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ORIGINAL ARTICLE

Precision education in the algorithmic age: Toward a conceptual framework for personalized learning in higher education

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Abstract

This article presents the design and implementation of *Kahbom*, a low-cost, game-Precision education in the algorithmic age has gained increasing relevance as higher education institutions seek to respond more effectively to student diversity, learning variability, and evolving demands for personalized teaching. Assisted by artificial intelligence, this emerging approach moves beyond traditional standardization by enabling more adaptive, data-informed, and responsive learning environments. This conceptual analysis examines precision education as a developing educational framework shaped by the integration of artificial intelligence, learning analytics, adaptive systems, and pedagogical decision-making. The article identifies its defining attributes, including personalization, predictive support, timely intervention, and continuous adjustment to learners' needs, progress, and contexts. It also discusses key antecedents, such as technological infrastructure, ethical governance, data literacy, and faculty preparedness, as well as its potential outcomes for engagement, equity,

Introduction

Defining Precision Education: Conceptual foundations and scope

Precision education in the age of artificial intelligence may be understood as an emerging pedagogical framework that draws on AI and machine learning to optimize educational experiences according to the needs and profiles of individual learners. Its central premise is that students do not learn in identical ways, at the same pace, or under the same conditions (Chen et al., 2020; Tapalova et al., 2022). Therefore, educational processes should be sufficiently flexible and responsive to accommodate such variability. Through the use of intelligent systems capable of analyzing patterns in learner performance, behavior, and preferences, precision education supports more refined forms of personalization, enabling tailored instruction, timely feedback, and differentiated learning trajectories (Maghsudi et al, 2021). In doing so, it moves beyond traditional standardized approaches and opens new possibilities for more effective knowledge acquisition, sustained engagement, and context-sensitive learning pathways, particularly within higher education environments shaped by digital transformation.

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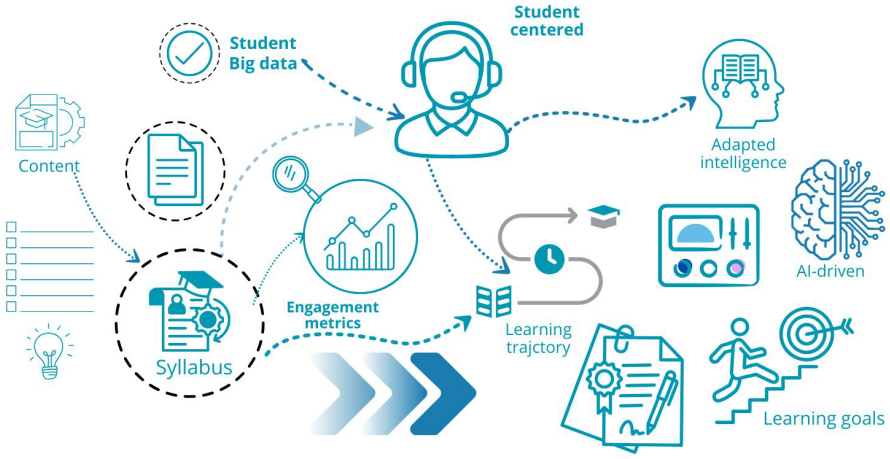
More specifically, precision education can be conceptualized as a data-informed and learner-centered educational approach that seeks to optimize learning, teaching and academic support through the systematic use of large-scale, multidimensional student data. Such data may derive from academic records, assessment results, engagement patterns, behavioral interactions with digital platforms, response times, learning trajectories, trainees' unique learning styles (Coates, 2025) and other indicators generated across students' educational experiences. Within this framework, the purpose is not merely to accumulate information, but to transform these diverse data streams into pedagogically meaningful insights that enable more adaptive, timely, and personalized forms of intervention. In other words, AI-driven precision education provides personalized learning paths, real-time feedback and targeted interventions (Vera, 2024). Accordingly, precision education may be understood as the pedagogical translation of student big data into informed educational action aimed at improving learning effectiveness, strengthening support mechanisms, and fostering student success. However, its significance lies not in datafication itself, but in the ethical, critical, and human-centered interpretation of data in ways that enhance, rather than displace, professional judgment and the relational dimensions of education (Figure 1).

Figure 1. *AI-driven precision education*



Source: Own elaboration.

From standardization to personalization

The shift from standardization to personalization has gained prominence because one-size-fits-all models often struggle to address the heterogeneity of learners in contemporary higher education. Standardized approaches have historically been associated with uniform curricula, fixed pacing, and common assessment structures designed for efficiency and comparability. Yet such models frequently overlook differences in students' prior knowledge, motivation, interests, sociocultural backgrounds, and learning trajectories. In contrast, personalized learning foregrounds the learner's needs, potential, and context, treating education as a more responsive and flexible process rather than a uniform delivery system. UNESCO (2012) defines personalized learning as teaching and learning focused on the learner's background, needs, potential, and perception, explicitly framing it as learner-centered education. Similarly, the rising emphasis on personalized learning is often linked to the belief that it may contribute to fairer academic outcomes across students from different social contexts (Sokolowski & Ansari, 2018).

Within this evolving landscape, precision education can be understood as a more data-informed expression of the broader move toward student-centered education. Rather than if all students benefit equally from identical instructional sequences, precision education acknowledges variability as a central feature of learning. This aligns with wider educational reforms that emphasize student agency, co-construction of learning, and pedagogical responsiveness (OECD, 2020). OECD's Learning Compass framework, for example, highlights student agency as a core principle for future-oriented education, suggesting that learners should be active participants rather than passive recipients of instruction. At the same time, personalization has become increasingly connected to adaptive learning environments that use learner data to refine content, pacing, and support. Recent reviews in higher education note that traditional methods are often insufficient for accommodating individual differences, whereas personalized and adaptive approaches show promise for improving engagement and learning outcomes when implemented thoughtfully. In this sense, precision education does not represent a break from student-centered education, but rather an intensification of its commitment to responsiveness, flexibility, and meaningful learner support.

The movement from standardization to personalization is also closely linked to inclusive education. Inclusion requires more than simply widening access. Thus, educational equity entails more than simply providing the same opportunities to every student (Ahmed et al, 2025). It requires recognizing individual needs and ensuring that each learner receives the resources and support necessary to fully develop their potential.; it involves reducing barriers and creating conditions in which diverse learners can genuinely participate and succeed. UNESCO (2020) frames inclusion as the removal of barriers within and beyond educational systems so that every learner has a real opportunity to benefit from education. From this perspective, precision education becomes relevant because it offers mechanisms for identifying learning needs earlier, tailoring interventions more carefully, and supporting students whose trajectories may be obscured by uniform instructional models. However, the promise of personalization must be approached critically. UNESCO (2020) has also stressed that equity and inclusion in higher education depend on fair representation and tailored frameworks that recognize student diversity, not merely on technological innovation. Accordingly, precision education should be situated within an inclusive and ethical agenda: one that uses data and adaptive tools to expand participation and support, while safeguarding human judgment, educational relationships, and sensitivity to context. Personalization, therefore, is most defensible when it serves inclusion rather than efficiency alone.

Precision Education in the Algorithmic Age

Precision education in the algorithmic age may be understood as an emerging educational framework that seeks to respond to learner variability using artificial intelligence, machine learning, and learning analytics (Bhutoria, 2022, Xu, 2025). Rather than treating students as members of a homogeneous group, this approach aims to identify needs, patterns, and risks at a more granular level to support timely and targeted intervention. In this sense, precision education is closely related to personalized learning, as both are concerned with adapting education to the characteristics and progress of individual learners. However, whereas personalized learning represents the broader pedagogical aspiration to tailor educational experiences, precision education may be seen as its more data-informed and analytically driven expression. Auhtours such as Bhutoria (2022) and Tao (2025) have said that AI-supported dashboards and knowledge graphs, as examples of multimodal technologies, enhance precision education by capturing students' learning behaviors and structuring resources in ways that facilitate more tailored teaching.

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From this perspective, precision education does not replace personalized learning but rather operationalizes it within digitally mediated environments, integrating longitudinal data, analytics, and continuous feedback cycles to deliver precise educational interventions that are proactive, timely, and predictive of meaningful outcome (Rajasekaran, 2024; Triola & Burk-Rafel, 2023). Its distinctive contribution lies in the capacity to transform large volumes of student data into pedagogically meaningful insights that can inform adaptive learning, feedback, pacing, and support. In AI-supported contexts, algorithms can identify behavioral traces, engagement patterns, and performance indicators that may not be immediately visible through conventional instructional observation. Thus, AI-driven precision education in smart learning environments can be seen as an approach that fosters the regulation of student learning through data-informed feedback and adaptive pedagogical support. Consistent with this view, Coates (2025) contends that precision education should be organized around individual learner needs, thereby minimizing the educational inefficiencies associated with conventional time-based learning structures. In such structures, students may be required to revisit content they have already mastered or progress according to predetermined schedules that do not reflect their actual readiness. Accordingly, person-specific AI models may be better positioned than aggregate models to capture the unique dynamics of learners' trajectories. This connection is especially significant in higher education, where growing student diversity exposes the limitations of one-size-fits-all models and underscores the importance of more responsive, flexible, and individualized approaches to teaching and learning

At the same time, precision education in the algorithmic age should not be reduced to technical optimization, prediction, or automated decision-making alone. AI and machine learning make it possible to identify learner characteristics with greater precision and to deliver more tailored educational content, although important challenges persist regarding student motivation, peer interaction, algorithmic bias, and the diversity of learning experiences (Bhutoria, 2022). Its educational value depends on how algorithmic systems are embedded within human-centered, ethical, and pedagogically sound frameworks. Although precision education enhances the goals of personalized learning by making educational adaptation more targeted and timelier, it also raises important concerns related to transparency, bias, surveillance, and the potential erosion of teacher agency (Alzahrani, 2024; Mst, 2025). For this reason, it is more appropriate to conceptualize precision education as a framework in which algorithmic insights complement, rather than replace, professional judgment. Accordingly, personalized learning provides the pedagogical rationale for attending to learner differences, while precision education offers the analytical means to address such differences with greater specificity and responsiveness.

Main characteristics of AI-driven precision education

The main characteristics of AI-driven precision education are presented below, understood as a data-informed and learner-centered approach aimed at improving the quality, relevance, and timeliness of educational decisions.

1. *Data-informed decision-making:* AI-driven precision education relies on the systematic collection and analysis of multidimensional student data, including academic performance, engagement patterns, behavioral traces, and learning progress.

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2. *Learner-centered personalization:* It seeks to adapt teaching, feedback, resources, and learning pathways to the characteristics, needs, strengths, and difficulties of individual learners.

3. *Granular identification of learner variability:* Through AI and machine learning, this approach enables a more precise recognition of differences in prior knowledge, pace of learning, preferences, risk factors, and support needs.

4. *Timely and targeted intervention:* Precision education supports early identification of learning difficulties and allows educators to intervene at the right moment with more specific and relevant support strategies.

5. *Adaptive learning pathways:* It promotes flexible and dynamic learning trajectories, adjusting content, tasks, and levels of support according to students' progress and evolving needs.

6. *Continuous feedback and monitoring:* AI-assisted systems can provide ongoing feedback to both students and educators, making learning processes more visible and enabling continuous pedagogical adjustment.

7. *Predictive capacity:* By detecting patterns in student data, AI can help anticipate potential outcomes such as disengagement, low performance, or dropout risk, thereby improving preventive action.

8. *Integration of multimodal data:* AI-driven precision education often draws on diverse data sources, such as assessment results, platform interactions, attendance, participation, and digital learning behaviors.

9. *Enhanced pedagogical responsiveness:* This approach strengthens educators' ability to make informed and context-sensitive decisions by combining technological insights with professional judgment.

10. *Commitment to inclusion and equity:* When implemented responsibly, precision education can help identify hidden learning needs and support more inclusive practices by responding to student diversity more effectively.

11. *Human-centered interpretation:* Although AI plays an important role, educational decisions should not depend on automation alone. Human interpretation remains essential for ensuring pedagogical relevance, fairness, and contextual understanding.

12. *Ethical and responsible use of data:* A core characteristic of AI-driven precision education is the need for privacy protection, transparency, bias awareness, and accountability in the use of student data and algorithmic systems.

Taken together, these characteristics suggest that AI-driven precision education represents more than the incorporation of advanced technologies into teaching and learning. Rather, it reflects a shift toward a more responsive, evidence-informed, and learner-sensitive educational model in which instructional decisions are increasingly guided by meaningful data and supported by intelligent systems. Its defining value lies in

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its capacity to recognize learner variability with greater accuracy, provide timely and targeted support, and promote more adaptive and inclusive learning pathways. At the same time, its effectiveness depends on the responsible interpretation of data, the preservation of human judgment, and a clear commitment to educational equity and ethical practice. In this sense, AI-driven precision education should be understood not as a substitute for pedagogy, but as a framework that can strengthen pedagogical action by making it more informed, contextualized, and responsive to the complex realities of contemporary higher education.

Methods and Materials

This study was conducted through a conceptual analysis aimed at examining the theoretical and pedagogical foundations of AI-driven precision education. This approach contributes to the development of a robust theoretical foundation that is highly valuable for subsequent empirical research (Heinonen & Gruen, 2024). Conceptual analysis may be understood as a systematic process of inquiry intended to clarify and define a concept by identifying its essential attributes, constitutive components, and related elements within a given disciplinary field.

More specifically, the conceptual analysis was based on the review and synthesis of academic literature on precision education, personalized learning, and the integration of artificial intelligence into the teaching–learning process in higher education. The selection of the literature was guided by the aim of identifying conceptual contributions related to AI-driven precision education, its pedagogical foundations, and its implications for the preparation of professionals for the 21st century. The information was subsequently organized into subtopics to facilitate a clearer and more coherent understanding of the concept under examination.

Conclusions

Precision education in the algorithmic age may be understood as an emerging educational framework that strengthens the shift from standardized instruction toward more personalized, adaptive, and learner-centered forms of teaching and learning in higher education. As discussed throughout this conceptual analysis, its value lies not merely in the use of artificial intelligence or learning analytics, but in the pedagogical capacity to translate diverse student data into timely, context-sensitive, and meaningful educational action.

This article has shown that AI-driven precision education is characterized by data-informed decision-making, granular recognition of learner variability, adaptive learning pathways, continuous feedback, predictive support, and targeted intervention. At the same time, its educational relevance depends on maintaining a human-centered orientation in which algorithmic systems complement, rather than replace, teacher agency and professional judgment. In this sense, precision education should be viewed not as a purely technological innovation, but as a pedagogical and ethical framework for improving responsiveness to student diversity in contemporary higher education.

A central conclusion of this analysis is that precision education has significant potential to contribute to inclusion, equity, engagement, and academic success when implemented responsibly. However, such potential is conditional upon the existence of key antecedents, including adequate technological infrastructure, faculty preparedness, data literacy, ethical governance, and critical awareness of issues

such as surveillance, bias, privacy, and transparency. Without these conditions, the promise of personalization may be reduced to technical efficiency rather than meaningful educational improvement.

Therefore, precision education in the algorithmic age should be conceptualized as a refined pathway toward more inclusive and context-sensitive learning environments, while remaining firmly grounded in pedagogical intentionality and ethical responsibility. Future research should move beyond conceptual clarification to examine how this framework is enacted in practice across diverse higher education settings, disciplines, and student populations. Empirical studies are needed to assess its actual impact on learning outcomes, student support, and educational equity, as well as to explore how educators can be better prepared to work critically and effectively with AI-assisted systems.

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