



Reconceptualizing Student Agency in AI-Supported STEM Learning: A Qualitative Study of Autonomy, Regulation, and Dependency

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Abstract. *This study explores student agency in Artificial Intelligence (AI)-supported STEM learning environments, addressing a critical gap in existing literature that predominantly focuses on learning outcomes rather than learner-centered processes. Drawing on an interpretive qualitative approach, this research investigates how students experience autonomy, self-regulation, and decision-making when interacting with AI technologies in STEM education. Data were collected from 15 participants engaged in AI-supported learning through in-depth semi-structured interviews, supported by observations and document analysis. The data were analyzed using thematic analysis to identify recurring patterns and meanings related to student agency. The findings reveal that student agency is a dynamic and multidimensional construct shaped by the interplay between technological affordances and learner engagement. Four major themes emerged: enhanced autonomy, development of self-regulated learning, negotiated decision-making, and ambivalent dependency on AI. While AI technologies provide adaptive support that empowers students to take control of their learning, they also introduce the risk of over-reliance, which may reduce cognitive engagement. This study contributes to the theoretical advancement of student agency by conceptualizing it as a spectrum rather than a fixed attribute, highlighting the dual role of AI as both an enabler and a constraint. The findings offer important pedagogical implications for designing AI-supported STEM learning environments that promote active, reflective, and responsible learning. Future research is recommended to explore this phenomenon across diverse contexts and through longitudinal designs.*

Keywords: *AI-Supported Learning; Educational Technology; Learning Autonomy; Qualitative Study; Self-Regulated Learning.*

1. INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has significantly transformed contemporary educational practices, particularly in Science, Technology, Engineering, and Mathematics (STEM) education. AI-based technologies, such as intelligent tutoring systems, adaptive learning platforms, and data-driven analytics, have enabled more personalized and efficient learning experiences (Strielkowski et al., 2025; Yekollu et al., 2024). These innovations are often associated with improved academic performance and enhanced student engagement. However, beyond these measurable outcomes, the integration of AI raises critical questions about how learners actively participate in and take control of their own learning processes (Sajja et al., 2025).

The concept of student agency has emerged as a central focus in modern educational discourse, emphasizing learners' capacity to make choices, set goals, and regulate their own learning. In STEM education, student agency is particularly essential because the nature of these disciplines requires inquiry, experimentation, and problem-solving (Smith et al., 2022; Tan et al., 2023). Learners are expected not only to acquire knowledge but also to construct understanding through active engagement. Therefore, fostering student agency is fundamental

to developing higher-order thinking skills and preparing students to address complex real-world challenges (Luo, 2025).

The integration of AI into STEM learning environments presents both opportunities and challenges for student agency. On the one hand, AI can support agency through real-time feedback, adaptive learning pathways, and personalized scaffolding tailored to individual needs (Xiao & He, 2025). These features can empower learners to exercise greater control over their learning trajectories. On the other hand, concerns have emerged that excessive reliance on AI systems may diminish cognitive engagement and decision-making autonomy, potentially fostering passive learning behaviors (Girma, 2025; Zhai et al., 2024).

Despite the increasing adoption of AI in education, existing studies remain predominantly focused on its effectiveness in improving learning outcomes, engagement, or efficiency. Attention to how AI influences student agency, particularly within STEM contexts, remains limited. Moreover, there is a lack of empirical and conceptual clarity regarding the mechanisms through which AI may either enhance or constrain agency. This gap highlights the need for deeper exploration through the integration of technological, pedagogical, and psychological perspectives (Al Harrasi et al., 2025; Rao et al., 2025).

In response to this gap, the present study aims to explore student agency within AI-supported STEM learning environments. Specifically, it seeks to examine how AI tools shape learners' autonomy, self-regulation, and decision-making processes, as well as to identify key factors that mediate this relationship. By combining quantitative and qualitative approaches, this research provides a comprehensive understanding of the dynamics between AI integration and student agency.

This study contributes to the advancement of the literature on AI in education by offering a learner-centered perspective that extends beyond performance metrics. It proposes a conceptual and empirical framework for understanding student agency in AI-driven STEM learning and provides practical implications for educators and instructional designers. Ultimately, this research supports the development of more balanced and pedagogically grounded AI integration, thereby empowering learners as active agents in their educational experiences.

2. THEORETICAL FRAMEWORK

Student Agency in Learning Contexts

Student agency in the context of learning refers to learners' capacity to consciously and purposefully influence their learning processes through goal setting, decision-making, and the management of learning strategies (Ponomariovienė & Jakavonytė-Staškuvienė, 2025). This concept positions students as active subjects who construct knowledge rather than merely receive information. In modern educational paradigms, student agency is regarded as a key element in creating meaningful and sustainable learning experiences (Sidiropoulos, 2022). Agency reflects individuals' ability to act autonomously and responsibly in directing their educational journeys. This aligns with twenty-first-century demands that emphasize independence, creativity, and critical thinking. The presence of agency enables learners to adapt their learning processes according to their needs and interests (Adeoye et al., 2024; Valqueresma, 2024). Furthermore, agency contributes to increased self-confidence and intrinsic motivation. Therefore, strengthening student agency has become a primary indicator of the success of learner-centered education systems.

Philosophically, the concept of student agency is rooted in constructivist theory, which asserts that knowledge is actively constructed through interactions between individuals and their environments (Zajda, 2021). Jean Piaget emphasized that learning involves assimilation and accommodation as primary mechanisms in the formation of cognitive structures (Piaget & Cook, 1952). Meanwhile, Lev Vygotsky highlighted the importance of social interaction and the role of cultural contexts in cognitive development (Vygotsky & Cole, 1978). The constructivist perspective positions students as active learners who construct meaning based on experience and reflection. Within this framework, teachers serve as facilitators who provide learning environments that support exploration and collaboration. Student agency emerges when learners are given opportunities to participate actively in the learning process. This includes the freedom to select learning strategies and the responsibility to achieve academic goals. Consequently, constructivism provides a robust theoretical foundation for the development of agency in contemporary education.

In practice, student agency reflects not only freedom of choice but also responsibility in managing learning independently. Agency involves reflective capacities that enable learners to evaluate their decisions and learning outcomes (Stenalt & Lassesen, 2022; Zebua, 2024). This process creates a balance between individual freedom and academic accountability. Freedom without responsibility may result in unfocused learning, making the role of educators crucial in providing guidance. Therefore, learning environments must be designed to support

autonomy while offering clear structures. This concept is known as “guided autonomy,” in which students exercise freedom within pedagogically structured boundaries. Such an approach enables learners to develop higher-order thinking skills. Thus, student agency represents the integration of independence, responsibility, and reflective capacity within the educational process.

Theoretically, student agency is closely associated with Self-Determination Theory (SDT), proposed by Ryan & Deci (2020). This theory emphasizes the fulfillment of three basic psychological needs: autonomy, competence, and relatedness. Autonomy refers to individuals’ ability to control their actions and learning choices independently. Competence relates to individuals’ perceptions of their ability to perform tasks effectively (Salman et al., 2020). Relatedness reflects the need to feel connected and accepted within a social environment. The fulfillment of these three needs has been shown to enhance intrinsic motivation and learning engagement. In educational contexts, SDT provides a conceptual framework for understanding how learning environments can support the development of agency (Shogren & Raley, 2022). Therefore, the application of SDT principles represents an essential strategy for improving the quality of learner-centered education.

In addition to Self-Determination Theory, student agency is closely linked to the concept of Self-Regulated Learning (SRL). SRL emphasizes individuals’ ability to plan, monitor, and evaluate their learning processes independently. According to Zimmerman (2002), effective learning involves three primary phases: forethought, performance, and self-reflection. During the forethought phase, students set goals and select appropriate learning strategies. In the performance phase, they monitor their progress and adjust strategies as needed. In the self-reflection phase, learners evaluate outcomes to improve future performance. This capacity for self-regulation represents a tangible manifestation of student agency in educational practice. Thus, SRL provides an operational framework that reinforces the concept of agency in educational contexts.

From a pedagogical perspective, student agency contributes significantly to enhanced learning engagement and academic achievement. Research indicates that students with high levels of agency tend to demonstrate stronger intrinsic motivation, perseverance, and superior learning outcomes (Cui et al., 2025). Agency enables learners to take an active role in determining the direction of their education. This fosters a sense of ownership over both the learning process and its outcomes. Moreover, agency promotes the development of critical thinking and complex problem-solving skills. Learning environments that support agency also enhance collaboration and communication among students (Taub et al., 2020). Therefore,

integrating student agency into instructional design represents a strategic approach to improving educational quality. The implementation of this concept aligns with twenty-first-century educational paradigms that emphasize holistic competency development.

In STEM education, student agency plays a strategic role due to the inquiry-based, problem-solving, and experimental nature of its learning processes (Ješková et al., 2022; Tan et al., 2023). STEM learning requires students to actively explore concepts through scientific and interdisciplinary approaches (Gao et al., 2020). Agency enables learners to formulate research questions, test hypotheses, and evaluate experimental results independently. This process fosters the development of critical, creative, and innovative thinking skills (Zebua, Ibrohim, et al., 2025). Furthermore, STEM education emphasizes the importance of collaboration and communication in addressing real-world problems. Student agency serves as a catalyst for creating authentic and contextualized learning experiences. With the presence of agency, students not only understand theoretical concepts but also apply them in everyday life. Therefore, strengthening student agency constitutes an essential indicator of success in STEM education.

Artificial Intelligence in STEM Education

Artificial Intelligence (AI) in education refers to the utilization of intelligent computational systems designed to emulate human cognitive processes such as learning, reasoning, decision-making, and problem-solving (Chen et al., 2020). This technology integrates multiple disciplines, including computer science, mathematics, cognitive psychology, and data science, making it highly relevant to the interdisciplinary nature of STEM education. In educational contexts, AI enables the automation and personalization of learning processes through complex data processing and predictive analytics. Its implementation reflects a transformation in educational paradigms toward technology-driven and data-informed approaches. AI-based systems are capable of identifying learners' patterns and providing more effective instructional recommendations (Ezzaim et al., 2025). This contributes to the enhancement of educational quality through approaches that are adaptive and responsive to individual needs. Moreover, AI improves the efficiency of educational management, including assessment and evaluation processes. Thus, AI represents a strategic innovation in advancing STEM education aligned with the demands of the Fourth Industrial Revolution and Society 5.0 (Leon et al., 2025).

In STEM education, AI has been implemented in various forms, such as intelligent tutoring systems, adaptive learning platforms, automated assessment, and learning analytics (Huang et al., 2025). Intelligent Tutoring Systems (ITS) are designed to provide instructional

guidance that resembles human tutoring through personalized and performance-based feedback (Lin et al., 2023). These technologies can identify conceptual errors and offer explanations tailored to students' needs. Adaptive learning platforms utilize machine learning algorithms to customize learning materials according to individual abilities. Automated assessment enables faster and more objective evaluation processes, particularly in computer-based testing environments (Lujak et al., 2022). Meanwhile, learning analytics is used to analyze educational data in order to understand students' learning behaviors and academic development. The integration of these technologies enhances the effectiveness of STEM learning, which requires strong conceptual understanding and problem-solving skills. Therefore, AI serves as a critical catalyst in improving technology-based education.

AI-driven approaches in education are often associated with the concept of Adaptive Learning, a system that dynamically adjusts content, difficulty levels, and feedback based on student performance (Strielkowski et al., 2025). This concept is rooted in differentiated instruction theory, which emphasizes the importance of tailoring learning strategies to individual characteristics (Shuell, 2021). Through real-time data analysis, adaptive systems can accurately identify students' strengths and weaknesses. This technology enables more personalized and efficient learning compared to conventional approaches. Adaptive learning also supports independent study by providing relevant content recommendations. In STEM education, this approach is particularly important due to the complexity of subject matter requiring gradual and in-depth understanding. Research indicates that AI-based adaptive systems can enhance student motivation and learning outcomes (Yekollu et al., 2024). Consequently, adaptive learning represents a major innovation in the transformation of digital education.

Artificial Intelligence (AI) plays a crucial role in data-driven education through learning analytics, which enables real-time monitoring of learning behaviors such as participation, academic progress, and interaction patterns (Ahmad et al., 2024; Sajja et al., 2025). These data support educators in designing more effective instructional strategies, particularly in STEM education by identifying students' conceptual difficulties and predicting potential academic risks early (Norm Lien et al., 2020). At the same time, AI integration transforms learning dynamics by creating more interactive and collaborative environments, where technology acts as a learning partner (Alam, 2021). Consequently, teachers' roles shift from being the primary source of knowledge to becoming facilitators and instructional designers, aligning with the Education 4.0 paradigm that emphasizes the integration of digital technologies to enhance learning quality.

However, the implementation of AI also presents several challenges, including issues of data privacy and security, potential algorithmic bias, and unequal access to technology. Overreliance on AI may reduce social interaction if not balanced with appropriate pedagogical approaches (Zhai et al., 2024). In the context of active learning, AI has the potential to increase student engagement through student-centered approaches such as simulations, virtual experiments, and project-based learning (Abdelfattah et al., 2025). It also supports the development of critical, creative, and analytical thinking, as well as digital and data literacy—key competencies for the twenty-first century. Therefore, AI integration requires clear regulatory frameworks and continuous evaluation to ensure its ethical, responsible, and effective use in fostering holistic student development (Kayal, 2024; Zebua & Ziraluo, 2026).

AI as a Mediating Tool for Student Agency

Artificial Intelligence (AI) can be theoretically positioned as a mediating tool that shapes the relationship between the learning environment and student agency, in line with the socio-constructivist perspective (Kharroubi & ElMediouni, 2024). Drawing on Lev Vygotsky's theory of mediation, AI functions as a modern psychological tool that extends learners' cognitive capacities through interaction with digital environments (Taber, 2020; Vygotsky & Cole, 1978). As a mediational instrument, AI facilitates access to information, supports independent understanding, and transforms learning experiences. This highlights that technology is not merely supportive but an integral component of the learning ecosystem that influences how students think, interact, and make decisions (Koul & Nayar, 2021).

From this perspective, AI also strengthens learning through its alignment with key constructivist principles, including collaboration, exploration, and reflection (Lee & Wong, 2025). It supports the concept of the Zone of Proximal Development (ZPD) by providing tailored assistance that enables learners to achieve higher levels of understanding (Xi & Lantolf, 2021). In addition, AI enhances student agency through mechanisms such as instant feedback and adaptive learning systems. Timely feedback promotes reflection, motivation, and improved learning outcomes, while adaptive systems allow students to learn based on their pace, needs, and learning styles. These features foster autonomy, self-confidence, and more inclusive learning environments.

Furthermore, AI contributes to the development of metacognitive skills by enabling learners to monitor their progress through learning analytics and data visualization (Pacheco et al., 2025). This supports self-reflection, planning, and decision-making, which are essential for self-directed and lifelong learning (Zebua et al., 2025). AI-based recommendations also help students optimize their learning strategies, strengthening their capacity for independent

learning. Through these mechanisms, AI acts as a facilitator that enhances reflective learning and reinforces student agency in meaningful ways.

However, the implementation of AI also presents challenges, including the risk of overdependence on technology, potential algorithmic bias, and concerns related to data privacy and security (Salgado Granda et al., 2024; Zebua & Ziraluo, 2026). If not carefully managed, AI may reduce social interaction and weaken critical thinking skills. Therefore, AI should function as scaffolding—providing temporary, adaptive support that gradually decreases as learners become more independent. Effective integration requires thoughtful pedagogical design and continuous evaluation to ensure that AI enhances, rather than replaces, human cognitive development and maintains its role as a facilitator of student agency.

Conceptual Model of AI-Supported Student Agency in STEM

The conceptual model of AI-Supported Student Agency in STEM is grounded in the integration of constructivist and socio-constructivist perspectives, along with Self-Determination Theory and Self-Regulated Learning (Zhang et al., 2026). Within this framework, Artificial Intelligence (AI) is positioned as a key variable that shapes learners' active participation by functioning not only as a technological tool but also as a mediator of exploration, problem-solving, and data-driven learning. The model emphasizes the importance of the interaction between technology and pedagogy in creating meaningful, learner-centered experiences. As such, it provides a comprehensive theoretical foundation for understanding how AI can support the development of twenty-first-century competencies in STEM education (Tan & Kidman, 2025).

In this model, AI-supported learning environments act as the independent variable influencing student agency. These environments include intelligent tutoring systems, adaptive platforms, automated assessment, and learning analytics, all of which enable personalized, flexible, and interactive learning. Such features encourage students to take responsibility for their learning through active engagement, supported by instant feedback and adaptive recommendations. Student agency itself is conceptualized through three core dimensions: autonomy, self-regulation, and decision-making, which are essential competencies for fostering critical thinking and scientific literacy in STEM contexts (Gupta et al., 2024).

The model also incorporates mediating variables that strengthen the relationship between AI and student agency, particularly pedagogical design and the role of teachers. Approaches such as inquiry-based, problem-based, and project-based learning provide meaningful contexts for active knowledge construction (Nghiem et al., 2025; Shocheb et al., 2025). At the same time, teachers function as facilitators who guide the effective and ethical use of AI in learning.

In addition, the type and design of AI technologies significantly influence student engagement and motivation, highlighting the need for alignment between technological tools and pedagogical strategies.

Furthermore, the model recognizes moderating contextual factors such as technological readiness, digital literacy, and individual learner characteristics, which determine the effectiveness of AI implementation. It also reflects a systemic interaction between technology, pedagogy, and human factors, consistent with frameworks like TPACK (Tseng et al., 2022). Methodologically, this model offers a basis for empirical research using approaches such as Structural Equation Modeling (SEM) and mixed methods to examine complex relationships among variables. Overall, the framework provides both academic and practical contributions for advancing AI-driven innovation in STEM education.

Research Proposition

Based on the theoretical framework outlined above, this study proposes several key propositions:

- a. AI-supported STEM learning environments positively influence student agency.
- b. The effect of AI on student agency is mediated by pedagogical design and learning interactions.
- c. Excessive reliance on AI may negatively affect students' decision-making autonomy.
- d. Teacher facilitation plays a critical role in strengthening the positive impact of AI on student agency.

3. METHODS

Research Design

This study adopts a qualitative approach with an interpretive design to explore how student agency is formed within Artificial Intelligence (AI)-supported STEM learning environments. The approach enables an in-depth understanding of learners' subjective experiences, particularly how they control, direct, and reflect upon their learning while interacting with AI technologies. The study focuses on the meanings constructed by students and the interactions among learners, technology, and the learning environment.

Participants and Context

The participants consisted of 15 university students engaged in AI-supported STEM learning, including adaptive learning platforms, intelligent tutoring systems, and digital simulations. They were selected through purposive sampling based on specific criteria: prior experience with AI in learning, active academic participation, and willingness to participate in

in-depth interviews. The research was conducted in courses that had integrated AI for at least one semester to ensure authentic learning experiences.

Data Collection

Data were collected through semi-structured, in-depth interviews and participatory observations. The interviews explored students' perceptions and experiences related to autonomy, self-regulation, decision-making, and potential dependence on AI, with each session lasting between 10 and 25 minutes. Participatory observations complemented the interviews by examining students' interactions with AI systems, including their responses to feedback, selection of learning strategies, and levels of engagement. Supporting documents were also collected to enrich the data.

Data Collection Procedure

The procedure was conducted in three stages:

- a. Preparation: Identification of the research site, participant selection, and development and validation of interview guidelines.
- b. Data Collection: Implementation of interviews, observations, and document collection.
- c. Data Organization: Transcription, systematic organization, and integration of data to identify emerging patterns and meanings.

Data Analysis

Data were analyzed using an iterative thematic analysis. The process involved familiarization with the data, open coding to identify significant meaning units, and axial coding to categorize themes such as autonomy, self-regulation, decision-making, and dependence on AI. These categories were synthesized into overarching themes representing the relationship between AI utilization and the development of student agency. Findings were interpreted in relation to relevant theoretical frameworks to ensure contextual and conceptual depth.

Trustworthiness

The rigor of the study was ensured through credibility, transferability, dependability, and confirmability. Credibility was strengthened through data triangulation from interviews, observations, and documents. Transferability was achieved by providing rich contextual descriptions. Dependability was ensured through systematic documentation of research procedures, while confirmability was maintained through reflexivity and data verification to minimize researcher bias.

Ethical Considerations

The study adhered to ethical research principles by obtaining informed consent, ensuring participant confidentiality, and using data solely for academic purposes. Participation was voluntary, and participants had the right to withdraw at any time without consequence. These measures ensured the integrity and ethical standards of scholarly research.

4. RESULTS AND DISCUSSION

Results

The data analysis indicates that student agency within Artificial Intelligence (AI)-supported STEM learning environments constitutes a multidimensional and dynamic construct shaped through the interaction among learners, technology, and pedagogical contexts (Leon et al., 2025). Through thematic analysis, four interrelated themes were identified: (1) enhanced learning autonomy, (2) the development of self-regulation, (3) negotiation in decision-making, and (4) ambivalence toward dependence on AI. These themes do not exist independently; rather, they form a continuum that reflects AI's dual role as both an empowering and constraining force in shaping student agency.

The first theme, enhanced learning autonomy, reveals that AI-based learning environments provide students with greater control over their learning processes (Hong & Guo, 2025). Participants consistently reported that the use of AI enabled flexibility in regulating learning pace, navigating content in a more personalized manner, and independently exploring learning materials. This flexibility allowed students to adapt their learning strategies to their individual needs and preferences. One participant stated, *“With AI, I can review the material as many times as I need without feeling left behind.”* Another participant added, *“I feel more in control because I can decide what I want to learn first and how deeply I want to understand it.”* These findings indicate that AI facilitates a shift from teacher-centered instruction toward learner-centered engagement.

The second theme, the development of self-regulation, emphasizes the role of AI in enhancing metacognitive awareness and reflective learning practices (Xu et al., 2025). Participants explained that real-time feedback, progress tracking, and performance analytics enabled them to monitor their understanding and adjust their learning strategies accordingly (Bernsteiner et al., 2025). AI-generated feedback functioned as continuous formative assessment that guided students' learning trajectories. For instance, one participant noted, *“Feedback from AI helps me immediately recognize my mistakes, so I can correct them right*

away.” This finding demonstrates that AI supports not only cognitive processes but also strengthens students’ abilities to plan, monitor, and evaluate their learning.

The third theme, negotiation in decision-making, reveals that student agency is not diminished by AI recommendations but is instead reconstructed through critical engagement. Although AI systems provide suggestions and learning pathways, students actively interpret, evaluate, and occasionally reject these recommendations. This finding indicates that decision-making within AI-supported environments is not passive but involves negotiation between human judgment and algorithmic guidance (Gomez et al., 2025). One participant remarked, “*I do not always follow the AI’s suggestions. Sometimes I choose another approach because I better understand my own needs.*” This evidence underscores that agency is preserved when students maintain epistemic authority over their learning decisions.

However, the fourth theme highlights a tension manifested as ambivalence toward dependence on AI. While AI enhances efficiency and accessibility, it also poses the risk of overreliance, particularly when students use it as a shortcut rather than as a supportive learning tool. Some participants acknowledged that the convenience offered by AI could reduce cognitive effort in certain situations. One participant stated, “*Sometimes I rely too much on AI for quick answers, and I realize that I think less deeply.*” This finding suggests that the same features that strengthen agency may also weaken it if not balanced with appropriate instructional design.

Overall, the results demonstrate that student agency in AI-supported STEM learning exists along a continuum rather than as a fixed outcome (Katsenou et al., 2025). On one end, AI functions as an enabler that promotes autonomy, reflection, and informed decision-making. On the other, it may become a source of dependency that diminishes students’ cognitive engagement. Students’ positions along this continuum are influenced by various factors, including digital literacy, prior learning habits, and the instructional design implemented in the learning process.

These findings affirm that AI plays a dual role in shaping student agency. It can serve as a catalyst that empowers learners, yet it may also act as a limiting factor if used excessively or without sound pedagogical design. Therefore, it is essential to design AI-supported STEM learning environments that not only leverage technological advantages but also intentionally foster active, reflective, and responsible student engagement.

Discussion

The findings of this study indicate that student agency within Artificial Intelligence (AI)-supported STEM learning environments is dynamic and contextual, and cannot be understood

in a linear manner. The results suggest that AI functions as both an enabling and constraining tool, capable of simultaneously strengthening and weakening student agency (Mingfeng & Wang, 2026). These findings expand the conceptual understanding of student agency by positioning it as a spectrum of interaction between technology and individuals, rather than as a fixed attribute possessed by learners.

From a theoretical perspective, the results align with the principles of Self-Determination Theory, particularly the dimensions of autonomy and competence (Ryan & Deci, 2023). AI systems that provide learning flexibility and real-time feedback have been shown to support the need for autonomy and enhance students' perceptions of competence (Yildiz Durak & Onan, 2025). However, the finding of ambivalence toward dependence indicates that the fulfillment of these psychological needs is not always optimal (Kluwer et al., 2020). When AI is used excessively without critical reflection, the intended autonomy may shift into dependency, thereby creating a paradox in the implementation of educational technology (Alhur et al., 2025).

Furthermore, the findings reinforce the framework of Self-Regulated Learning, in which AI functions as scaffolding that supports the processes of planning, monitoring, and evaluating learning (Jin et al., 2023; Siu et al., 2025). Features such as adaptive feedback and learning analytics enable students to develop metacognitive awareness more systematically. Nevertheless, this study introduces a new dimension by demonstrating that the effectiveness of AI in supporting self-regulation largely depends on students' ability to interpret and utilize the information provided by the system. Thus, AI does not automatically produce self-regulated learners but requires active engagement from students (Jin et al., 2023).

Moreover, the findings concerning negotiation in decision-making provide a significant contribution to the literature on agency in the digital era. Contrary to earlier assumptions that technology tends to diminish students' active roles, this study reveals that learners retain epistemic authority through the evaluation of AI-generated recommendations. This indicates that agency in AI-supported contexts is not diminished but rather reconfigured into a form of distributed agency, in which decision-making results from interactions between humans and intelligent systems (Aysan, 2025). This perspective enriches scholarly discourse on the relationship between technology and learning, particularly within STEM education.

In terms of scientific contribution, this study addresses a critical gap in the literature, which has predominantly focused on the effectiveness of AI in improving learning outcomes. Instead, it shifts attention to the processual dimension—how students function as active agents in learning. The study offers a conceptual framework that integrates AI, STEM pedagogy, and

student agency into a coherent analytical model. Furthermore, the identification of an agency spectrum provides a novel theoretical contribution that may serve as a foundation for future research examining the interplay between technology and learning.

Regarding its positioning within the research gap, this study explicitly addresses the limitations of previous research, which has largely been quantitative and outcome-oriented. By employing a qualitative approach, the study uncovers the dynamics of students' learning experiences that cannot be fully explained through numerical data alone (Ghafarpour & Moinzadeh, 2020). Additionally, it extends the scope of inquiry into AI-supported STEM learning, an area that remains relatively underexplored in the literature, particularly within developing educational contexts.

The practical implications of this research underscore the importance of balanced pedagogical design in AI integration. Educators and instructional designers must ensure that AI is utilized as a tool to strengthen students' cognitive engagement rather than replace their thinking processes. Approaches such as inquiry-based learning and problem-based learning can be integrated with AI to sustain students' active roles. Furthermore, strengthening students' digital literacy and metacognitive awareness is essential for maximizing the potential of AI without compromising student agency.

Nevertheless, this study has several limitations, including a limited number of participants and a specific research context, which necessitate caution in generalizing the findings. Therefore, future research is recommended to examine this phenomenon across broader contexts, employ longitudinal approaches, or combine qualitative and quantitative methods to achieve a more comprehensive understanding.

5. CONCLUSION

This study affirms that student agency within Artificial Intelligence (AI)-supported STEM learning environments constitutes a dynamic, contextual, and multidimensional construct. AI functions not only as a supportive learning tool but also as a factor that shapes how students interact, make decisions, and regulate their learning processes. The findings indicate that AI can enhance autonomy, strengthen self-regulation, and foster more reflective decision-making. However, at the same time, AI also has the potential to create dependency that may weaken students' cognitive engagement if not used critically.

The primary contribution of this study lies in the reconceptualization of student agency as a spectrum influenced by the interaction between technology and individuals. This perspective offers new insights, demonstrating that agency is not static but evolves dynamically

depending on how AI is integrated into instructional design. Therefore, the successful implementation of AI in STEM education is determined not only by technological sophistication but also by pedagogical approaches that maintain a balance between technological support and students' active roles.

The practical implications of this research highlight the importance of the roles of teachers and instructional designers in creating learning experiences that utilize AI not merely as a tool for efficiency but also as a means to strengthen student engagement, reflection, and learning responsibility. For future research, cross-contextual studies, longitudinal approaches, and the integration of mixed methods are recommended to broaden understanding of the relationship between AI and student agency in STEM learning.

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