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Artificial intelligence and the pursuit of SDG 4: A SWOT–TOWS analysis of educational transformations and strategic pathways

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Abstract

Artificial intelligence (AI) is increasingly recognized as a transformative force for enhancing the quality, equity, and accessibility of education and for accelerating progress toward Sustainable Development Goal 4 (SDG 4), quality education. This study adopts a conceptual analysis approach, integrating a focused exploration of scholarly and policy literature with a strategic SWOT–TOWS analysis of AI applications in education to inform ethical and policy-oriented implementation frameworks. It is anchored in an established taxonomy of AI in education (AIED) systems and a critical socio-technical perspective that treats AI's educational effects as conditional on governance and institutional context. Rather than a systematic review, it synthesized conceptually relevant publications indexed in Scopus and Web of Science and policy reports from UNESCO and the United Nations. Findings indicate that AI can advance SDG 4 through personalized and adaptive learning, predictive analytics, improved learning outcomes, data-driven decision-making, administrative automation, and expanded access, particularly in resource-constrained contexts. Persistent challenges include algorithmic bias, data privacy risks, inequitable digital access, and diminished human interaction. The SWOT–TOWS synthesis translated these findings into strategic pathways for responsible AI integration. Recommendations include national AI policies that promote inclusive public–private partnerships, culturally representative datasets to mitigate bias, human-in-the-loop safeguards, algorithmic impact assessments, AI literacy initiatives, international collaboration on teacher training, and ethical guidelines that address privacy, fairness, and transparency. Collectively, these strategies underscore that AI's contribution to SDG 4 is conditional rather than automatic and aim to ensure that AI enables inclusive and equitable quality education and lifelong learning for all.

Introduction

The rapid evolution of emerging technologies has sparked extensive academic inquiry and policy action. Technologies such as artificial intelligence (AI), quantum computing, and immersive technologies (e.g., virtual and augmented reality) are not only reshaping economic, educational, and governance systems but are also driving new paradigms in knowledge production, service delivery, and global connectivity. Among these technologies, AI stands out for its cross-sectoral potential by offering novel solutions to some of the world's most persistent challenges. As governments and institutions seek to harness technological innovation for social good, the integration of AI into global development agendas has gained significant traction. In this context, the Sustainable Development Goals (SDGs), adopted in 2015 as a universal call to action for people, planet, and prosperity, provide a critical framework for aligning technological progress with inclusive and equitable outcomes (United Nations, 2015). However, progress toward these goals has been uneven. A confluence of global crises (e.g., COVID-19 pandemic, climate change, and geopolitical instability) has derailed advancements, with reports indicating that 80% of SDG targets are stalled or regressing, and only 15% remain on track as of 2023 (ITU & UNDP, 2023; Gosselink et al., 2024). Against this backdrop, AI emerges as a powerful enabler of sustainable development (Singh et al., 2024), with the capacity to serve as a delivery platform for essential services, a generator of actionable insights, and a catalyst for systemic innovation in pursuit of the 2030 Agenda.

As the global community moves closer to the 2030 deadline, there is a growing urgency to accelerate progress across all SDGs (Leal Filho et al., 2023). In this context, AI can serve as a pivotal instrument in advancing the SDG agenda through three primary roles: as a platform for delivering essential services, as a tool for generating data-driven insights, and as a catalyst for transformative innovation in systems and processes (ITU & UNDP, 2023). These capabilities position AI as a strategic enabler of more agile, responsive, and scalable solutions to complex development challenges. However, the deployment of AI is neither inherently beneficial nor universally effective (Sarker, 2022). Its outcomes are not automatic: they depend on how AI systems are designed, funded, and governed, so that the same technology can expand opportunity in one setting while deepening exclusion in another, depending on infrastructure quality, data practices, and institutional capacity. This dual-edged potential necessitates a critical examination of the risks it poses, particularly the danger of exacerbating existing inequalities related to gender, geography, and access to digital infrastructure (Bentley et al., 2024). To ensure AI contributes meaningfully to inclusive and equitable development, its integration must be guided by human-centered principles and grounded in the protection of human rights. This calls for proactive governance frameworks that emphasize ethical design, equitable access, data privacy, and algorithmic accountability (ITU & UNDP, 2023). Embedding these safeguards allows stakeholders to help ensure that AI supports the core mission of the SDGs: to leave no one behind.

Within this broader context, a growing body of scholarship recognizes AI as a transformative force with far-reaching implications across multiple sectors, including education (Bozkurt et al., 2024; Wang et al., 2024). In the educational sphere, AI offers promising avenues to enhance instructional quality, support personalized and adaptive learning, automate administrative processes, and augment the research capabilities of educators and institutions. Importantly, AI is increasingly viewed as a key enabler in the pursuit of SDG 4, which seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. While the potential of AI in education is widely acknowledged, a critical gap remains in systematically linking specific AI applications to the nuanced targets of SDG 4, particularly through a strategic management lens that balances transformative potential against profound ethical and operational risks (Kulkov et al., 2024). This study aims to bridge this gap by critically examining how AI can be strategically leveraged to advance SDG 4, while addressing the ethical, technical, and social challenges associated with its use in educational contexts. Guided by the central research question (i.e., What are the most effective pathways for AI to fulfill SDG 4's promise?), the study adopts a three-pronged methodological approach: (1) a focused exploration of relevant literature; (2) a strategic SWOT–TOWS analysis of AI applications in education; and (3) the development of ethical implementation frameworks to inform policy and practice.

Although a substantial body of review and conceptual literature already addresses AI in education broadly (e.g., Bozkurt et al., 2024; Wang et al., 2024), this study's specific contribution lies in three moves. First, rather than surveying AI in education in general terms, the analysis is explicitly anchored in the SDG 4 target structure (Table

1), tracing specific AI applications to specific targets rather than to broad claims about educational benefit. Second, it pairs the Holmes and Tuomi (2022) AIED taxonomy with a critical socio-technical lens (Section 2.1) to explain why comparable AI applications can produce divergent outcomes across institutional contexts (Eynon, 2023), an explanatory step that existing SWOT-style treatments of AI in education (e.g., Denecke et al., 2023; Farrokhnia et al., 2024) generally do not undertake. Third, it translates this critical mapping into TOWS-based strategic pathways framed explicitly for higher education pedagogy, governance, curriculum design, and educator practice, rather than leaving recommendations at the level of general policy statements. Together, these moves distinguish the present study from the broader review literature on AI in education and clarify its intended contribution specifically to higher education teaching and learning scholarship.

Literature review

Within the broader agenda of sustainable development, SDG 4 holds a central place in ensuring that all individuals have access to quality education and lifelong learning opportunities. It aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (United Nations, 2015). To operationalize this goal, the United Nations established seven specific targets to be achieved by 2030, each addressing a critical dimension of educational access, equity, and quality, alongside three additional means of implementation that support the operationalization of this agenda (see Table 1).

Table 1. SDG 4 and Associated Targets

Targets	Major Emphasis
4.1	Ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes.
4.2	Ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education.
4.3	Ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university.
4.4	Substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.
4.5	Eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations.
4.6	Ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy.
4.7	Ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development
Means	**Means of Implementation**
4.a	Build and upgrade inclusive and safe schools.
4.b	Expand higher education scholarships for developing countries.
4.c	Increase the supply of qualified teachers in developing countries.

Source: United Nations (2015). Transforming our World: The 2030 Agenda for Sustainable Development.

Several international reports (UNESCO, 2019a, 2019b, 2019c, 2021a, 2021b, 2022, 2023; Gast, 2022; Giannini, 2023; Singh et al., 2024) and studies (Vinuesa et al., 2020; Lampis, 2021; Páez, 2023; Gosselink et al., 2024) refer to the vast opportunities associated with AI technologies to accelerate progress towards the achievement of SDGs in general and SDG 4 in particular. These sources highlight how AI technologies can support inclusive, equitable, and quality education through data-driven insights, adaptive learning systems, and enhanced access. However, the rapid pace of AI developments inevitably introduces numerous risks and challenges, which have so far outpaced policy debates and regulatory frameworks (UNESCO, 2021a).

In 2019, UNESCO adopted the "Beijing Consensus on Artificial Intelligence and Education" – the first global policy framework aimed at fostering the preparedness of education policymakers for the integration of AI into teaching and learning systems (UNESCO, 2019b). Since then, artificial intelligence has demonstrated transformative potential in the education sector, prompting growing scholarly interest in its role in advancing the objectives of SDG 4. To systematize this emerging field, Holmes and Tuomi (2022) developed a comprehensive taxonomy of AI in Education (AIED) systems, which categorizes AI applications into three interrelated domains: (1) student-focused, (2) teacher-focused, and (3) institution-focused tools (Holmes et al., 2019). This framework further distinguishes each application by its stage of maturity: speculative (*), under active research (* *), or commercially available (* * *). The taxonomy presented in Table 2 is not merely a catalog of tools but a crucial framework for analyzing AI's multifaceted role in advancing SDG 4 (Holmes & Tuomi, 2022). We employ this taxonomy not as an end, but as an analytical lens to map the existing technological landscape against the equity, quality, and inclusion targets of SDG 4. It allows us to identify where current AI capabilities are strongest, where critical gaps persist, and how different applications contribute to or potentially complicate the goal of inclusive and equitable quality education.

Table 2. A Taxonomy of AIED Systems

Student-Focused AIED	**Maturity**
Intelligent Tutoring Systems (ITS)	* * *
AI-assisted Apps (e.g., maths, text-to-speech, language learning)	* * *
AI-assisted Simulations (e.g., games-based learning, VR, AR)	* * *
AI to Support Learners with Disabilities	* * *
Automatic Essay Writing (AEW)	* * *
Chatbots	* * */* *
Automatic Formative Assessment (AFA)	* * */* *
Learning Network Orchestrators	* * */* *
Dialogue-based Tutoring Systems (DBTS)	* * *
Exploratory Learning Environments (ELE)	* *
AI-assisted Lifelong Learning Assistant	*
Teacher-Focused AIED	**Maturity**
Plagiarism detection	* * *
Smart Curation of Learning Materials	* * *
Classroom Monitoring	* * *
Automatic Summative Assessment	* * */* *
AI Teaching Assistant (including assessment assistant)	* * */*
Classroom Orchestration	* *
Institution-Focused AIED	**Maturity**
Admissions (e.g., student selection)	* * *
Course-planning, Scheduling, Timetabling	* * *
School Security	* * *
Identifying *Dropouts* and *Students at risk*	* * *
e-Proctoring	* * *

Source: Holmes and Tuomi (2022). State of the art and practice in AI in education.

While Holmes and Tuomi's taxonomy usefully categorizes AIED tools, it primarily reflects a techno-centric perspective. It underemphasizes the socio-cultural dimensions of implementation, such as teacher agency and community readiness, which are critical for achieving SDG 4's equity goals.

Theoretical framework

This study is anchored by two complementary lenses rather than by the AIED taxonomy alone. The first is Holmes and Tuomi's (2022) classification of student-, teacher-, and institution-focused AIED systems, which is used here as a mapping device to locate where current AI capabilities sit relative to the equity, quality, and inclusion targets of SDG 4. The second is a critical socio-technical perspective on AI in education (Eynon, 2023), which treats AI systems not as neutral technical artefacts but as arrangements of infrastructure, data, institutional practice, and human judgement whose educational effects depend on the governance and context in which they are deployed. Read together, the taxonomy identifies what AI applications exist and where they cluster, while the socio-technical lens explains why comparable applications can produce divergent, even contradictory, outcomes for equity and quality across institutions and higher education systems.

These two lenses are, in turn, mobilized analytically through the SWOT–TOWS framework (Helms & Nixon, 2010; Benzaghta et al., 2021), which supplies the interpretive logic connecting critical mapping to strategic recommendation. Rather than treating SWOT–TOWS as a purely descriptive device, this study uses it as the mechanism through which the taxonomy's classificatory findings and the socio-technical critique are jointly translated into strategic pathways: strengths and weaknesses are read through the socio-technical lens to identify where institutional context conditions AI's effects, and the resulting TOWS strategies operationalize these conditions into recommendations for higher education pedagogy, governance, curriculum design, and educator practice. This conceptual anchoring distinguishes the analysis that follows from a purely descriptive SWOT exercise and clarifies the theoretical basis on which the study's strategic claims rest.

AI applications thematically mapped to SDG 4 Targets

To critically evaluate AI's role in education, it is essential to move beyond a mere catalog of technologies and instead analyze how specific applications align with or potentially undermine the specific targets of SDG 4. This section synthesizes the literature by mapping prominent AI applications to core SDG 4 objectives, namely enhancing learning outcomes (Target 4.1), promoting equity and inclusion (Targets 4.5 and 4.7), and expanding educational access (implicit across all targets, e.g., Targets 4.2, 4.3, and 4.4). This thematic organization provides a focused lens through which to assess AI's tangible contributions and persistent challenges.

Enhancing learning outcomes and personalization

It has commonly been assumed that the core contribution of AI lies in its capacity to support Targets 4.1 and 4.4 by enabling personalized, adaptive learning. Intelligent Tutoring Systems (ITSs), as an example of student-focused AIED, are AI-driven adaptive learning environments that identify students' learning needs and provide timely, personalized support. Using technologies like neural networks and machine learning, ITSs model students' cognitive and motivational states to enhance learning experiences and support quality education (Xu et al., 2019). Similarly, the advent of generative AI, particularly ChatGPT, launched by OpenAI in late 2022 and similar large language models, has dramatically expanded the scope of personalization. These tools can act as conversational partners, provide instant feedback on writing, and simulate tutoring dialogues, thereby fostering engagement and supporting mastery of skills relevant for employment (Qadir, 2023). The development of smart content, such as digital textbooks and adaptive lectures that respond to learners' progress, has been reported to facilitate personalized learning pathways (Ahmad et al., 2022). However, this promise is contingent on the quality and bias of the underlying algorithms. The tendency of generative AI to produce plausible but inaccurate or unsourced information (Adams & Chuah, 2022; OpenAI, 2023) poses a direct threat to the "quality" and "relevant learning outcomes" mandated by SDG 4.1, raising critical questions about their uncritical adoption.

Promoting equity, inclusion, and early intervention

AI also shows promise in expanding educational accessibility and promoting equity (SDG 4.5) through data-driven interventions. For example, AI technologies can analyze educational data to identify trends and patterns in student behavior and performance, which can provide insights that help enhance the quality of the educational experience, for example, flagging declining engagement in a course, identifying students at elevated risk of falling behind, or prompting timely advisor outreach before performance drops further (Ahmad, 2020). Applications include using learning analytics to identify students who need intervention in blended learning environments (Kim et al., 2016; Viberg et al., 2018).

However, rapid technological advancement poses significant challenges. At the time of its 2022 release, ChatGPT did not reliably cite sources in its responses, raising concerns about transparency and credibility, and citation behavior has continued to vary across generative AI tools and subsequent versions, with accuracy not always guaranteed even where citation features exist (OpenAI, 2023). While future AI tools may be able to reference scientific literature accurately and quickly, this evolution must be approached with caution due to its potential impact on education (Adams & Chuah, 2022). Effective implementation requires addressing challenges such as ethics, bias, privacy, educator training, and cost.

Augmenting educational capacity and research

AI also contributes to SDG 4 (i.e., Targets 4.4, 4.6, and 4.7) by augmenting the capabilities of educators and institutions, particularly in higher education (Xu et al., 2019; Hermann & Hermann, 2022). AI technologies enable more efficient and accurate analysis of large datasets (big data), that is, datasets whose volume, velocity, and variety exceed what conventional analytic methods can readily process, and can detect patterns and trends that would be impossible to identify using traditional research methods through tools such as machine learning and neural networks. Applications include detecting student attention levels in online lectures via brain signals (Chen et al., 2017). AI also automates routine research tasks such as data entry and analysis, allowing researchers to focus on more innovative and creative work (UNESCO, 2021a; Holmes & Tuomi, 2022).

It is often assumed that developing essential human knowledge and skills is crucial in the AI age, as it enables individuals to leverage AI to enhance education, employment, and research outcomes (Eid et al., 2025). This foundational human expertise is also seen as a key strategy to avoid cognitive debt: a cumulative deficit in critical thinking, ethical reasoning, and professional judgment that arises from offloading cognitive tasks (Watts, 2025). Another study stresses the need for students, employees and society to become active, engaged, effective and responsible citizens in an AI-driven world, urging a thoughtful and cautious integration of AI into education to support both learners and teachers (Yasmin & Mazhar, 2022). This aligns with the aim of the World Economic Forum (WEF) to maximize the benefits of AI and machine learning while ensuring privacy, accountability, sustainability, inclusion, and protection of vulnerable groups (World Economic Forum, 2023). To unlock AI's full potential in education, educators and students must be equipped with the necessary knowledge, skills, and competencies.

Synthesis and gap identification

In summary, the literature suggests that AI offers transformative opportunities in teaching, learning, research, and administration and can help fulfil the promise of SDG 4. Nevertheless, further research is needed to fully understand its benefits, risks, and ethical implications, particularly regarding data privacy, algorithmic bias, and the potential for AI to exacerbate existing social inequalities.

Methodology

This study adopted a conceptual analysis approach (Machado & Silva, 2007), that combined a focused exploration of relevant scholarly and policy literature with a strategic SWOT–TOWS analysis (Helms & Nixon, 2010; Alyamani et al., 2025), of AI applications in education and the development of ethical implementation frameworks to inform policy and practice. The main aim of this study was to explore how AI can contribute to achieving SDG 4, while identifying associated challenges and policy implications. Given the emergent and interdisciplinary nature of AI in education, a rigid systematic review protocol was deemed less suitable than a conceptual analysis aimed at synthesizing key arguments and discourses (Kennedy, 2007). Unlike systematic or scoping reviews, this exploratory approach relied on conceptual relevance, drawing on sources that offered meaningful insights into the promises, limitations, and policy implications of AI in relation to Sustainable Development Goal 4 (SDG 4), rather than on predefined inclusion or exclusion criteria.

To build the analytical foundation for the study, relevant publications were identified through keyword searches (Artificial Intelligence (AI) + Education; AI + SDG 4; Generative Artificial Intelligence (GenAI) + Education; Generative Artificial Intelligence (GenAI) + SDG 4) in reputable academic databases, including Scopus and Web of Science, alongside authoritative policy documents issued by organizations such as UNESCO and the United Nations. These sources were selected for their credibility, contemporary relevance, and contribution to ongoing discussions about the role of AI in enhancing educational access, equity, and quality. This exploratory literature mapping enabled the identification of dominant themes - particularly personalized learning, algorithmic bias, and digital equity, which informed the development of the subsequent analytical framework as depicted in Figure 1.

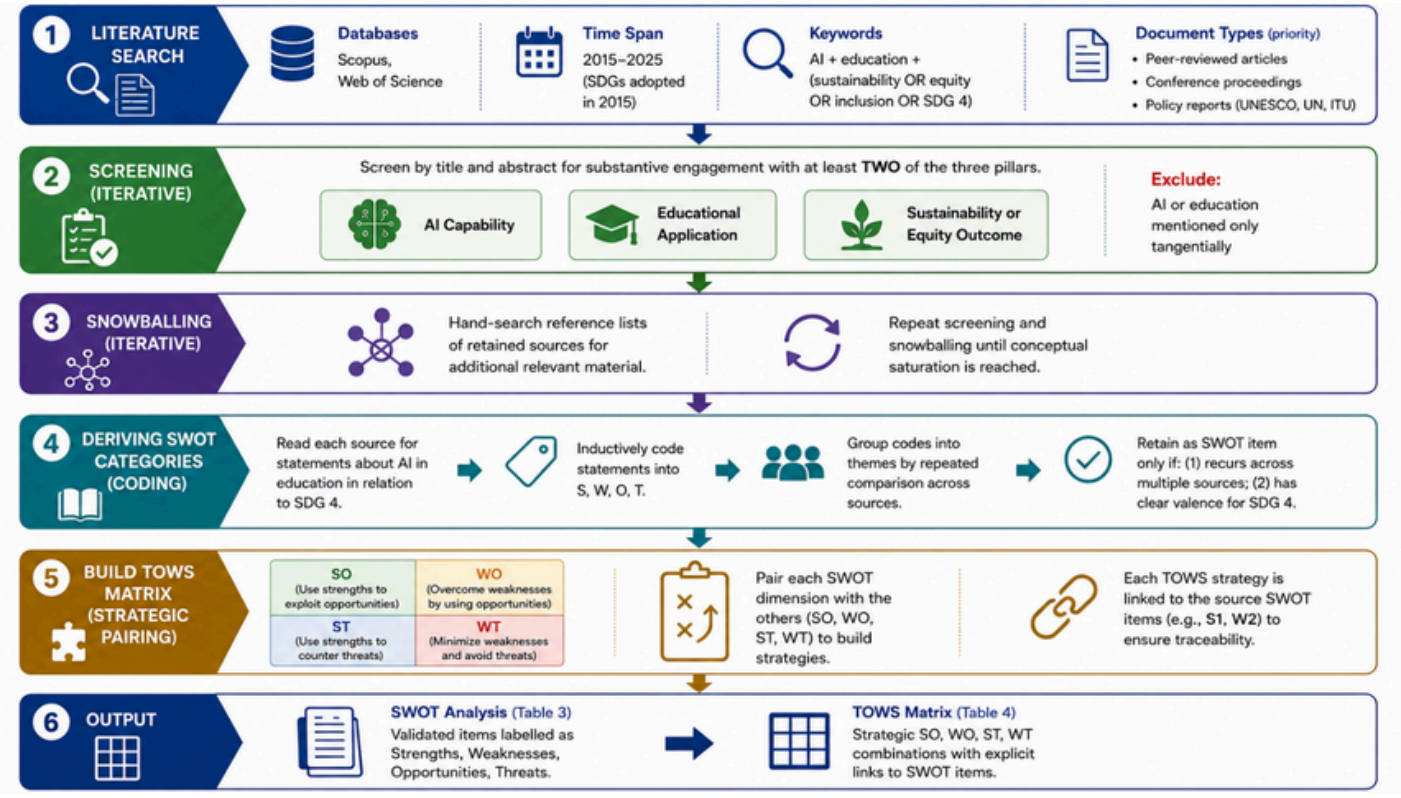

Figure 1. Methodological framework for the development of the SWOT–TOWS analysis

To provide greater methodological transparency, searches used the keyword combinations noted above across Scopus and Web of Science, restricted to publications from 2015 (the year the SDGs were adopted) to 2025, and prioritized peer-reviewed journal articles, conference proceedings, and policy reports issued by bodies such as UNESCO, the United Nations, and the ITU. Records were screened by title and abstract for substantive engagement with at least two of the study's three conceptual pillars (AI capability, educational application, and sustainability or equity outcome) and were excluded where AI or education featured only tangentially. This screening was iterative rather than a single-pass protocol: the reference lists of retained sources were hand-searched for additional conceptually relevant material, a snowballing step consistent with the exploratory, conceptual-analysis design adopted here (Machado & Silva, 2007) rather than with a systematic review protocol.

The derivation of the SWOT categories followed a structured coding process. Each retained source was read for statements bearing on AI's educational strengths, weaknesses, opportunities, or threats in relation to SDG 4; these statements were inductively coded and iteratively grouped into higher-order themes (e.g., personalization, algorithmic bias, cost, digital divide) through repeated comparison across sources, following the SWOT coding logic described by Benzaghta et al. (2021). A theme was retained as a labelled SWOT item in Table 3 only where it recurred across multiple independent sources and carried a clear valence (enabling or constraining) for SDG 4 outcomes; single-source or ambiguous observations were treated as illustrative rather than admitted as standalone items. The TOWS matrix in Table 4 was then generated by systematically pairing each SWOT dimension with the others (SO, WO, ST, WT) and constructing strategies that specify how a given strength or weakness could be used to exploit an opportunity or counter a threat, consistent with established TOWS logic (Helms & Nixon, 2010; Saari et al., 2024). To keep this pairing process traceable, every TOWS strategy in Table 4 is linked explicitly back to the labelled SWOT items from which it was derived (e.g., S1, W2), rather than being generated from a general reading of the literature.

Based on these insights, a SWOT analysis was conducted to systematically categorize the strengths, weaknesses, opportunities, and threats associated with AI integration in the education sector, following established methodological guidance by Benzaghta et al. (2021). Drawing on evidence from both scholarly literature and empirical assessments, and informed by the work of Denecke et al. (2023) and Farrokhnia et al. (2024), the SWOT framework highlighted key issues such as the potential of AI for adaptive learning, the risks of algorithmic discrimination, and persistent challenges related to digital divides.

The SWOT analysis findings were then synthesized into a TOWS matrix, which transformed descriptive insights into strategic pathways and actionable recommendations for education stakeholders. This process enabled the identification of strategies that leverage AI’s strengths to advance SDG 4, address structural weaknesses, capitalize on emerging opportunities, and mitigate ethical, social, and technological threats (Saari et al., 2024; Alyamani et al., 2025). The resulting strategic directions informed the development of a set of ethical and policy-oriented recommendations aimed at ensuring that AI is implemented responsibly, equitably, and with a clear focus on enhancing inclusive and equitable quality education. Building on this analysis, we further refined these strategic directions into a comprehensive set of ethical and policy-oriented recommendations designed to help policymakers, educators, and researchers harness AI’s potential while ensuring that these strategies remain grounded in evidence, fairness, ethics, and real-world educational impact. This integrative approach ensured that the study remained both evidence-informed and strategically aligned with the pursuit of inclusive and equitable quality education.

Findings and discussion

Promises of AI in education

Building on the literature synthesized in Section 2, and the methodology in Section 3, this section moves from descriptive review toward the study's own analytical contribution: it draws together the promises and challenges identified in the literature as the evidentiary basis for the SWOT–TOWS analysis that follows, rather than restating that literature for its own sake. The literature reviewed highlights several significant opportunities offered by AI to support the realization of SDG 4, with particular relevance for higher education teaching and learning contexts. One of the most widely recognized promises of AI in education is its capacity to facilitate pers-

-onalized learning. AI algorithms can analyze individual student data (e.g., learning styles, performance trends, and engagement patterns) to generate tailored learning pathways that align with each learner's specific needs. This individualized approach enhances student engagement, improves academic outcomes, and supports learner retention, while also enabling educators to intervene proactively when students show signs of academic struggle (Ahmad, 2020). These features directly align with the goals of SDG 4.1 and 4.5, which call for improved learning outcomes and reduced educational inequalities. AI technologies also show promise in expanding educational accessibility. Tools such as chatbots and virtual assistants offer 24/7 academic support, making learning resources more available to students who face constraints related to geography, disability, or time (Chrisinger, 2019). This feature can play a critical role in addressing barriers to education and promoting equity in line with SDG 4's overarching vision.

In addition, AI can strengthen research capacity in higher education by enabling more efficient processing of large datasets through machine learning and data analytics, supporting pattern identification, predictive modeling, and the generation of new research insights (Webber & Zheng, 2024). AI tools can also support research tasks such as literature reviews, data collection, and visualization, which helps accelerate academic inquiry and innovation. Another notable promise lies in administrative efficiency. AI systems are likewise increasingly being used to automate time-intensive tasks such as grading, scheduling, and student progress tracking (UNESCO, 2021a; Holmes & Tuomi, 2022). This streamlining of operations allows educators to redirect their time and energy toward instruction and student engagement, ultimately enhancing the quality of teaching and institutional effectiveness. Collectively, these applications illustrate the multifaceted potential of AI to advance the core dimensions of SDG 4. While the integration of AI is not a panacea, its thoughtful implementation can serve as a powerful enabler of inclusive, data-driven, and learner-centered education systems. These promises underscore the importance of continued research, strategic investment, and ethical foresight to fully realize AI's contribution to global education goals.

Challenges of AI in education

Complementing the strengths identified above, this subsection turns to the risks and constraints that the literature associates with AI adoption, providing the evidentiary basis for the Weaknesses and Threats dimensions of the SWOT–TOWS analysis in Section 4.3, with particular attention to their implications for higher education governance and practice. Despite these promises, the rapid pace of technological development inevitably brings multiple risks and challenges (Garcia et al., 2025) that continue to outpace policy debates and regulatory frameworks (UNESCO, 2019c, 2021b). A particularly critical concern is the risk of algorithmic bias. AI systems, if trained on biased or incomplete datasets, may inadvertently reproduce or even amplify existing inequalities related to race, gender, language, or socioeconomic status (Pedro et al., 2019). For example, predictive models used in admissions, performance tracking, or adaptive learning may disadvantage students from marginalized groups if the data underpinning them reflect systemic biases (Xiao et al., 2025). This pitfall directly threatens SDG 4.5, which calls for the elimination of gender disparities and the provision of equal access to education for vulnerable groups. Without deliberate and inclusive design, AI tools risk undermining the very equity goals they are intended to support. These concerns underscore the urgency of adopting ethical and transparent frameworks that ensure AI systems uphold principles of fairness, accountability, and inclusivity (UNESCO, 2019c, 2021b).

In addition to ethical concerns, several practical barriers hinder the effective implementation of AI in ways that advance SDG 4's broader targets. Technical challenges such as data privacy, cybersecurity, and system reliability can jeopardize safe and equitable access to education. These vulnerabilities directly affect progress toward SDG 4.1 (ensuring quality primary and secondary education) and SDG 4.3 (ensuring access to affordable tertiary education), particularly in contexts where digital infrastructure is limited or weakly regulated (UNESCO, 2021a; 2022). They also impede the realization of SDG 4.a, which calls for the creation of inclusive, safe, and technologically supported learning environments, conditions that are essential for responsible AI integration.

Financial barriers further complicate implementation efforts. The high cost of AI systems and supporting infrastructure presents significant risks for equitable adoption, especially in low-income countries or underserved regions, thereby threatening to widen rather than close existing digital divides (Popenici & Kerr, 2017; Yang & Evans, 2019). This challenge also has implications for SDG 4.b, which seeks to expand scholarship

opportunities for learners in developing countries, an imperative that becomes more critical when advanced digital and AI-based learning tools form an increasing part of higher education.

Moreover, the lack of educator preparedness continues to be a major obstacle (Acut et al., 2025). Achieving SDG 4.c, which emphasizes increasing the supply of qualified teachers, requires targeted investment in professional development programs to ensure that educators have the skills needed to integrate AI meaningfully and ethically into their instructional practices.

Addressing these multi-layered challenges will require coordinated investments, inclusive policymaking, and sustained capacity-building efforts to ensure that AI serves as a tool for empowerment in the pursuit of SDG 4.

A SWOT–TOWS analysis of AI in advancing SDG 4

Building on the focused exploration of relevant scholarly and policy literature, this section presents a SWOT analysis that systematically examines the strengths, weaknesses, opportunities, and threats associated with AI integration in education and its potential to advance SDG 4. The analysis aimed to develop a structured and evidence-informed understanding of how AI can both support and challenge the pursuit of inclusive and equitable quality education.

The focused exploration of relevant scholarly literature and international policy reports provided contemporary and authoritative perspectives on AI's educational implications. Insights drawn from Denecke et al. (2023) and Farrokhnia et al. (2024) revealed several cross-cutting themes that consistently shape the discourse, most notably the rise of personalized learning, concerns surrounding algorithmic bias, and persistent inequalities in digital access. These themes informed the conceptual boundaries of each SWOT domain and ensured alignment with current global discussions on AI in education.

The analysis identified several strengths of AI that hold significant promise for enhancing educational quality. Among these strengths is AI's capacity for personalized and adaptive learning, which can improve learning outcomes and provide tailored support to students who may otherwise be underserved. Additionally, AI-driven analytics facilitate data-informed decision-making, enabling school leaders to identify patterns, diagnose performance gaps, and implement targeted interventions (Alsbou & Alsaraireh, 2024). These strengths indicate that AI, when applied responsibly, can be a powerful enabler of SDG 4.

At the same time, notable weaknesses emerged, particularly those linked to ethical and technical limitations. Algorithmic bias was identified as a central structural concern, with Eynon (2023) demonstrating how biased data sets and design choices can disadvantage specific learner groups. Lee et al. (2024) further argue that such weaknesses can perpetuate inequities in educational systems when AI tools are adopted without rigorous oversight or transparency. These limitations highlight the need for caution, accountability, and equitable design in AI implementation.

The analysis also pointed to substantial opportunities for leveraging AI to expand access, improve administrative efficiency, and support differentiated teaching. Advances in predictive analytics, intelligent tutoring systems, and automated feedback mechanisms offer promising avenues for addressing teacher workload, enhancing learning personalization, and reaching underserved populations (UNESCO, 2023). Such opportunities highlight AI's potential contribution to the core dimensions of SDG 4: equity, inclusion, and lifelong learning.

However, the SWOT analysis also identified significant threats that may undermine these potential benefits. These include widening digital divides (Mac Fadden et al., 2024), data privacy and security concerns (Lee et al., 2024), reduced human interaction in learning environments, and growing dependency on proprietary technologies. Such threats pose substantial risks to fairness, autonomy, and long-term sustainability within educational systems and therefore require proactive mitigation strategies. A synthesis of these interconnected elements, along with their implications for scalability and digital equity, is presented in Table 3.

Table 3. SWOT Analysis of AI in Achieving SDG 4

Strengths	Weaknesses
- S1: Personalized Learning: AI enables adaptive learning by tailoring content to individual student needs, learning styles (Sajja et al., 2024). **- S2: Scalability & Accessibility:** AI-powered tools can enhance education and research by reaching underserved populations, including remote learners and students with disabilities (UNESCO, 2023). **- S3: Data-Driven Decision Making:** AI learning analytics provide educators with actionable insights on student performance, enabling targeted interventions and adaptive teaching strategies (Alsbou & Alsaraireh, 2024; Ouyang & Zhang, 2024). **- S4: Administrative Efficiency:** Automation of grading and scheduling reduces educator workload, allowing more focus on pedagogy and student interaction (Weegar & Idestam-Almquist, 2024).	**- W1: Algorithmic Bias**: AI platforms trained on biased datasets may reinforce inequities, leading to unfair treatment of marginalized student groups (Eynon, 2023). **- W2: High Implementation Costs:** Developing and implementing AI technologies can be expensive, potentially limiting access for underfunded schools and institutions, especially in developing countries (Park & Kwon, 2024). **- W3: Resistance to Adoption**: Educators and institutions may be hesitant to adopt AI technologies due to concerns about effectiveness, ethical concerns or lack of understanding of AI applications in education (Al-Mughairi & Bhaskar, 2025). **- W4: Reduced Human Interaction:** Over-reliance on AI may diminish socio-emotional learning and student-teacher interactions (Guingrich & Graziano, 2024).
Opportunities	**Threats**
- O1: Bridging Educational Gaps: AI can deliver quality resources to underserved regions via digital platforms (Han & Kumwenda, 2025). **- O2: Innovative Pedagogies**: AI integration fosters immersive learning through VR, AR, and gamification (Wang & Huang, 2025). **- O3: Lifelong Learning**: AI supports continuous skill development across age groups (Tariq, 2024). **- O4: Public-Private Partnerships**: Cross-sector collaboration (tech firms, schools, governments) can spark educational AI innovations (Upadhyay et al., 2025)	**- T1: Ethical Risks**: Data privacy violations and surveillance concerns may erode trust in AI systems (Habbal et al., 2024; Lee et al., 2024). **- T2: Cognitive Impacts**: Excessive AI dependence could weaken critical thinking and creativity (Alshamy et. al., 2025a, 2025b; Yousef et al., 2025). **- T3: Digital Divide**: Inequitable access to technology may deepen educational inequalities (Mac Fadden et al., 2024). **- T4: Regulatory Gaps**: AI's rapid development may exceed regulatory capacity, raising risks in education (Shalaby, 2024).

As shown in Table 3, this SWOT analysis highlights the multifaceted role of AI in transforming education and contributing to achieving SDG 4 while also emphasizing the challenges and risks that must be addressed. The strengths include personalized learning, scalability and accessibility, data-driven decision-making, and administrative efficiency, whereas the weaknesses include algorithmic bias, high implementation costs, resistance to adoption, and reduced human interaction. The opportunities include bridging educational gaps, innovative pedagogies, lifelong learning, and public–private partnerships, whereas the threats include ethical risks, cognitive impacts, the digital divide, and regulatory gaps. By leveraging the strengths and opportunities of AI while mitigating its weaknesses and threats, stakeholders can work towards creating a more inclusive, equitable, and effective educational landscape that benefits all learners and contributes positively to fulfilling the promise of SDG 4. While Table 3 catalogues the critical factors, its strategic utility is realized when these factors are dynamically interrelated. To this end, a TOWS matrix (Saari et al., 2024; Alyamani et al., 2025) was developed to generate actionable strategies, translating analysis into practical pathways for policymakers, educators, and technologists as presented in Table 4.

Strategic pathways: A TOWS matrix analysis of AI for SDG 4

There are several examples that illustrate the diverse ways in which AI solutions are driving progress towards fulfilling the promise of SDG 4. These initiatives demonstrate practical applications that align with the strategic pathways identified in the TOWS Matrix, showing how stakeholders actively navigate AI's complex landscape in education while ensuring technologies are deployed ethically, responsibly, and inclusively to maximize benefits and minimize potential risks for society.

The predictive analytics systems at the Open University (OU Analyse) (Kuzilek et al., 2015; OU Analyse, 2023) and Universitat Oberta de Catalunya (UOC) (López, 2023) exemplify Strengths Opportunities (SO) Strategies (Leveraging Strengths to Seize Opportunities). These systems directly leverage the strength of data-driven insights to seize the opportunity of bridging educational gaps. By analyzing big data including students' demographic information and their interaction with Virtual Learning Environments, these AI applications enable early identification of students at risk of failing. The continuous monitoring helps reduce the time between the first signs of risk and intervention, significantly improving student retention and preventing dropouts in higher education.

Similarly, the APAT initiative (Education at your convenient time) in India demonstrates how scalability and accessibility can be directed through Strengths Threats (ST) Strategies (Using Strengths to Counteract Threats) to prevent the digital divide from worsening. By setting up educational booths equipped with high-performance workstations that function similarly to Internet cafes, APAT makes technology and educational materials accessible to students who may not have these resources at home. This approach ensures that the pursuit of educational efficiency through AI-driven personalized learning does not exacerbate existing inequalities, instead create an inclusive educational environment that bridges the digital divide for school dropouts in rural areas (Mani, 2022).

The implementation of these solutions also underscores critical Weaknesses Opportunities (WO) Strategies (Overcoming Weaknesses by Capitalizing Opportunities). The Argentina dropout prevention system, funded by the US-based Tinker Foundation, shows how high implementation costs can be addressed through international funding partnerships. Furthermore, the algorithm's requirement for a comprehensive database that is at least two years old highlights the importance of overcoming data infrastructure limitations to ensure accurate identification of at-risk students. As noted by the Ocampo school head, these tools transform figures into meaningful stories, ensuring that AI supports rather than replaces human judgment (Páez, 2023).

Finally, these global examples validate the importance of Weaknesses Threats (WT) Strategies (Defensive Posture to minimize weaknesses and threats) through their emphasis on maintaining human oversight. APAT's incorporation of local facilitators who act as guides and mentors, combined with its Dual Teacher System where AI technology assists rather than replaces teachers, ensures a "human-in-the-loop" approach. This guards against the erosion of human interaction and prevents algorithmic limitations from devaluing the educational experience, ensuring that technology enhances rather than diminishes the pedagogical relationship.

Table 4. TOWS Matrix: Strategic Actions for AI in SDG 4

	Strengths (S) • S1: Personalized Learning • S2: Scalability & Accessibility • S3: Data-Driven Insights • S4: Administrative Efficiency	**Weaknesses (W)** • W1: Algorithmic Bias • W2: High Implementation Cost • W3: Resistance to Adoption • W4: Reduced Human Interaction
Opportunities (O) • O1: Bridge Educational Gaps • O2: Innovative Pedagogies (VR/AR) • O3: Support Lifelong Learning • O4: Public-Private Partnerships	**SO Strategies** (Maxi-Maxi: Use strengths to capitalize on opportunities) • Leverage S1 & S2 to seize O1: Develop low-cost, adaptive learning platforms for refugees and remote or underserved communities. • Combine S3 & S4 with O3: Use AI to create personalized, modular upskilling pathways for adult learners in the informal economy. • Use S2 & S4 to enable O2: Partner with EdTech providers (O4) to provide schools with AI-powered AR/VR tools for immersive science labs.	**WO Strategies** (Mini-Maxi: Overcome weaknesses by leveraging opportunities) • Address W1 using O4: Establish multi-stakeholder consortia to develop and share open-source, de-biased educational datasets. • Mitigate W2 with O4: Create grant-funded initiatives (O4) to subsidize AI infrastructure for schools in developing countries. • Counter W3 with O2: Use innovative, game-based AI pedagogies (O2) as a low-stakes entry point to demonstrate value and reduce teacher resistance.
Threats (T) • T1: Ethical Risks (Privacy) • T2: Cognitive Impacts • T3: Digital Divide • T4: Regulatory Gaps	**ST Strategies** (Maxi-Mini: Use strengths to mitigate threats) • Use S3 to counter T2: Design AI analytics that don't just track performance but also monitor and encourage metacognitive and collaborative skills. • Leverage S2 to address T3: Deploy lightweight, offline-first AI tools (e.g., on smartphones) to bypass infrastructure barriers. • Apply S4 to manage T1: Automate compliance checks and data anonymization processes to proactively protect privacy.	**WT Strategies** (Mini-Mini: Defensive strategies to minimize weaknesses and threats) • Guard against W1 & T4: Develop and implement mandatory "Algorithmic Impact Assessments" for any AI system used in public education. • Address W4 & T2: Mandate a "human-in-the-loop" design principle in all educational AI, ensuring technology augments rather than replaces teacher-student interaction. • Mitigate W2 & T3: Advocate international "AI in Education" funds to prevent a new form of technological colonialism.

Taken together, these cases reinforce the value of the TOWS Matrix as a strategic tool for guiding the responsible and effective implementation of AI in education. To harness AI's full potential, it is essential to leverage its capacity to reach large numbers of learners and to use data-driven insights to personalize instruction, while fostering strong partnerships between governments and private-sector innovators to close educational gaps and expand lifelong learning opportunities (SO). At the same time, these strengths must also be directed toward designing simple, accessible, and context-appropriate tools that function effectively in low-resource environments, and toward safeguarding learners' critical thinking skills by mitigating the risks of over-reliance on automated technologies (ST).

Concurrently, addressing inherent weaknesses, such as algorithmic bias, high development costs, and unequal access, requires coordinated efforts to fund the creation of more representative datasets and to improve affordability for underserved regions (WO). Finally, ensuring that AI remains a safe and trusted component of educational ecosystems demands enforceable policies that mandate algorithmic bias audits and uphold the principle of human-in-the-loop instruction to preserve fairness, accountability, and the irreplaceable value of human interaction in learning (WT).

Read through the socio-technical lens introduced in Section 2.1, the four strategy clusters differ in the institutional conditions under which they are most appropriate. The SO strategies presuppose sufficient funding and digital infrastructure and are therefore most feasible in well-resourced systems, whereas ST and WT strategies are oriented toward protecting existing provision rather than expanding it, making them more relevant to under-resourced or weakly governed settings. This contextual conditionality distinguishes the TOWS matrix from a list of universal best practices.

Strategic recommendations based on TOWS matrix analysis

The strategic actions below translate the TOWS matrix (Table 4) into recommendations focused specifically on higher education teaching, learning, governance, and curriculum design, since it is at this level of institutional practice that the conditional effects identified in the theoretical framework (Section 2.1) are ultimately realized. Each set of strategies is organized according to the SWOT dimensions it addresses.

SO Strategies (Leveraging Strengths to Seize Opportunities)

- Develop national AI policies that promote public-private partnerships to create scalable, personalized learning platforms for underserved communities.
- Establish funding mechanisms for AI infrastructure that enables lifelong learning opportunities across all age groups.
- Support research initiatives that leverage AI's data-driven capabilities to address learning poverty and skills gaps.

ST Strategies (Using Strengths to Counteract Threats)

- Implement policies ensuring equitable access to low-bandwidth, offline-capable AI tools to prevent widening digital divides.
- Create frameworks that use AI's analytical capabilities to monitor and foster critical thinking skills alongside academic achievement.
- Develop AI literacy curricula that help students analyze AI-generated content while maintaining essential human interaction.

WO Strategies (Overcoming Weaknesses by Capitalizing Opportunities)

- Allocate dedicated funding for creating diverse, culturally representative datasets to mitigate algorithmic bias.
- Establish international partnerships to subsidize AI infrastructure and teacher training in low-income regions.
- Facilitate interdisciplinary research collaborations to address ethical challenges in AI implementation.

WT Strategies (Defensive Posture to Minimize Weaknesses and Threats)

- Mandate regular Algorithmic Impact Assessments for all educational AI systems.

- Enforce "human-in-the-loop" requirements in all AI educational tools through regulatory frameworks.
- Develop comprehensive ethical guidelines that address algorithmic bias, data privacy, and accountability mechanisms in the design and deployment of AI in education.
- Create professional development programs that enhance educator capacity to critically evaluate and implement AI technologies.

Conclusion

This study set out to examine how AI can be strategically leveraged to advance SDG 4, using a conceptual analysis that combined a focused literature synthesis with a SWOT–TOWS framework anchored in the Holmes and Tuomi (2022) AIED taxonomy and a critical socio-technical lens (Eynon, 2023; Section 2.1). Read together, the findings indicate that AI's contribution to SDG 4 is conditional rather than automatic: the same categories of application (personalized learning, predictive analytics, and administrative automation) can either advance or undermine equity and quality depending on the governance, funding, and institutional context in which they are deployed. The TOWS strategies developed in Section 4.4 and the recommendations in Section 5 translate this conditionality into concrete pathways for higher education pedagogy, governance, curriculum design, and educator practice, rather than treating AI adoption as inherently beneficial or inherently risky.

For theory and research, the study's principal contribution is to show that a taxonomy of AI applications (what AI does) is analytically insufficient on its own to explain its educational effects; a socio-technical account of how AI is governed and resourced is required to explain why comparable applications diverge in their outcomes for SDG 4. This suggests that future research on AI in higher education would benefit from designs that explicitly test this conditionality, for example through comparative institutional case studies that hold the AI application constant while varying governance and resourcing context, rather than through further descriptive cataloguing of AI applications and their possible benefits and risks.

This study has several limitations that qualify these conclusions. As a conceptual analysis rather than a systematic review, the study assembled its source base through iterative, author-led screening and snowballing, and the SWOT themes were coded by the authors (Section 3); these choices were appropriate to the study's exploratory aims but limit the replicability of the analytic pathway from literature to strategic matrix. The recommendations, while framed for higher education specifically, remain conceptual rather than empirically tested and should be treated as a strategic starting point rather than as validated interventions. Future work that empirically tests the TOWS strategies proposed here, particularly across institutions with differing levels of digital infrastructure and governance capacity, would help establish which strategic pathways are most effective for advancing SDG 4 in practice.

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