

Balancing AI-Driven Adaptation and Learner Self-Regulation: A Conceptual Framework for Enhancing Learning Outcomes in Generative AI-Supported Education

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The rapid proliferation of Generative Artificial Intelligence (GenAI) has expanded the potential for personalization, feedback, and immediate support within educational environments. Despite growing evidence of its ability to enhance certain learning outcomes, increased AI-driven support does not necessarily improve all cognitive and regulatory aspects; indeed, it may raise challenges regarding over-reliance and a decline in learner autonomy. This conceptual paper aims to develop a pedagogical framework to balance AI-driven adaptation with learner self-regulation in GenAI-supported educational settings. The framework was constructed based on an integrative analytical review of recent literature in the fields of GenAI in education, adaptive learning, self-regulated learning, and human-AI hybrid regulation. The framework proposes the concept of "Balanced AI-Learner Regulation," which structures the relationship across three graduated levels: AI-led regulation, co-regulation, and learner-led regulation. It also proposes the principle of "Adaptive Fading of AI Support," based on providing support according to need and then gradually reducing it as the learner's capacity for independent self-regulation grows. The paper's primary contribution lies in shifting the focus from maximizing GenAI usage to designing a pedagogical balance that preserves autonomy, self-regulation, and critical thinking alongside the improvement of academic performance.

Keywords: Generative Artificial Intelligence; Adaptive Learning; Self-regulated learning; human-AI coordination; learning outcomes; learner autonomy.

1. Introduction

Generative AI has rapidly transformed educational environments, demonstrating the ability to generate content, explain concepts, provide feedback, respond instantly to learners' questions, and personalize certain aspects of the learning experience. This development is part of a broader shift in educational AI toward systems that are increasingly capable of personalization, interaction, and responsiveness to learners' characteristics and needs (S. Wang et al., 2024). However, the educational value of these technologies is determined not merely by their technical capacity to produce answers, but by how they are integrated into an instructional design that sustains the learner's cognitive engagement.

Recent aggregated evidence indicates that Generative AI (GenAI) has positive effects on learning, yet it also reveals significant variability in these effects. In a systematic review and meta-analysis of experimental and quasi-experimental studies, Han et al. (2025) found a moderate positive impact of GenAI on learning outcomes, with substantial variation depending on educational level, discipline, intervention duration, and context. Similarly, Chen and Cheung (2025) demonstrated positive effects on academic achievement, higher-order thinking, and motivational aspects, whereas no significant impact was observed regarding metacognition. These findings suggest that enhancing learner performance through GenAI does not necessarily foster the ability to independently monitor and regulate one's own learning.

This issue takes on particular significance when linking artificial intelligence to the concept of Self-Regulated Learning (SRL). Self-regulation is not limited to the successful completion of tasks; rather, it encompasses the learner's ability to set goals, plan, select strategies, monitor comprehension and performance, and subsequently reflect on outcomes and adjust strategies as needed (Panadero, 2017). Given Generative AI's (GenAI) capacity to perform an increasing number of these functions on the student's behalf, the central pedagogical question becomes not whether AI can support learning, but rather which functions it should support and which should remain the learner's responsibility.

A systematic review by Xia et al. (2026) demonstrated that GenAI can support multiple stages of self-regulation, ranging from setting learning goals and searching for resources to problem-solving and receiving feedback. Applied studies have also shown that pedagogically designed GenAI systems can support aspects of self-regulated learning (Ng et al., 2024). However, the ease of obtaining answers and guidance may cause the system to shift gradually from a supportive role to one that replaces the learner's own activity a challenge highlighted in literature regarding the use of large language models in education (Yan et al., 2024).

This issue is also linked to adaptive learning. AI-powered systems can adjust the level of content, tasks, and feedback based on the learner's performance, and aggregated evidence has shown that AI-supported adaptive learning systems can positively contribute to learning outcomes (X. Wang et al., 2024). However, the adaptation performed by the system can become problematic if it results in the complete transfer of learning decisions from the learner to the system.

Molenaar (2022) introduced the concept of "Hybrid Human–AI Regulation" to address this issue, emphasizing the importance of a gradual transition from AI-led regulation to learner-led regulation. With the emergence of Generative AI (GenAI), this issue has become even more pressing, as generative systems can intervene in a far wider range of decisions and cognitive processes than traditional adaptive systems.

Accordingly, this paper proceeds from the need to rethink the relationship between AI-driven adaptation and learner-driven regulation. It proposes the "Balanced AI–Learner Regulation" framework as a conceptual extension for the context of Generative AI, focusing on the dynamic balance between the external support provided by the system and the internal responsibility retained by the learner for managing their own learning.

1.1. Research Problem:

The research problem lies in an educational tension between two simultaneous trends. On one hand, Generative AI (GenAI) and adaptive learning applications seek to enhance personalization and provide increased support and feedback tailored to the learner's needs. On the other hand, education aims to cultivate learners capable of planning, monitoring, decision-making, and independent learning.

Current evidence does not indicate that increased GenAI support automatically leads to overall improvements in learning. In a randomized controlled trial, Fütterer et al. (2026) demonstrated that GenAI interventions designed to support self-regulation yielded specific benefits regarding motivational aspects but did not result in clear differences in certain cognitive and strategic outcomes. This finding aligns with broader evidence showing that the impact of GenAI varies depending on the type of outcome, the context, and the nature of the instructional design (Chen & Cheung, 2025; Han et al., 2025).

Furthermore, the system's capacity to handle certain regulatory processes may reduce opportunities for learners to engage in these processes themselves. Thus, the issue is not a choice between using or not using artificial intelligence; rather, it lies in how to distribute the responsibility for regulating learning between the system and the learner in a way that preserves the benefits of adaptability without undermining self-regulation and autonomy.

Consequently, the research problem centers on the need for a pedagogical framework that outlines how to transition between varying levels of Generative AI (GenAI) intervention: the system provides support when necessary and involves the learner in regulating learning when their capabilities allow, with support gradually tapering off to foster learner autonomy.

1.2. Research Questions and Objectives:

The research proceeds from the following primary question:

How can a conceptual framework be constructed to achieve a pedagogical balance between AI-driven adaptation and learner self-regulation, thereby enhancing learning outcomes in educational environments supported by generative AI?

This gives rise to the following questions:

1. What are the theoretical foundations governing the relationship between AI-driven adaptation and self-regulated learning?
2. How can the responsibility for regulating learning be distributed between GenAI and the learner without undermining learner autonomy?
3. What components and principles should be included in a framework for balancing adaptive support with self-regulation?
4. How can the proposed framework guide the design of GenAI environments aimed at enhancing learning outcomes?

The primary objective is to develop a pedagogical conceptual framework for balancing AI-driven adaptation with learner self-regulation. This entails analyzing the relationship between adaptive learning and self-regulation, defining levels of responsibility for regulation, proposing pedagogical principles for the progressive provision of GenAI support, and establishing a theoretical foundation for future empirical research.

1.3. Significance of the Research:

The theoretical significance of this research lies in integrating two approaches often addressed separately: adaptive learning, which focuses on the system's responsiveness to the learner's needs, and self-regulated learning, which focuses on the learner's ability to manage their own learning process. The research also introduces the concept of "Balanced AI-Learner Regulation" to explain the relationship between these two approaches within the context of Generative AI (GenAI).

From an educational perspective, the framework shifts the focus from the extent of AI usage to a more critical question: what is the appropriate level of support, at what time, and for which learner? It

also provides a foundation to guide educators and learning environment designers in utilizing GenAI as a form of educational support, rather than a substitute for critical thinking and self-regulation.

2. Methodology:

The study adopts a conceptual research design based on an integrative, analytical literature review. It does not aim to conduct a comprehensive systematic review or statistical analysis; rather, it seeks to synthesize relevant literature to develop a new explanatory framework. This approach is well-suited for research that reorganizes existing theoretical concepts and relationships to produce a more integrated explanation or conceptual construct (Jaakkola, 2020; Snyder, 2019).

The synthesis process focused on five interconnected areas: GenAI in education, adaptive learning, self-regulated learning, human-AI regulation, and learning outcomes. Priority was given to recent peer-reviewed research specifically studies published between 2022 and 2026 in international journals indexed in Scopus and Web of Science while drawing on a limited number of older theoretical references where necessary to establish foundational concepts.

3. Theoretical Foundation:

3.1. Generative AI in Education

Generative AI (GenAI) represents a shift from systems that merely retrieve or classify information to systems capable of creating new content and engaging in natural, continuous interaction with the learner. While the literature has demonstrated its potential for content delivery, feedback, and personalization, the success of its integration depends on clear pedagogical design rather than technical capabilities alone (Liu & Zhong, 2025). Furthermore, reviews concerning large language models emphasize the importance of human oversight, AI literacy, and critical thinking when utilizing these technologies in educational settings (Yan et al., 2024).

3.2. Adaptive Learning

Adaptive learning involves tailoring the educational experience based on a learner's data, performance, and needs. This adaptation can encompass content, difficulty level, the type of feedback provided, and the sequencing of activities. A meta-analysis by X. Wang et al. (2024) demonstrated that AI-powered adaptive learning systems can improve learner outcomes, underscoring the importance of personalization as a key role for AI in education.

In the context of Generative AI (GenAI), adaptation has become more flexible, enabling the real-time creation of materials and tasks aligned with a learner's interests and specific context. Tasdelen and Bodemer (2025) demonstrated the potential of using GenAI-generated, contextually personalized

content and tasks to influence motivation and performance. However, pedagogically effective personalization should not eliminate the learner's role in making choices and decisions.

3.3. Self-Regulated Learning

Self-regulated learning encompasses cognitive, metacognitive, motivational, and behavioral processes that enable learners to direct their learning toward specific goals (Panadero, 2017). In GenAI-supported environments, the system can be utilized to facilitate goal setting, suggest strategies, provide feedback, and encourage self-reflection.

Chiu (2024) proposed methods for leveraging GenAI to support self-regulation based on motivational principles, while a study by Ng et al. (2024) demonstrated that a generative chatbot designed to support self-regulated learning (SRL) could play an educational role in science learning. However, GenAI's capacity to perform these processes underscores the need to distinguish between supporting self-regulation and replacing it.

3.4. Hybrid Human-AI Regulation

The concept of hybrid regulation forms a significant basis for the present paper. Molenaar (2022) demonstrated that adaptive systems can assume certain regulatory functions during initial stages, with control gradually shifting to the learner as their skills develop. The current paper extends this rationale to the context of GenAI where interventions become more flexible and expansive and proposes that regulation should operate through dynamic levels tailored to the learner's needs and the nature of the task.

4. Literature Review and Research Gap:

Recent studies reveal rapid progress across three interconnected areas. The first involves the use of GenAI to enhance learning outcomes; meta-analyses indicate generally positive, albeit heterogeneous, effects (Chen & Cheung, 2025; Han et al., 2025). The second concerns personalization and adaptation, as GenAI has become capable of generating experiences that are better aligned with specific contexts and individual needs (Tasdelen & Bodemer, 2025). The third area focuses on supporting self-regulated learning (SRL); a review by Xia et al. (2026) demonstrated the diverse functions GenAI can perform across the various stages of SRL.

A review by Zhu and Sari (2026) demonstrated that various AI technologies can support self-regulated learning (SRL) processes and proposed an AI-SRL framework involving both the learner and the teacher; however, it also highlighted challenges associated with employing AI in this domain. This body of literature indicates that the relationship between AI and SRL has become an advanced field of

research; consequently, merely proposing the use of Generative AI (GenAI) to support self-regulation does not, in itself, constitute a sufficient conceptual contribution.

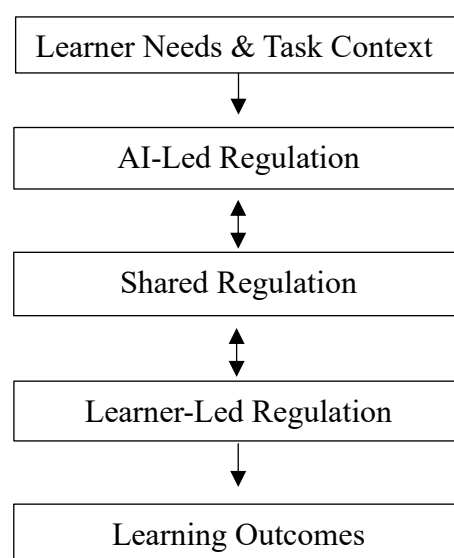
Conversely, the literature points to risks associated with the unbalanced use of AI. Farrokhnia et al. (2024) highlighted the opportunities ChatGPT offers for personalization and immediate support, alongside potential threats regarding higher-order thinking, academic integrity, and reliance on system outputs. Similarly, Yan et al. (2024) emphasized the need for a human-centered design approach when employing large language models in education.

Thus, the gap lies not in a lack of studies on GenAI, adaptation, or SRL in isolation, but rather in the need for a more specific conceptual framework that clarifies how to manage the relationship between the degree of adaptation provided by GenAI and the level of self-regulation responsibility retained by the learner. The contribution of the current study lies in developing the concept of balancing within the context of GenAI and linking it to clear levels of regulation and a principle of progressive scaffolding withdrawal.

5. Proposed Conceptual Framework: Balanced AI–Learner Regulation:

The framework is grounded in the principle that the goal is neither to maximize nor minimize AI support in absolute terms, but rather to provide the appropriate level of support based on the learner's needs while ensuring a gradual shift of responsibility toward the learner.

Figure 1. *Proposed Balanced AI–Learner Regulation Framework for Generative AI-Supported Education*



Adaptive Fading of AI Support

Higher AI Support → Greater Learner Responsibility and Self-Regulation

The framework comprises four interconnected key elements:

First, learner needs and the task context, including prior knowledge, task difficulty, performance level, and the need for guidance. These factors determine the appropriate initial level of GenAI intervention.

Second, AI-driven adaptive support, encompassing content personalization, hints, feedback, guiding questions, and the adjustment of the amount of guidance provided.

Third, learner self-regulation, involving goal setting, planning, strategy selection, comprehension monitoring, reflection, and self-assessment.

Fourth, learning outcomes; the framework prioritizes not only academic achievement but also autonomy, self-regulation, and critical thinking.

This balance is achieved across three regulatory levels:

1- AI-Led Regulation: GenAI plays a relatively prominent role when the learner requires significant support, while avoiding completely relieving the learner of cognitive engagement.

2- Shared Regulation: Responsibility is distributed between the system and the learner; GenAI provides guidance and feedback, while the learner remains responsible for making choices, providing justifications, and making key decisions.

3- Learner-Led Regulation: GenAI intervention becomes limited and available only when needed, while the learner takes greater responsibility for planning, monitoring, and evaluation. The general logic of the framework can be represented as follows:

This transition does not follow a fixed, linear path; a learner may require greater support when facing a new or more complex task, before returning to a higher level of autonomy.

Adaptive Fading of AI Support

The adaptive fading of AI support constitutes the framework's central mechanism. It ensures that support does not remain static once the learner becomes capable of performing the task independently. When a learner requires substantial support, Generative AI (GenAI) can provide explicit guidance, subsequently shifting to hints and questions, and finally to on-demand feedback, thereby gradually increasing the learner's responsibility.

In this way, GenAI does not function merely as a constant provider of answers, but rather as an adaptive scaffolder intervening when necessary and stepping back when continued intervention would hinder learner autonomy.

6. Principles and Conceptual Relationships:

The framework proposes five interconnected principles:

Principle 1: Matching support to need. The educational value of support lies not in its quantity, but in its alignment with the learner's needs and the nature of the task.

Principle 2: Support is not a substitute. GenAI should facilitate planning, monitoring, and reflection without permanently taking over these processes on the learner's behalf.

Principle 3: Gradual transfer of responsibility. Learner responsibility should increase as their capacity for independent performance and self-regulation grows.

Principle 4: Dynamic balance. There is no single, optimal level of support suitable for all learners and tasks; therefore, movement between the three levels of regulation should be permitted.

Principle 5: Learning quality transcends performance speed. The success of GenAI should not be judged solely by the quality of the answer or the speed of task completion, but also by the preservation of self-regulation, autonomy, and critical thinking.

These principles suggest that the relationship between the amount of AI support and learning outcomes may not be linear. Insufficient support may fail to meet learner needs, and appropriate support can enhance learning, whereas excessive, continuous support may diminish opportunities for self-regulation. The mixed findings of recent studies reinforce the need to empirically examine this relationship in the future, rather than assuming that more support invariably leads to better outcomes (Fütterer et al., 2026).

7. Theoretical and Educational Implications:

7.1. Theoretical Implications:

The framework offers three key theoretical contributions.

First, it links adaptive learning with self-regulated learning by viewing them as complementary forms of learning regulation: external regulation performed by the system and internal regulation performed by the learner.

Second, it develops the concept of hybrid regulation within the context of GenAI by identifying three distinct levels of regulatory relationships and linking the transitions between them to the principle of the "Adaptive Fading of AI Support."

Third, it shifts the focus of GenAI evaluation from the general question of its effectiveness to the question of the optimal distribution of regulatory responsibility between humans and AI. This shift

aligns with literature emphasizing that the effective integration of GenAI requires a sound pedagogical foundation and appropriate guidance, rather than merely making the technology available (Liu & Zhong, 2025).

7.2. Educational Implications:

The framework recommends that GenAI begin with the minimum level of support necessary to enable the learner to proceed with the task such as a hint or a guiding question before moving to a more detailed explanation. Furthermore, activities should require learners to explain their choices, evaluate system responses, and justify solutions, rather than simply reproducing GenAI outputs.

Educators can leverage AI to provide feedback and adaptive support while designing tasks that keep learners accountable for their own goals and decisions. Similarly, developers of educational systems can design adjustable levels of support, rather than relying on a single, fixed mode of assistance.

8. Future Research Agenda:

The proposed framework requires empirical testing across various educational levels and disciplines. Future research could compare the effects of AI-led, shared, and learner-led regulation on achievement, self-regulation, autonomy, and critical thinking.

It is also necessary to identify the conditions under which "adaptive fading" is most effective, examining how its impact varies based on learner expertise, task type, and prior SRL levels. Furthermore, comparing different forms of GenAI intervention—such as direct answers, hints, Socratic questioning, and reflective feedback—is crucial to determining which best sustains cognitive and regulatory engagement.

Future studies could also investigate the potential non-linear relationship between the level of GenAI support and learning outcomes, helping to identify the threshold at which support shifts from a facilitating factor to one that may foster over-reliance.

9. Study Limitations:

The proposed framework remains a conceptual construct that has not undergone empirical testing; therefore, the relationships outlined within it cannot be interpreted as proven causal links. Furthermore, this paper relies on a targeted analytical review rather than a comprehensive systematic review of all available studies.

Additionally, the field of Generative AI (GenAI) is evolving rapidly, and new system capabilities may give rise to different patterns of interaction between the learner and the technology. The

appropriate level of support may also vary depending on age group, discipline, cultural context, and the nature of the task. Consequently, the framework should be viewed as a theoretical foundation open to further development and testing, rather than a definitive model applicable to all contexts.

10. Conclusion:

This paper addressed the educational challenge of leveraging the adaptive capabilities of Generative AI (GenAI) while preserving the learner's ability to independently regulate their learning. It proceeded from the premise that improving learning outcomes should not be measured solely by the extent of support GenAI can provide, but rather by how the responsibilities for planning, monitoring, decision-making, and evaluation are distributed between the system and the learner.

The paper proposed the "Balanced AI–Learner Regulation" framework, based on three dynamic levels—AI-led regulation, co-regulation, and learner-led regulation—alongside the principle of "Adaptive Fading of AI Support" to gradually transfer regulatory responsibility to the learner.

The framework's central message is that GenAI is most educationally valuable when it acts as an adaptive scaffold supporting the learner's capacity for independent learning, rather than as a substitute for the processes the learner ought to develop and practice personally. This conceptualization provides a theoretical foundation that can guide the design of more balanced learning environments and inform future empirical studies on the relationship between AI-driven adaptation, self-regulation, and learning outcomes.

11. Declaration:

The researcher confirms that no funding was received for this research and that there are no conflicts of interest. Artificial intelligence models were used to compile the scientific references for this study.

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