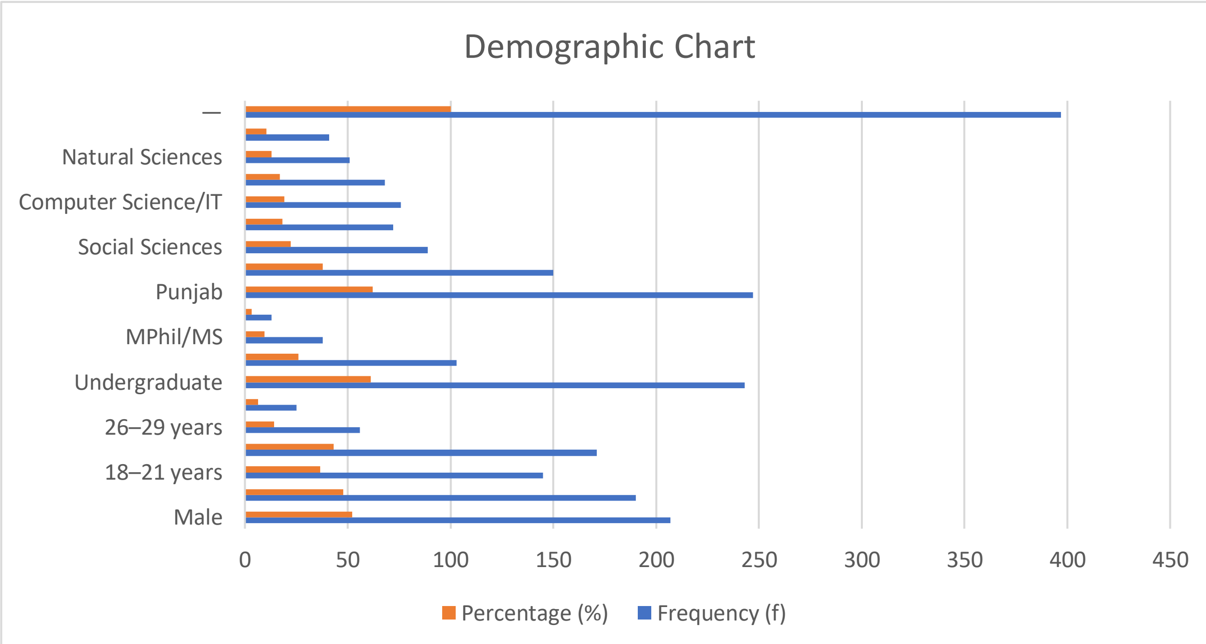

Fig 1. Demographic Chart

Table 2: Pearson Correlation Matrix of the Study Variables (N = 397)

Variables	1	2	3	4
1. Cognitive Agility	1			
2. Generative AI-Assisted Learning	.462**	1		
3. Metacognitive Competence	.571**	.548**	1	
4. Problem-Solving Effectiveness	.624**	.593**	.681**	1

Note. p < .01 (2-tailed). N = 397.

Positive correlations for all study variables were confirmed by the analysis of Pearson correlations. For cognitive agility, positive and significant correlations were observed for Generative AI-assisted learning ($r = .462, p < .01$), metacognitive competence ($r = .571, p < .01$), and problem solving ($r = .624, p < .01$). For Generative AI-assisted learning, correlations were positive and significant for metacognitive competence ($r = .548, p < .01$) and problem solving ($r = .593, p < .01$). The strongest correlation was found for metacognitive competence and problem solving ($r = .681, p < .01$). This suggests that problem solving was more automated and accomplished with greater ease for participants with higher levels of metacognitive competence. The overall results indicated that positive correlations exist among cognitive agility, Generative AI-assisted learning, metacognitive competence, and problem solving. From a research standpoint, the positive correlations among the study constructs support the hypothesis.

Table 3: Multiple Linear Regression Predicting Problem-Solving Effectiveness (N = 397)

Predictor	B	SE	β	t	p
Constant	0.842	0.214	—	3.93	< .001
Cognitive Agility	0.286	0.051	.271	5.61	< .001
Generative AI-Assisted Learning	0.241	0.049	.238	4.92	< .001
Metacognitive Competence	0.394	0.052	.386	7.58	< .001

Model Summary

R	R^2	Adjusted R^2	F	df	p
.741	.549	.545	159.68	3, 393	< .001

Data obtained from the multiple regression analysis describe cognitive agility, Generative AI-assisted learning, and metacognitive competence as significant positive predictors of problem-solving effectiveness for University students. The overall regression model was significant at the level of $p < .001$ and contained an R^2 of .549, indicating that the combined predictors explained 54.9% of the variability in problem-solving effectiveness. Cognitive agility positively predicted problem-solving effectiveness, and was significant at $p < .001$ and the value of β was .271. These results show that the more students demonstrate cognitive agility, the more likely it is that students will be able to solve problems. Participants' engagement with Generative AI for learning also positively predicted problem-solving effectiveness, and was significant at $p < .001$ and the value of β was .238. Of the three predictors, participants' metacognitive competence was the strongest predictor of problem-solving effectiveness. Based on the results, all three predictors made independent significant contributions to problem-solving effectiveness, with metacognitive competence being the absolute strongest of the three.

Table 4: Tukey HSD Post-Hoc Comparisons by Academic Level (N = 397)

Dependent Variable	Significant Pairwise Comparison	Mean Difference	p
Cognitive Agility	Undergraduate – MPhil/MS	-0.26	.018
	Undergraduate – PhD	-0.38	.031
Generative AI-Assisted Learning	Undergraduate – MPhil/MS	-0.31	.006
	Undergraduate – PhD	-0.46	.004
	Master's – PhD	-0.29	.047
Metacognitive Competence	Undergraduate – MPhil/MS	-0.27	.021
	Undergraduate – PhD	-0.41	.015
Problem-Solving Effectiveness	Undergraduate – MPhil/MS	-0.31	.009
	Undergraduate – PhD	-0.44	.012
	Master's – PhD	-0.29	.039

Overall, the group-comparison findings showed significant differences in the main study variables for gender and academic level groups. For cognitive agility, learning with the assistance of Generative AI, metacognitive skills, and problem-solving, female students showed higher mean scores compared to male students. From the ANOVA results, it showed that the participants in the study, with more advanced academic levels, showed higher mean scores in the four constructs, with the most noticeable differences being shown between participants in the undergraduate level and participants enrolled in MPhil/MS or PhD programs. In line with the significant omnibus ANOVA results, the Tukey HSD post-hoc analysis showed significant results. These results showed that students' demographics and academic levels may affect their cognitive agility, their use of Generative AI in their academic work, their metacognition, and the effectiveness of their problem-solving skills.

Table 5; Mediation Analysis of Metacognitive Competence (N = 397)

Predictor (X)	Mediator (M)	Outcome (Y)	Direct Effect (c′) β	Indirect Effect (ab) β	SE	95% LLCI	95% ULCI	Total Effect (c) β	p
Cognitive Agility	Metacognitive Competence	Problem-Solving Effectiveness	.287**	.220**	.041	.143	.305	.507**	< .001

Predictor (X)	Mediator (M)	Outcome (Y)	Direct Effect (c′) β	Indirect Effect (ab) β	SE	95% LLCI	95% ULCI	Total Effect (c) β	p
Generative AI-Assisted Learning	Metacognitive Competence	Problem-Solving Effectiveness	.238**	.207**	.039	.134	.287	.445**	< .001

Note. β = standardized effect; SE = standard error; LLCI = lower-limit confidence interval; ULCI = upper-limit confidence interval. p < .01. Bootstrap resamples = 5,000; N = 397.

Results of the mediation analysis show that a metacognitive competence mediates the relation between cognitive agility and problem-solving effectiveness. An indirect effect was significant (β = .220, SE = .041, 95% CI [.143, .305]). The confidence interval did not include Zero, therefore the indirect effect was significant. Cognitive agility also had a direct effect on problem-solving effectiveness, and this effect was significant after controlling for metacognitive competence (β = .287, $p < .001$). This shows that metacognitive competence partially mediates the relation between Cognitive agility and problem-solving effectiveness. Similarly, in the mediation analysis of Generative AI-assisted learning, metacognitive competence also had a significant mediating effect (β = .207, SE = .039, 95% CI [.134, .287]), and Generative AI-assisted learning also had a significant direct effect on problem-solving effectiveness (β = .238, $p < .001$) on problem-solving effectiveness, showing a partial mediating effect. The total effects of cognitive agility (β = .507, $p < .001$) and Generative AI-assisted learning (β = .445, $p < .001$) on problem-solving effectiveness were significant. These results indicate cognitive agility and Generative AI-assisted learning have direct and indirect effects on problem-solving effectiveness through metacognitive competence. These results indicate that planning, monitoring, evaluating, and regulating one's cognitive processes has great relevance in the conversion of flexible thinking and AI-driven learning towards greater problem-solving effectiveness.

Discussion

The focus of this study was on the relationships between cognitive agility, Generative A.I.-enhanced learning, metacognition, and effectiveness in problem-solving amongst university students. The overall findings suggested a positive relationship amongst the four constructs. This suggested that participants who reported a high level of cognitive agility demonstrated a high level of involvement with Generative A.I. and metacognition, and thereby reported a high level of problem-solving effectiveness. The regression analysis also confirmed cognitive agility, Generative A.I.-enhanced learning, and metacognition as predictors of problem-solving effectiveness, in that order of importance. The results further confirmed that problem-solving effectiveness in the contemporary university context is a function of cognitive flexibility, the right level of technology engagement, and the self-regulation of thinking processes. The results were in line with Al-Qaisi and Saleh (2024) who identified cognitive agility as an important feature of university students, while other studies have consistently shown that metacognition has a strong impact on the problem-solving abilities of students.

The positive association between cognitive agility and problem solving effectiveness shows that students who are capable of shifting their perspectives and changing their assumptions, and those who can mention other views, are adept more than most at solving complex academic problems. Problem-solving at times requires students to move beyond usual patterns. Many students use a strategy, but if that strategy fails, they should be able to change their strategies. Cognitive agility provides the flexibility needed to consider different solutions. This finding is consistent with the research that shows the role of higher order cognitive skills in problem solving of university students. The recent research provides evidence that metacognition and critical thinking have a great influence in problem-solving, and this shows that effective problem-solving requires the possession of knowledge and the flexibility to control its application.

Generative AI-based learning and problem solving ai tools demonstrate an even deeper understanding of the intricate nature that learning and problem-solving require. The teaching and assessment of learning activities should therefore adopt the principles proposed in this research. Several examples of AI based educational tools include AI offering alternative explanations, answers, and feedback to students as well as helping students to generate potential solutions to problems by suggesting multiple solution paths. This view is further supported by Urban et al. (2024) who reported that the use of ChatGPT during a problem-solving task made a positive impact on the quality, elaboration, and originality of the solutions provided by university students. Additionally, Yoo and Ahn (2024) indicated that the use of Generative AI for educational activities was related to students' metacognition and problem-solving skills. It is important to note, however, that these findings should not lead us to conclude that the use of AI in education is the panacea to the myriad of problems that face the education sector. The AI tools that are currently available offer students the potential to learn, but the onus is on students to assess and adjust the AI generated outputs, as the outputs may include inaccurate, misleading, or inappropriate information.

The present study found that metacognitive competence and problem-solving effectiveness have the strongest relationship. Additionally, mediation analysis showed that metacognitive competence mediates the relationships of cognitive agility and problem-solving effectiveness and Generative AI-assisted learning and problem-solving effectiveness. This suggests that metacognitive competence is critical in helping students think flexibly and use Generative AI to learn, as it enables them to plan, monitor, evaluate, and control their cognitive activities to better achieve problem-solving effectiveness. While in the present study, cognitive agility is concerned with students' ability to come up with multiple problem-solving strategies, metacognitive competence is concerned with students' ability to evaluate the strategies they generate and assess whether the strategies help them to reach the desired goal. In the context of Generative AI, students need to figure out the responses generated by the program, assess the responses critically, suggest alternative solutions, and take responsibility for the consequences of their decisions, as no one but them can do that. Urban et al. (2024) showed that students' ability to self-evaluate continues to be an important limitation when assisted by ChatGPT. Based on the mediation analysis, the educational impact of Generative AI is still restricted unless students are able to regulate their interactions with it.

In summary, the findings begin the integration of cognitive agility, learning with Generative AI, metacognitive competence, and problem solving in a single explanatory framework. The findings provide direction for universities on how they should position Generative AI for their students beyond its capacity to generate information. The use of Generative AI should be integrated with learning systems that require students to reflect and metacognitively self-regulate. Examples of such activities may require students to present their solutions and then compare their solutions with the solutions provided by the AI. Students may also be tasked to assess AI outputs for accuracy. Furthermore, they may explain why certain solutions should be validated or dismissed. The findings should be treated with caution and should not be generalized beyond the current study. The cross-sectional, self-report nature of the study does not establish causal relationships. Objective problem-solving tasks should be used in conjunction with longitudinal or experimental studies to determine whether the relationships are dependent on cognitive performance when students are measured and AI-use behaviors are assessed.

Conclusion

This study has reported (1) cognitive agility, assisted learning with Generative AI, and metacognitive competence and (2) the problem-solving effect of university students. The regression analysis showed that cognitive agility, assisted learning with Generative AI, and metacognitive competence contribute to problem-solving effect differently, and the last of them showed the greatest dominance. This suggests the importance of planning and controlling and evaluating one's cognitive processes when dealing with problems. The results showed that contemporary higher education requires not only deep knowledge, but also flexible thinking and the proper use of new technologies.

Furthermore, the results displayed that metacognitive competence plays a mediating role in the effects of cognitive flexibility and assisted learning with Generative AI on problem-solving. Being in control and not being passive to generated information has a major effect on students' use of assisted learning. Therefore, fostering the responsible and self-reflective use of Generative AI, and cognitive flexibility along with the use of metacognition, are recommended. Despite the valuable evidence of the research, the cross-sectional design impedes the interpretation of cause and effect. For that reason, future studies are recommended to use longitudinal and experimental methods along with validated objective measures to examine the interactions of the three factors in the higher education learning environment.

Recommendations

- Integrate Generative AI into university teaching through structured learning activities that support students' understanding, analysis, and problem-solving skills.
- Develop students' metacognitive competence by incorporating planning, self-monitoring, self-evaluation, and reflection activities into academic courses.
- Strengthen cognitive agility through case studies, problem-based learning, debates, simulations, and tasks requiring students to consider multiple solutions.

- Promote responsible Generative AI use by training students to critically evaluate, verify, and cross-check AI-generated information before using it academically.
- Provide faculty training so instructors can design AI-supported learning activities that encourage independent reasoning rather than excessive dependence on AI-generated answers.
- Establish institutional AI-literacy guidelines addressing appropriate AI use, academic integrity, information verification, privacy, and responsible engagement with Generative AI.
- Conduct future longitudinal and experimental research using larger and more diverse samples, objective problem-solving tasks, and behavioural measures of Generative AI use to examine causal relationships among cognitive agility, metacognitive competence, AI-assisted learning, and problem-solving effectiveness.

Future Implications

The results of this study offer many timely and important directions for the advancement of university education in an environment dominated by technological support and especially the support of AI. Generative AI will likely become an integral part of future educational systems. Research will likely benefit from the use of generative AI. Metacognition will become a dominant part of educational systems. It will be integrated with cognitive flexibility and problem-based learning. AI literacy will be offered at universities and faculty will be able to design learning systems that support the use of AI. Future studies should focus on longitudinal and experimental studies to establish the relationship between cognitive agility and Generative AI-assisted learning and metacognitive competence with the help of larger and more diverse samples and measures of problem-solving performance that are not subject to judgment. It could be of interest to other researchers to what extent factors such as AI literacy, digital competence, and academic discipline, as well as learning motivation and critical thinking skills, affect the aforementioned relationships. These advances could promote a higher education system that integrates Generative AI to enhance cognitive tools while learners remain in charge of the planning and directing of their own learning and cognitive processes.

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