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The personalizing power of error: Leveraging Artificial Intelligence in 21st century learning

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Abstract

This opinion piece explores the role of artificial intelligence in transforming the perception of errors into opportunities for personalized and lifelong learning. By leveraging AI's ability to systematically analyze error patterns, educational institutions can create controlled environments where errors are embraced as catalysts for learning growth. The introductory section sets the context, presenting AI as a tool for shaping Education 4.0 and addressing urgent needs in the 21st century. The body of this opinion piece delves into its central claim: AI is the mechanism that will allow not only to take advantage of error but to intentionally and controllably encourage students to fail in learning as a starting point to turn errors into a catalyst for personalized learning. Claim-related arguments are provided, including using AI to analyze errors and nurture a growth mindset, preparing students for future challenges, and reducing teacher workloads. The conclusion emphasizes the significance of adopting an error-driven approach to foster lifelong learning. Overall, the paper underscores AI's potential to revolutionize education by harnessing the power of errors.

Introduction

The digital revolution has begun to transform virtually every aspect of our society, and as we move towards an increasingly technological future, the need to adapt educational systems to the realities of the 21st century becomes imperative (Nayan et al., 2024). In this context, artificial intelligence (AI) emerges as a powerful tool with the potential to catalyze structural change in the way we teach and learn (Burbules et al., 2020). By leveraging its capacity to analyze data, personalize content, and turn errors into learning opportunities, AI promises to redefine education as we know it.

AI and Education 4.0: Present and future of educational systems?

According to Kim (2022), in the current digital era, education faces an unprecedented challenge: the need to adapt to the unique needs of each student. In this context, where education intersects with the development of the fourth industrial revolution, the so-called "Education 4.0" emerges (Aziz Hussin, 2018), which has gained relevance in recent years, advocating for a student-centered educational approach that leverages disruptive digital technologies to personalize learning (Bremner, 2021). Thus, as Huk (2021) points out, Education 4.0 is based on the premise that learning should be personalized, and adapted to the skills, interests, and learning styles of each individual.

Considering the above, Nabizadeh et al. (2020) mention that current educational systems must transition from standardized and rigid structures to models more oriented towards addressing the ambiguity and uncertainty of today's world. In this context, pedagogical approaches must adapt to the changing demands of the 21st century, where personalization plays a fundamental role (Vargas et al., 2024). It is important to mention that this paradigm shift implies a transformation in the way educational programs are designed and implemented, moving from a "one-size-fits-all" approach to one that recognizes and celebrates student diversity (Shemshack et al., 2021).

Personalization of learning not only brings benefits to students but also to teachers and educational institutions as a whole (Du Boulay, 2019). By understanding and addressing the individual needs of students, educators can optimize resources and pedagogical strategies, which in turn leads to better outcomes and greater satisfaction for all involved (Iatrellis et al., 2019).

For instance, platforms like Carnegie Learning's MATHia utilize adaptive algorithms to analyze individual student performance in mathematics, adjusting the difficulty and type of problems presented based on the learner's progress. Similarly, language learning apps such as Duolingo employ AI to tailor vocabulary and grammar exercises to each user's proficiency level and learning pace. Furthermore, AI-powered writing assistants like Grammarly not only provide real-time feedback on grammar and style but also offer personalized suggestions for improvement based on the individual's writing patterns. In the realm of intelligent tutoring systems, tools like Third Space Learning use AI to match students with the most suitable online tutors and adapt teaching strategies in real-time during one-on-one sessions. These examples show how AI can facilitate a more engaging and effective learning experience by offering personalized guidance and support tailored to each student's unique needs and learning style.

Regarding personalization of learning in Latin America, Colombia has made notable strides in this area. For instance, Lavalle et al. (2024) report some research results regarding an intelligent tutoring system based on personalized learning for teaching health care protocols. For its part, Parra Sanchez et al. (2023) report an experience of personalizing resources for teaching university mathematics using artificial intelligence. Likewise, Intriago-Mera (2024) mentions other similar experiences in Ecuador, which highlight their positive effect on academic performance and student motivation.

Ultimately, and in line with what Holmes et al. (2019) mention that as we advance in the digital era, it is crucial that educational systems evolve to keep up with emerging demands and challenges. Therefore, the transition towards more personalized and adaptable approaches is desirable and a pressing necessity to ensure that education remains relevant and effective in the 21st century. In this sense, in the context of a heated conversation that is intensely debated between pros and cons, enthusiasts and detractors, ethical concerns (Popenici, 2023) and critical socio-political and cultural positions (Sevnarayan & Potter, 2024), artificial intelligence is emerging as one of the most promising tools to achieve learning personalization, by allowing educational systems to dynamically adjust to different learning styles and rhythms (Shemshack et al., 2021).

Personalized learning: An imperative for the future of education

Regarding Education 4.0, personalized learning has gained increasing relevance in the discussion about the future of education (Fariani et al., 2023). Unlike the homogenizing and standardized approach traditionally used, personalized learning recognizes that each student has their strengths, weaknesses, interests, and learning styles. Personalized learning is considered a student-centered philosophy and practice, based on understanding the unique needs, strengths, and interests of each learner (Bray & McClaskey, 2016).

In the context of trends related to Education 4.0, personalized learning emerges as an alternative to transforming conceptions, goals, and paradigms of conventional education. In this regard, UNESCO (2017) refers to personalized learning as a student-centered educational approach, where the learning process recognizes and addresses the needs, interests, skills, and strengths of each individual.

This approach also implies giving students the possibility of choice and autonomy during training experiences and curricular trajectory, addressing what, when, how, and where to learn (Lee et al., 2021; Xi et al., 2024). The strategies used

to develop personalized learning share the particularity of identifying individual student characteristics, including cognitive and/or non-cognitive aspects. However, they differ significantly in terms of technological integration, which tends to be increasingly sophisticated (Walkington & Bernacki, 2020). At the same time, these strategies vary in the level of personalization, as they can include one or several educational components, such as content, teaching or learning methods, learning rhythms, educational resources, assessment methods, and interfaces used (Barrera Castro et al., 2024; Bernacki et al., 2021).

Nevertheless, traditional teaching faces serious challenges in achieving true personalization, including overcrowded classrooms, limited resources, and a lack of accurate data on student performance, making it difficult to provide individualized attention. Consequently, as Pane et al. (2015) warn, that many students fall behind or do not reach their full potential due to the lack of adaptation to their specific needs.

AI as a driving agent for personalized education

As mentioned by Luckin et al. (2024), in this context, AI emerges as a powerful technology with high transformative potential, with the capacity to involve a variety of educational stakeholders in the AI-related conversation and to thrive in various ways to achieve personalized education. Unlike previous digital technologies, which were limited to complementing traditional methods, AI offers an unprecedented capacity to analyze large amounts of data on student performance, identify learning patterns and gaps, and adapt content and instruction accordingly (Hwang et al., 2022; Kim, 2022; Qin et al., 2020).

Moreover, through the use of advanced algorithms and machine learning techniques, AI can constantly monitor each student's progress and dynamically adjust the learning experience according to their specific needs (Rasheed et al., 2023). This not only has the potential to improve teaching effectiveness but would also foster student motivation and engagement by providing a personalized and relevant approach (Li et al., 2019; Rosli et al., 2024).

From the perspective of using digital technologies to support learning personalization, different ways of addressing this issue are mentioned on a scale from least to most technological sophistication, including "Flexible Learning", "Adaptive Learning", "Intelligent Tutoring Systems", "Humanoid Robot Tutor" and "Behavior Prediction" (Peng et al., 2019; Velasco Suárez et al., 2023; Yang et al., 2013).

The potential of AI to understand and manage error

Although errors have traditionally been considered negative, which can generate frustration and demotivation in students, at the heart of the transformation that AI can bring to personalized education is a key perspective to transform this frequent conception: "error" should be seen as a valuable opportunity for learning, rather than a failure (Hashim et al., 2022).

Error has played a crucial role in learning processes throughout different stages of everyday life. For example, learning the mother tongue, walking, riding a bicycle, overcoming obstacles in a video game until winning it. Error is a natural phenomenon that can be beneficial for learning and memory (Metcalfe & Huelser, 2020). However, as people grow and depend on the environment in which they develop, their attitude towards errors changes. Particularly in the school context, fears of making mistakes or not meeting the expectations of the teacher or peers become more evident (Alvarez-Herrero, 2019). It is essential to seek mechanisms that allow both intentional and accidental errors to be used to create meaningful learning situations.

In this sense, as Knight et al. (2023) point out, AI has the potential to leverage errors to better understand the specific difficulties of each student and provide personalized feedback and support. Thus, by analyzing error patterns, AI can identify problem areas and adapt content and instruction accordingly, reinforcing weak concepts and effectively addressing comprehension gaps.

Depending on the interpretation, error can contribute to the learning process or simply be an indicator of failure. In this sense, AI can play a fundamental role. There is evidence of technology-mediated learning personalization strategies, where AI helps in the analysis, understanding, and decision-making on how to articulate unique characteristics with pedagogical designs that precisely adjust to the difficulties and strengths of each student (Jang et al., 2022; Pratama et al., 2023). Thus, the conceptual construct presented throughout this paper becomes an invitation to explore the capabilities of machine learning to develop different stages of personalized learning through student error, thus providing an interesting didactic opportunity for the learning process.

Encouraging error: A controversial proposal

While the benefits of learning personalization have already been mentioned on the one hand, and the convenience of identifying and taking advantage of errors as a mechanism to reinforce learning on the other, in this opinion piece, we propose a view that integrates both aspects in a controversial way. This approach constitutes its central claim: AI is the mechanism that will allow students to not only take advantage of an error but to intentionally and controllably encourage them to fail in learning as a starting point that turns errors into a catalyst for personalized learning and thereby generate educational change and consistent and durable learning.

It is important to recognize that specialized literature has already provided broad and numerous aspects from which to address the characterization of a particular student, such as learning styles, interests, skills, context, knowledge levels, memory capacity, and emotions, among others (Benton et al., 2021; Namoun & Alshanqiti, 2020). To these elements that are at the basis of learning personalization, we add another component that we consider key in this process: the errors that students make in their learning process. Just as several authors such as Cabrera Albert & Fariñas León (2005), and

Farconesi (2012) point out that human beings are unique and unrepeatable, we will add to this statement another of equal relevance: "Everyone makes mistakes differently". Such a statement would be the basis for considering "error" as the starting point for tracing personal learning processes.

Considering the above, designing training routes starting from the encouragement of errors is an educational bet that is interesting to explore. It is then proposed that personalized learning can arise as a result of a unique component of each student: "their errors". Errors can reveal prior knowledge and learning gaps, and can also support different stages of learning by improving cognitive and affective learning (Desai, 2020). The proposal would be configured with designs of suitable environments for deep learning, where student errors are the source of information on which the AI system relies throughout the journey to achieve learning. These strategies seek to transcend pre-designed learning routes towards increasingly personalized routes, taking advantage of the potential of emerging technologies.

In line with the central claim of this paper, Bogdanova and Snoeck (2018) argue that AI's ability to leverage errors as a learning tool, rather than viewing them as failures, represents a fundamental paradigm shift in education. By turning error into a catalyst for personalized learning, AI promises to significantly improve the effectiveness and relevance of education for each student, better preparing them for the challenges of an uncertain world.

Errors, AI and learning

After establishing the importance of errors in learning, its personalization, and the transformative role that AI can play in this context, it is essential to examine in more detail how AI can leverage students' errors as a valuable opportunity to facilitate truly personalized learning adapted to the unique needs of each individual. The following presents relevant arguments and evidence supporting the central claim of this article.

Matching errors and AI: The gateway to personalized learning

In the quest for truly personalized learning, it is fundamental to understand that errors are not mere failures but windows into a deeper understanding of each student's strengths and weaknesses. As Waladi et al. (2024) affirm, error analysis is crucial for learning personalization, as it provides valuable information about students' problem areas and difficulty patterns, considering errors as opportunities for deeper learning and better understanding of concepts.

However, in traditional educational environments, tracking errors in detail and adapting to them can be an overwhelming and impractical task due to the large amount of data and the diversity of student needs. As Pane et al. (2015) point out, teachers often lack the necessary tools and resources to accurately track individual student progress and adapt instruction accordingly.

This is where artificial intelligence emerges as a powerful tool, capable of efficiently and accurately analyzing large volumes of data on student performance and error patterns. As Rasheed et al. (2023) point out, through the use of advanced algorithms and machine learning techniques, AI can identify problem areas and error patterns of each student, allowing for dynamic adaptation of content and instruction. In agreement, González-González (2023) highlights that generative AI is revolutionizing various fields, as it can learn, devise and create new content, activities, and experiences, as well as represent information based on parameters, in this case, error patterns. This capacity for in-depth analysis and real-time adaptation is fundamental to providing a truly personalized learning experience tailored to the unique needs of each individual.

A change in mindset is needed

It has already been mentioned that instead of viewing errors as failures, a more constructive perspective considers them as valuable opportunities for growth and learning. Related to what is mentioned by Williams and Lewis (2021), it is noteworthy that a learning mindset focused on growth from errors is fundamental to developing lifelong learning skills in the 21st century. However, in conventional educational contexts, this learning mindset focused on leveraging errors can be difficult to implement due to the lack of adequate resources and tools to systematically analyze and address errors. As Zohuri (2024) warns, a new teaching mindset or educational paradigm change is expected to happen, and in this context, it may be apt to start considering errors not as failures but as personalization learning opportunities.

The concept of growth mindset, postulated by Dweck (2006), maintains that abilities and intelligence are not innate and immutable qualities, but can be developed through effort, conscious self-evaluation, and a willingness to face challenges and failures. This concept contrasts with the fixed mindset, which views capabilities as static and considers failure as indicative of a lack of natural talent, generating fear of error and avoiding difficult tasks.

Developing the ability to face failures becomes a crucial aspect in transitioning from a fixed mindset to a growth mindset. Various studies have applied growth mindset training as a methodological strategy, demonstrating its positive impact on subsequent academic success (Lewis et al., 2020). Furthermore, it has been shown that teachers' perceptions of their students can significantly influence the promotion of a growth mindset (Muenks et al., 2021). The design of school environments that allow students to learn from their mistakes and improve from them, through more elaborate practices, also contributes to strengthening this mindset (Yeager & Dweck, 2020).

At this point, it becomes interesting to consider AI as a central tool to facilitate the construction of a learning mindset centered on leveraging errors. Thus, by analyzing each student's error patterns, AI can provide personalized feedback and support, reinforcing weak concepts and effectively addressing comprehension gaps. Regarding this, Ayeni et al. (2024) indicate the existence of a wide set of

educational technology, AI included, that allows to creation of a digital ecosystem in which this new mindset can be addressed, via personalized learning paths, leveraging errors to better understand students' specific difficulties and adapt content and instruction accordingly, turning errors into catalysts for personalized learning.

Risks of leveraging error as a driver of personalized learning

Thus far in this paper, the potential advantages of personalizing learning have already been mentioned earlier, and the importance of error to foster more meaningful learning has been addressed. However, it is also necessary to consider that there are risks in the initiative to promote error and turn it into a mechanism to chart personalized learning paths. Indeed, there is a double risk to consider; on the one hand, there is the possibility that students may become demotivated due to the errors they make, considering that the traditional system in which they have grown up for years views errors as something undesirable that should be avoided, focusing and valuing only successes. On the other hand, the other risk is failing to detect the presence of errors and allowing them to consolidate within the student's body of knowledge.

Faced with these two possibilities, the use of AI must be designed in a way that allows close monitoring of the errors generated, identifying possible states of mind reflecting demotivation or engagement problems, mainly through content and sentiment analysis tools (Islam et al., 2024; Suresh Kumar et al., 2024). In addition, AI should help teachers, through these tools, to identify inconsistencies or comprehension errors in the discourses, conversations, or products generated by students and to project strategies or activities that lead students to recognize and transform them into accurate knowledge.

Promote, address and intervene errors as part of lifelong learning skills

In today's constantly changing and increasingly complex world, students must develop adaptive skills and a mindset of continuous learning. As Thwe and Kálmán (2024), Tobias (2004) and Findsen (2012) state, in the 21st century, learning is no longer just about acquiring knowledge but also about developing the ability to adapt and learn continuously throughout life. In this context, it is proposed in this paper that lifelong learning skills must include the ability to learn from errors and adapt to new situations, as a key skill for success in a constantly changing world.

The concept of lifelong learning has transcended beyond any intentional learning activity conceived as a practice of continuous improvement (Omirbayev et al., 2021). Currently, it is conceived as an integral process that encompasses all stages of life, from childhood to old age, and develops in various contexts such as family, school, work, and community, and through different modalities, such as formal, non-formal, and informal (UNESCO, 2017). This perspective recognizes that lifelong learning is fundamental for comprehensive human development, as it allows people to acquire and update knowledge and skills flexibly, responding to the changing demands of society and contributing to economic, social, cultural, and environmental well-being (Thwe & Kálmán, 2024).

In this sense, the development of skills for lifelong learning is essential in a society characterized by the accelerated growth of knowledge and information. These skills, which include interpersonal, cognitive, and technical aspects, allow people to learn autonomously, adapt to new contexts, and evolve continuously (Alt et al., 2022; Evans et al., 2022). Among the interpersonal skills, self-regulation, self-evaluation, and autonomy stand out, allowing individuals to manage their own learning process. In turn, cognitive skills such as critical thinking, creativity, and problem-solving are necessary to analyze information, generate innovative ideas, and find effective solutions. Additionally, technical competencies, which encompass specialized knowledge and emerging digital skills (Alt & Raichel, 2022; Blaschke, 2021; Gönderen Çakmak & Ayhan Başer, 2024), equip people to face the challenges of a constantly changing world and allow them to contribute to sustainable development.

Regarding the above, it is noteworthy, as Poquet and De Laat (2021) warn, that in traditional educational environments, there is often too much emphasis on knowledge acquisition or transfer and neglect of the development of these important adaptive skills. Considering the above, AI can play a fundamental role in preparing students for these future challenges by fostering more personalized and relevant learning based on analyzing individual errors and bringing them timely and tailored feedback.

Conclusions

This opinion piece has critically explored the transformative role that artificial intelligence can play in education by leveraging and even encouraging student errors as catalysts for truly personalized learning adapted to the unique needs of each individual. This challenging, albeit controversial, perspective becomes highly relevant in the current and future educational context.

Firstly, what has been presented in the body of the paper highlights the importance of adopting a lifelong learning mindset towards error. Instead of seeing it as a failure, the error should be understood as an opportunity to analyze difficulties, enrich knowledge, and develop strategies to overcome learning barriers. The implementation of AI as a mechanism to encourage "learning errors" and to systematize the analysis of error patterns would catalyze this process, turning errors into a facilitator of personalized learning.

The implications of this perspective are significant, both for teaching practice and for the development of learning processes in students at all levels. As for educators, they must adopt an open and receptive mindset to error, implementing strategies and activities that promote its occurrence, analysis, and utilization. This implies a paradigm shift from traditional approaches that tend to treat errors as

failures (Ronnie & Philip, 2021).

For their part, students must assume a proactive attitude, willing to face error as an opportunity for growth and not as an obstacle. This requires the development of a learning mindset centered on growth from errors, which is fundamental to acquiring lifelong learning skills in the 21st century.

At the institutional level, this vision of error as a catalyst for learning will demand the implementation of spaces and resources that promote its systematic analysis, as well as the adoption of pedagogical approaches oriented towards leveraging error as a driver of learning. Only through a comprehensive approach that incorporates the experience of error as an opportunity for enrichment will it be possible to transition towards truly transformative and permanent education.

Furthermore, the integration of AI in this process is fundamental, as it offers the ability to efficiently and accurately analyze large volumes of data on student performance and error patterns. As Chen et al. (2020) point out, through the use of advanced algorithms and machine learning techniques, AI can identify problem areas and error patterns of each student, allowing for dynamic adaptation of content and instruction. This capacity for in-depth analysis and real-time adaptation is essential to provide a truly personalized learning experience tailored to the unique needs of each individual. Moreover, AI can play a crucial role in facilitating a learning mindset centered on leveraging errors. By analyzing each student's error patterns, AI can provide personalized feedback and support, reinforcing weak concepts and effectively addressing comprehension gaps.

Additionally to the well-known potential of AI for personalized learning by allowing students to progress at their own pace and receive content and activities adapted to their specific needs and learning styles, AI can better prepare students for future challenges by fostering the development of adaptive skills and a continuous learning mindset, which also, can significantly improve academic performance, engagement, and motivation.

Another aspect widely addressed in the literature is AI´s capacity to alleviate teachers' workload by automating tasks, generation of personalized content, and provision of individualized feedback. So, it is time to include the processes of personalized error analysis in this package of benefits. This is particularly relevant in traditional educational environments, where teachers are often overwhelmed by the need to address individual student needs, in addition to other tasks, as pointed out by Lameras and Arnab (2021).

By adopting this challenging perspective, which assumes error as an opportunity for growth and leverages AI's ability to systematically analyze and adapt to error patterns, educational institutions can better prepare students for the challenges of the 21st century, fostering lifelong learning skills, motivation, and academic engagement.

While this vision implies a significant paradigm shift in how error is conceived and addressed in education, its implementation promises to redefine the learning experience, turning it into a truly personalized, adaptive, and transformative adventure for each student. Ultimately, this paper has highlighted the importance of harnessing the power of AI to catalyze profound educational change, where error ceases to be an obstacle and becomes a springboard towards growth and continuous learning.

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