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Artificial intelligence and educational data mining technologies for the 4th SDG quality education: A systematic review

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Abstract

This systematic review covers the role of artificial intelligence (AI) in education relating to the United Nations' Sustainable Development Goal 4 (SDG 4), covering studies from 2020 to 2024. The review examines AI's transformative potential in six key educational areas. Following PRISMA guidelines, 366 research works were initially identified from two databases, with 19 meeting the inclusion criteria for detailed analysis. The findings reveal that AI enhances personalized learning, fosters inclusivity, and improves accessibility through adaptive learning systems, virtual classrooms, and predictive analytics. AI tools, including chatbots and machine learning models, significantly contribute to equity in educational guidance and performance prediction, while immersive technologies offer culturally responsive learning environments. However, algorithmic bias and data privacy are challenges where concerns persist, underscoring the need for transparent, accountable AI systems and robust data governance to prevent inequities. Policymakers and educators are urged to develop ethical guidelines, adopt responsible AI practices, and ensure equitable access to educational technologies. These actions are essential for aligning AI applications with SDG 4 objectives, providing sustainable and inclusive educational outcomes globally.

Keywords: AI for education, Digital transformation in education, Educational data analytics, Educational data mining, Learning analytics.

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1. Introduction

1.1. Background on AI and Educational Transformation

Integrating artificial intelligence (AI) into the educational sector significantly transforms traditional teaching and learning methodologies, addressing the diverse needs of students from various backgrounds [2]. Analyzing extensive datasets on student demographics, interests, and performance underscores that AI technologies, such as adaptive learning and tutoring systems, customize educational interventions to accommodate each student's unique learning trajectory [3, 4]. This transformation enhances student engagement and academic achievement and alleviates teachers' workloads, facilitating more responsive and effective teaching practices [5]. Furthermore, the amalgamation of AI with technologies such as the Internet of Things and machine learning can improve educational processes and foster a more inclusive learning environment, rendering education more relevant and accessible for all students [6].

AI is transformative in advancing the United Nations' Sustainable Development Goal 4 (SDG 4), which aims to provide inclusive and equitable quality education for all individuals. AI technologies, including extensive language models and adaptive learning systems, facilitate the creation of personalized educational experiences that accommodate diverse learner needs, often overlooked by conventional educational frameworks [7]. For instance, digital learning platforms in India utilize AI to enhance educational accessibility, particularly in rural regions where resources are scarce [8]. These platforms are prime examples of how AI can dismantle barriers to quality education, promoting more significant equity [9, 10]. Nonetheless, the ethical challenges associated with AI, such as algorithmic bias and data privacy concerns, necessitate careful consideration to maximize the potential of these technologies while mitigating associated risks [11]. Therefore, the effective utilization of AI holds significant promise for realizing SDG 4 and ensuring both inclusivity and high-quality education globally.

1.2. Current Trends in AI in Education

Current patterns in AI in education highlight the transformative potential of technologies such as large language models (LLMs) and adaptive learning systems, which help create personalized and inclusive learning experiences. These tools allow teachers to modify their lessons to suit students' diverse needs, enhancing engagement through customized feedback mechanisms [7]. However, AI platforms that provide immediate feedback and adaptive learning paths promote equity and inclusion in diverse learning environments. Still, these advancements also raise ethical concerns such as algorithmic bias, data privacy, and the risk of passive learning due to over-reliance on technology [12]. Thus, innovation and ethical considerations must be balanced when including AI in education, ensuring technology is used responsibly [13].

1.2.1. Personalized and Adaptive Learning

AI-driven technologies have fundamentally transformed the development of personalized learning environments by utilizing real-time data and sophisticated algorithms to assess student progress. For instance, platforms such as DreamBox and Knewton autonomously generate customized learning pathways for students, accommodating diverse learners and promoting inclusivity within educational contexts [7, 14]. Research indicates that these platforms significantly enhance student engagement and improve academic outcomes, particularly for students from underrepresented communities, by adapting to their needs and pace. These applications exemplify the role of artificial intelligence in fostering educational equity by delivering tailored support that was previously unattainable within traditional classroom settings [15].

1.2.2. Data-Driven Insights and Learning Analytics

Educational data mining (EDM) and learning analytics (LA) have become increasingly pivotal in enhancing student outcomes by providing data-driven insights that inform teaching and learning strategies. These tools empower educators to analyze student engagement patterns and performance, facilitating personalized feedback and targeted interventions [16]. However, ethical concerns such as data privacy and the potential misuse of student data underscore the necessity for robust frameworks to safeguard learners. It is imperative that the careful implementation of EDM and LA, accompanied by appropriate safeguards, promotes educational equity through informed decision-making and tailored student support [17].

1.2.3. Advancements in AI-Powered Educational Technologies

AI-powered systems, encompassing intelligent tutoring systems, flexible learning platforms, and advanced language processing applications, significantly transform educational environments. For example, AI tools such as Squirrel AI employ machine learning algorithms to identify knowledge gaps among students, thereby providing targeted interventions to enhance learning outcomes [18, 19]. Moreover, AI has proven to be a practical educational resource, particularly in addressing language barriers and promoting inclusivity for students across diverse linguistic backgrounds. Language learning applications and conversational agents have shown notable advancements in language proficiency and communication across various cultures, facilitating personalized learning experiences tailored to individual needs [20, 21].

- AI in Mobile Learning

The integration of AI in mobile learning applications is changing educational experiences by providing personalized and on-the-go learning solutions. Tools such as Google Socratic and Duolingo leverage AI to analyze student data, identify knowledge gaps and deliver tailored content, which helps with increased engagement and comprehension [22, 23]. These tools use real-time data analytics, personalized feedback loops and conversational AI to further optimize student engagement for the benefit of learners in remote and underserved regions, allowing for learning, although with many challenges, to be done almost anywhere [23, 24].

- Integration of Emerging Technologies in Mobile Learning

The emerging technologies such as 5G, Augmented Reality (AR), Virtual Reality (VR) and AI, are significantly transforming mobile learning by enhancing interactivity and immersion. AI-AR systems, for example, facilitate real-time content adaptation, fostering tailored learning experiences that engage students more effectively [25]. Furthermore, the growing trend of mobile microlearning, where AI curates bite-sized learning materials tailored to individual needs, which also promotes accessibility and inclusivity in education, is gaining traction as an effective instructional strategy [26, 27]. The synergy between AI and mobile technologies holds vast potential for fostering accessible, inclusive, and lifelong learning opportunities.

1.3. Purpose and Scope of the Study

This systematic review aims to examine artificial intelligence's role in furthering the United Nations' Sustainable Development Goal 4, which seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all individuals [28]. This study will concentrate on six essential domains to analyze the impact of artificial intelligence on education.

- Artificial Intelligence in Education.
- Information Technologies Supporting Learning.
- Learning/Teaching Methodologies and Assessment.
- Social Context and Learning Environments with New Emerging Technologies.
- Ubiquitous Learning.
- Educational Data Mining.

Through a systematic review of studies in the specified domains, this comprehensive analysis seeks to address the pivotal question: In what manner does the implementation of artificial intelligence in the educational sphere correspond with the objectives of Sustainable Development Goal 4, which advocates for equitable, inclusive, and high-quality education for all? The insights derived from this study are designed to assist educators, policymakers, and developers in making well-informed decisions regarding integrating artificial intelligence in a manner consistent with sustainable educational objectives.

1.4. Significance and Future Implications

Integrating artificial intelligence within the educational sector presents substantial opportunities and challenges. Artificial Intelligence technologies, such as personalized learning algorithms and adaptive assessment tools, enhance student engagement and academic performance by accommodating various learning needs [19]. For instance, platforms like DreamBox and Squirrel AI afford personalized experiences that are profoundly transformative in underrepresented communities, facilitating greater accessibility to quality education [18].

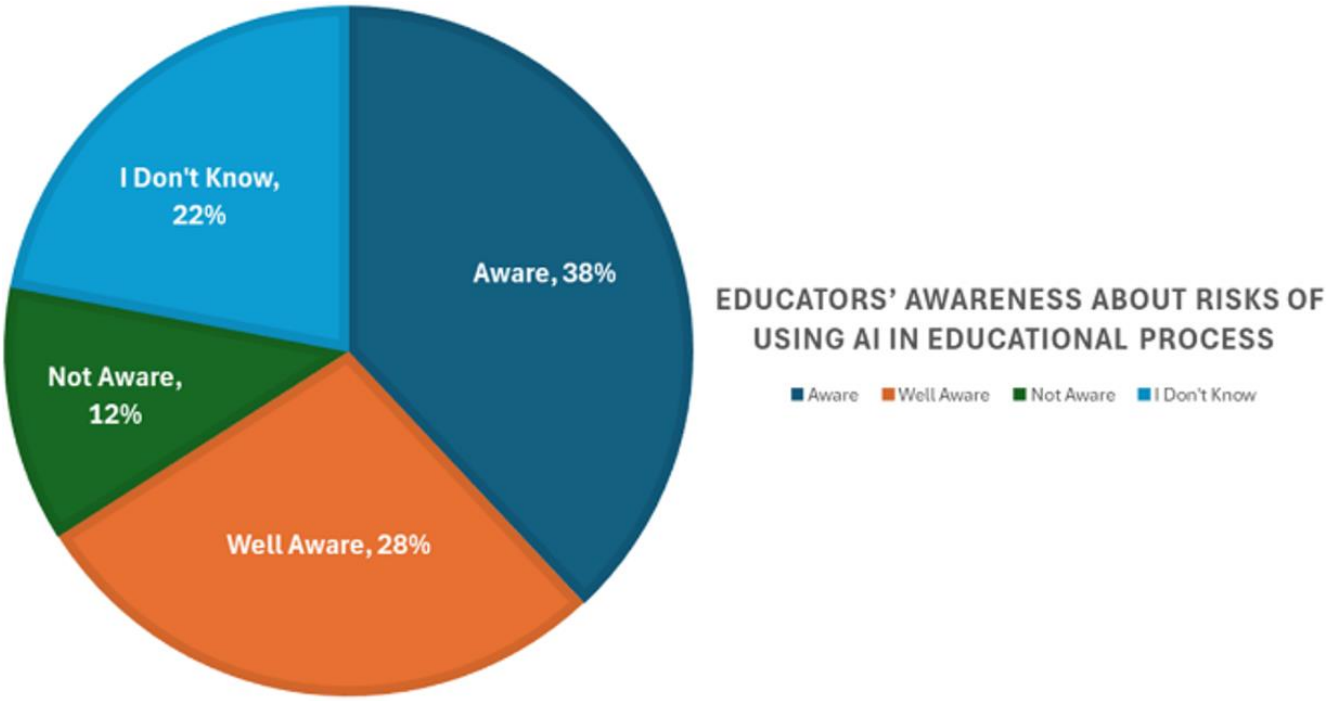

Figure 1.
Educators' Awareness About Risks of Using AI in Educational Process.

Nevertheless, ethical concerns, including algorithmic bias and data privacy, must be addressed to guarantee equitable outcomes. As illustrated in Figure 1, the survey indicates that the educators' awareness of AI risks revealed that 12% were unaware, 38% had a general awareness, 28% considered themselves aware, and 22% were uncertain [29]. It suggests a necessity for educational initiatives aimed at those with limited awareness to bridge knowledge gaps.

Future initiatives should prioritize sustained research and positions such as AI Data Privacy Coordinators to effectively confront these ethical challenges while aligning artificial intelligence with Sustainable Development Goal 4, promoting inclusive and equitable education [30, 31]. Notwithstanding existing awareness, implementing AI tools remains minimal, revealing disparities between students' competencies in AI and educators' understanding [32, 33]. It may result in erroneous assessment evaluations, underscoring the critical need for ongoing professional development for educators.

1.4.1. Future of AI-Powered Mobile Learning Implementation

The evolution of AI-driven mobile learning applications allows enhanced educational outcomes, where research indicates that AI technologies, including intelligent tutoring systems and adaptive learning platforms, significantly improve personalized learning experiences and streamline administrative tasks in education [34-36]. Policymakers and educators should prioritize investment in AI-driven mobile learning research and infrastructure while addressing challenges such as data privacy, device accessibility and digital literacy gaps [35].

As mentioned, 5G, AR and VR technologies will continue to help greatly enhance AI-powered mobile education with personalized and immersive learning experiences. AI facilitates adaptive learning through intelligent tutoring systems and predictive analytics, tailoring educational content to individual learner needs and preferences, thereby improving engagement and outcomes [23]. Future research should focus on the ethical implications of these technologies, such as data privacy and algorithmic bias, ensuring responsible AI integration while maximizing inclusivity and effectiveness in educational settings [23].

2. Materials and Methods

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. It elucidates the developmental potential of artificial intelligence (AI) alongside emerging educational technologies in promoting the United Nations' Sustainable Development Goal 4 (SDG 4), which focuses on Quality Education. AI facilitates personalized learning experiences, as demonstrated by its implementation in intelligent tutoring systems and adaptive learning platforms, which address the diverse needs of learners and enhance educational outcomes [37, 38].

A systematic review of artificial intelligence-driven educational technologies illustrates considerable advancements and challenges in improving the quality of education, accessibility, and personalized learning, aligning with Sustainable Development Goal 4. Artificial intelligence-related technologies, including intelligent tutoring systems and platforms designed for individualized, customized learning, can tailor educational experiences, enhance student engagement, and furnish data for educators [28, 39].

2.1. PICO Framework

This systematic review investigates the pivotal inquiry: "How does the implementation of artificial intelligence within the educational sector correspond with the goals of Sustainable Development Goal 4, which aims to foster equitable, inclusive, and quality education for all individuals?" This review adheres to the PICO framework, which delineates the fundamental elements of the research:

- Population (P): Learners, students, educators, and/or teachers.
- Intervention (I): AI-powered tools and technologies, such as flexible learning systems, smart tutoring systems, and education analytics platforms.
- Comparison (C): Traditional teaching methods or non-AI-based educational tools.
- Outcome (O): Improvements in educational accessibility, inclusivity, student engagement, and academic performance.

This framework provides a clear foundation for analyzing the intersection of AI advancements and their potential to address disparities in educational access and quality, aligning with the overarching goals of SDG 4.

2.2. Research Questions

Building on the PICO framework, this systematic review seeks to address three primary research questions that align with the objectives of SDG 4 and the inclusion of AI in education.

- What are the prevalent AI and information technology applications in educational settings aimed at improving quality?
- How do these technologies contribute to creating inclusive, accessible, and equitable educational experiences?
- What challenges and limitations are associated with AI implementation in education, particularly in the context of SDG 4?

These inquiries facilitated a thorough examination of artificial intelligence's role in enhancing education quality. They underscore both the opportunities and challenges while ensuring a critical alignment with Sustainable Development Goal 4 principles.

2.3. Search Strategy

The IEEE Xplore and MU E-database were selected for this review because of their extensive and pertinent collections of peer-reviewed literature on artificial intelligence (AI) and education. At the time of the evaluation, these databases emerged as the most accessible and provided the most comprehensive coverage of the subject matter under investigation. Although other databases were considered, they were excluded due to the limitations in access at that time, which hindered the ability to procure a wider array of studies. Considering the access restrictions and the emphasis on acquiring high-quality, peer-reviewed sources, IEEE Xplore and MU E-database were the most appropriate choices for this systematic review.

The PICO framework guided the formulation of the search strategy to ensure a comprehensive and pertinent retrieval of studies. Keywords were meticulously crafted to encompass all elements of PICO, including terminology related to population, intervention, and outcomes. Boolean operators were utilized to enhance the search across databases, namely IEEE Xplore and the MU E-database. Below is a detailed breakdown of the search terms alongside the corresponding Boolean combinations:

2.3.1. Population (P)

- ("Students" OR "teachers" OR "learners" OR "educators").
- ("Education", "school", "classroom").

2.3.2. Intervention (I)

- ("AI" OR "Artificial Intelligence" OR "A.I.").
- ("Adaptive learning systems" OR "educational data mining" OR "learning analytics" OR "intelligent tutoring systems").
- ("Information technology" OR "communication technology").
- ("Remote learning platforms" OR "virtual classrooms" OR "digital resources management").
- ("Sustainable Development Goals" OR "SDGs" OR "SDG 4").

2.3.3. Outcome (O)

- ("Student engagement" OR "academic performance" OR "accessibility" OR "inclusive education" OR "improving instructional quality" OR "teaching strategies" OR "learning assessment").
- ("Social content awareness" OR "collaborative learning").
- ("Ubiquitous learning" OR "mobile learning" OR "cloud-based learning").

2.3.4. Boolean Combination Examples

- ("AI" OR "Artificial Intelligence" OR "A.I.") AND ("education" OR "school" OR "learning" OR "teaching" OR "classroom") AND ("SDGs" OR "Sustainable Development Goals").
- ("information technology" OR "communication technology") AND ("learning" OR "education" OR "teaching") AND ("SDGs" OR "Sustainable Development Goals") AND ("remote learning" OR "virtual learning" OR "support learning").
- ("AI" OR "Artificial Intelligence") AND ("learning methods" OR "teaching methods" OR "improving instructional quality") AND ("Sustainable Development Goal" OR "SDG 4").

2.4. Inclusion and Exclusion Criteria

2.4.1. Inclusion Criteria

Studies were considered eligible for inclusion if they examined artificial intelligence or technology-driven tools in the context of education, specifically regarding quality enhancement, personalization, accessibility, or inclusivity. Peer-reviewed journals, conference proceedings, and systematic reviews were prioritized, with a stipulated publication date range from 2020 to 2024.

2.4.2. Exclusion Criteria

Research that has not undergone peer review, studies unrelated to education, research that does not address the outcomes delineated in the PICO framework, and papers concentrating on non-educational applications of artificial intelligence were excluded from consideration. Furthermore, research published in languages other than English was excluded.

2.5. Research work Selection and Screening Process

The selection process commenced with an initial screening predicated on the titles and abstracts of the research works. The research works that successfully passed the initial stage underwent a comprehensive review to ascertain their congruity with the study's inclusion criteria. A PRISMA flow diagram delineates the phases of identification, screening, eligibility, and inclusion of the research works, offering a transparent overview of the selection process.

2.6. Data Extraction

The data for this review was methodically extracted from designated studies utilizing spreadsheet applications to organize information across key themes, as previously referenced systematically. Each entry was classified to delineate specific domains within artificial intelligence and educational technologies as follows:

2.6.1. Artificial Intelligence in Education

The extracted data encompasses artificial intelligence applications designed to enhance education quality through resources such as adaptive learning systems, intelligent tutoring systems, and AI-driven assessments. This category also delineates the primary algorithms and methodologies employed.

2.6.2. Information Technologies Supporting Learning

The data collected in this study pertains to digital tools and systems that utilize artificial intelligence to enhance various learning modalities, including remote learning platforms, virtual classrooms, and systems designed to manage digital resources. Factors such as tool types, features, and usage contexts were thoroughly examined.

2.6.3. Learning/Teaching Methodologies and Assessment

This section encompasses data on AI-enhanced methodologies designed to enhance instructional quality and precision in assessment. Detailed information regarding the various approaches, assessment techniques, and instructional frameworks has been thoroughly documented.

2.6.4. Social Context and Learning Environments with New Emerging Technologies

In this category, data were extracted concerning the role of artificial intelligence in promoting inclusive, context-aware educational environments. Emphasis was placed on how artificial intelligence facilitates collaborative learning, social interaction, and cultural diversity within academic settings.

2.6.5. Ubiquitous Learning

The relevant information encompassed artificial intelligence solutions facilitating learning anytime and from any location, particularly emphasizing mobile learning platforms and cloud-based educational resources. Furthermore, details regarding accessibility features and their application across varied contexts were systematically organized.

2.6.6. Educational Data Mining

This section examines studies concerning the utilization of data mining and learning analytics within educational contexts. It specifically emphasizes the role of artificial intelligence in facilitating personalized feedback, monitoring student progress, and identifying at-risk students. Furthermore, we documented the methodologies, data sources, and key outcomes associated with student engagement and performance.

2.7. Quality Assessment

To maintain methodological rigor, relevance, and credibility, each selected study underwent a quality appraisal utilizing a standardized checklist based on PRISMA guidelines. A systematic review evaluating compliance with PRISMA guidelines in prominent dermatology journals revealed an average compliance rate of 73%, which signifies a favorable trend in adherence over time [40]. This enhancement highlights the significance of PRISMA in advancing rigorous reporting standards, thus enabling improved data filtering and quality assessment in systematic reviews [41].

This methodology facilitates a structured and transparent review process, thereby enhancing the reliability of findings on the role of artificial intelligence (AI) in education. By aligning with Sustainable Development Goal 4 (SDG 4), this systematic review emphasizes AI methodologies and technologies that aid in attaining equitable, inclusive, and quality education. Studies that meet established quality criteria have been incorporated into the analysis, contributing to a robust evaluation of AI's transformative impact on advancing educational development in alignment with SDG 4.

3. Results

3.1. Inclusion and Exclusion of Research Works

This systematic review encompasses 366 research studies that comply with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. It intends to evaluate the transformative effects of AI-driven educational technologies on achieving Sustainable Development Goal 4 (SDG 4). Following a meticulous manual screening process based on established inclusion and exclusion criteria, 19 studies were selected for comprehensive analysis, as depicted in Table 1 and Figure 2.

Table 1.
Studies and Reasoning for Inclusion or Exclusion during.

Title	Key Aspects Addressed	Research Questions	Relevance to SDG 4	Inclusion / Exclusion
The Impact of Generative Artificial Intelligence on Learning: A Case Study at the University of Petra, El-Khalili and Al-Nashashibi [42]	Explores AI tools (GAI) in education; discusses quality improvement, student learning personalization, and need for proper utilization and regulations.	RQ1: Application of GAI for quality improvement; RQ2: Enhances accessibility and equity in learning.	Supports quality education through personalized learning and improved student engagement, addressing equitable use of AI in educational contexts	Included
Design and Development i-AVEN|GER as High-Tech Virtual Remote Teaching and Learning Platform with STEAM Education Nee et al. [43]	Proposes an innovative, inclusive learning platform that bridges the digital divide; addresses accessibility challenges.	RQ1: Application of an inclusive education platform; RQ2: Enhances accessibility and inclusivity for underrepresented regions or groups.	Promotes inclusivity and accessibility in education by leveraging advanced technology. Addresses the challenge of unequal access to quality education, supporting equity in learning outcomes.	Included
Artificial Intelligence-based Chatbot for Promoting Equality in High School Advising Assayed et al. [44]	Introduces an affordable AI chatbot promoting equality and inclusivity in educational advising.	RQ1: Use of AI chatbots for equality. RQ2: Promotes equitable access to educational support for high school students.	Advances SDG 4 by ensuring inclusive and equitable access to educational resources and support systems for high school students, enhancing fairness in academic advising.	Included
Intelligent Learning Systems for Inclusive Education in Ghana Abosi et al. [45]	Develops a system for inclusive education for Deaf/Hard of Hearing students; includes sign language resources and transcription tools.	RQ1: AI in inclusive education; RQ2: Promotes accessibility and inclusivity for marginalized learners; RQ3: Addresses challenges in designing inclusive tools for diverse needs.	Directly aligns with SDG 4 by fostering inclusivity and reducing inequalities in education for students with disabilities, improving access to quality education.	Included
Machine Learning Approach for Prediction of Ammonia in Freshwater Bodies. Tamatgar et al. [46]	Focuses on environmental applications of machine learning, not educational technologies.	Not applicable to any research question; unrelated to education, accessibility, or inclusivity.	Not relevant to SDG 4 as it does not pertain to educational goals or quality improvement in learning environments.	Excluded
Online Learning for High Quality Education: Perspective of Indonesian Educators Karnalim et al. [47]	Quantitative study of 210 Indonesian educators' views on online learning, highlighting benefits and addressing issues like teaching presence, support for vulnerable students, and student integrity.	RQ2: Investigates educators' insights on inclusivity and accessibility challenges in blended learning.	Emphasizes the importance of addressing barriers to equity and inclusion in education before implementing blended learning approaches.	Included
TPACK: Technology, Pedagogy, and Content Knowledge for Paraeducators in the	Highlights collaborative learning using social media, TPACK framework for paraeducators, and the	RQ1: Examines technological frameworks like TPACK for education. RQ2: Explores	Promotes collaborative learning and technological capacity building to prepare students and	Included

Title	Key Aspects Addressed	Research Questions	Relevance to SDG 4	Inclusion / Exclusion
Context of SDG 4 Enriquez, et al. [48]	importance of parent-teacher partnerships for sustainable educational practices.	inclusivity and collaborative learning in digital contexts.	paraeducators for digital futures, aligning with SDG 4's equity goals.	
Using Design Thinking for Social Innovation: Undergraduate Students' Experiences, Petersen and Philander [49]	Investigate how design thinking can address barriers to quality education by enabling students to prototype mobile applications.	RQ1: Explores innovative approaches to digital educational tools. RQ2: Examines how technology addresses inequities in learning.	Aligns with SDG 4 by fostering innovation and improving access to quality education through student-designed digital tools.	Included
Digital Emotional Intelligence: Fostering Lifelong Learning in the Digital Age among Indonesian Zillenials Herlina et al. [50]	Uses structural equation modeling to study the relationship between digital self-awareness, relationship management, and achievement motivation, emphasizing DEI in educational frameworks.	RQ2: Analyze how emotional intelligence enhances inclusivity and lifelong learning.	Highlights DEI's role in lifelong learning and self-regulation, fostering equity in education in line with SDG 4.	Included
Using Machine Learning-Based Algorithms to Predict Academic Performance Wu et al. [51]	Systematic review of machine learning models for predicting student outcomes, emphasizing early interventions and data-driven improvements in educational quality.	RQ1: Identifies prevalent AI applications in academic performance. RQ2: Discusses inclusivity through predictive interventions.	Supports SDG 4 by enabling targeted interventions to improve student success and reduce educational disparities.	Included
Can Edu-Metaverse Reshape Virtual Teaching Community to Promote Educational Equity? Zhai et al. [52]	Investigates immersive environments, affective communication via avatars, and equitable mechanisms for resource sharing within the Metaverse to enhance educational equity.	RQ1: Evaluates new educational technologies like the Metaverse. RQ2: Explores equitable knowledge creation and collaboration in virtual spaces.	Promotes inclusive and equitable learning environments through immersive technology, supporting SDG 4's aim for universal quality education.	Included
Enhancing Early Stunting Detection: A Novel Approach using Artificial Intelligence with an Integrated SMOTE Algorithm and Ensemble Learning Model Pramana et al. [53]	AI-based detection of stunting in children under five; comparison of machine learning classifiers (Random Forest, Ada Boost, Bagging) using SMOTE techniques to improve healthcare diagnostics.	RQ1: AI-based detection for improving healthcare diagnostics; RQ2: The role of improved child health in educational outcomes.	Limited relevance as it indirectly supports SDG 4 by improving children's health and learning potential.	Inclusion
Exploring the Connectivity Between Education 4.0 and Classroom 4.0: Technologies, Student Perspectives, and Engagement in the Digital Era Joshi et al. [54]	Examines the integration of Education 4.0 and Classroom 4.0 technologies, student perspectives, and the challenges in transitioning from traditional to digital classrooms.	RQ1: Impact of Education 4.0 technologies on teaching and learning; RQ2: Student engagement and perspectives in digital classrooms.	High relevance to SDG 4 through its focus on equitable, quality education in a digital era.	Inclusion

Title	Key Aspects Addressed	Research Questions	Relevance to SDG 4	Inclusion / Exclusion
DePondFi'23 Challenge on Real-Time Pond Environment: Methods and Results Sasithradevi et al. [55]	Focused on improving underwater fish detection methods using AI and machine learning to address environmental issues in aquatic ecosystems.	RQ1: AI methods for environmental sustainability; RQ2: Use of AI in non-education sectors.	No relevance to SDG 4.	Exclusion
MedPlantBot: AI Chatbot Architectural Design Framework for Responsible Use of Medicinal Plants Vera and Palaoag [56]	AI-based chatbot platform for educating communities on the responsible use of medicinal plants as an alternative healthcare.	RQ1: Use of AI in community education; RQ2: Addressing healthcare education through AI.	Limited relevance to SDG 4, but does focus on SDG 3.	Exclusion
Building a Sustainable, Student-Centered, and Resilient Higher Education 5.0 Through Intra and Interinstitutional Collaborations. Ciolacu et al. [57]	Explores intra- and interinstitutional collaborations in higher education using Education 4.0 technologies and innovative teaching methods to achieve sustainability and inclusivity.	RQ1: Strategies for inclusive and equitable education; RQ2: Collaboration in higher education for sustainable learning environments.	High relevance to SDG 4 through fostering sustainable and student-centered higher education practices.	Inclusion
Chief Remote Officer Role in COVID-19 for Work Sustainability and Use of Artificial Intelligence (AI) Tayal et al. [58]	Explores the need for the Chief Remote Officer role and the integration of AI for work sustainability in remote setups post-COVID-19.	RQ1: Role of AI in post-pandemic work environments; RQ2: Sustainability and remote work challenges.	No direct relevance to SDG 4.	Exclusion
Embedding SDGs in Higher Education Curricula: A Case Study [59]	Examines how higher education curricula can integrate SDGs, focusing on building students' skills and perspectives to address real-world challenges with data analytics and sustainable development initiatives.	RQ1: Integrating SDGs in higher education; RQ2: Educating students on sustainable development using data analytics.	High relevance to SDG 4 through curriculum development and sustainability education in higher education.	Inclusion
Optimizing IT-Tools and Production Processes for Supporting Participation of Workers with Disabilities, Faller, et al. [60]	Investigates the use of IT tools and optimized processes to support individuals with disabilities in industrial settings, applying Universal Design principles.	RQ1: Role of IT tools in inclusive workplaces; RQ2: Participation of workers with disabilities in industrial production.	No relevance to SDG 4.	Exclusion
Artificial Intelligence-Based Life Cycle Engineering in Industrial Production: A Systematic Literature Review Rahman et al. [61]	Discusses the integration of AI with Life Cycle Engineering (LCE) to improve industrial production sustainability. Focus on AI techniques, subfields, and their impact on sustainable production.	RQ1: AI integration in industrial sustainability; RQ2: Impact of AI on sustainable development goals in production and infrastructure.	Indirect relevance to SDG 4 primarily aligns with SDGs related to industry and innovation.	Exclusion

Title	Key Aspects Addressed	Research Questions	Relevance to SDG 4	Inclusion / Exclusion
Mobile application for disease diagnosis using tongue imaging: a health and information tool, Peralta-Flores et al. [62]	A mobile app that uses AI for early disease diagnosis based on tongue images, aligned with SDG 3 (Good Health and Well-being).	RQ1: AI in healthcare for early diagnosis; RQ2: Impact of mobile health tools on public health and education.	Limited relevance to SDG 4 but contributes to SDG 3 by improving healthcare access.	Exclusion
Hypertension Diagnosis and Management in Africa Using Mobile Phones: A Scoping Review Oronti et al. [63]	Focus on hypertension management through mobile phones, particularly in low- and middle-income countries, using AI for better healthcare delivery.	RQ1: Mobile AI tools for healthcare; RQ2: Improving access to healthcare for underserved communities.	Indirect relevance to SDG 4, more directly aligned with SDG 3 (Good Health and Well-being).	Exclusion
Effectiveness of artificial intelligence, decentralized and distributed systems for prediction and secure channeling for Medical Tourism Subasinghe et al. [64]	AI and blockchain-based system for enhancing medical tourism with secure patient information handling and treatment predictions.	RQ1: AI and secure systems in medical tourism; RQ2: Enhancing healthcare access and delivery through AI and digital systems.	Limited relevance to SDG 4, more aligned with SDGs on good health and well-being (SDG 3).	Exclusion
Exploring the Connectivity Between Education 4.0 and Classroom 4.0: Technologies, Student Perspectives, and Engagement in the Digital Era Joshi et al. [54]	Investigates the integration of digital technologies in education to transform classrooms through Education 4.0, enhancing student engagement.	RQ1: Impact of Education 4.0 on teaching and learning; RQ2: Student perspectives on digital learning environments.	Strong relevance to SDG 4, focused on inclusive, equitable, and quality education in digital environments.	Inclusion
RFID Attendance System-Enabled Automated Hand Sanitizer Dispenser using IoT Kaveri et al. [65]	Combining IoT for automating hand sanitizing and attendance, contributing to public health hygiene in schools and public spaces.	RQ1: Use of IoT in education and healthcare; RQ2: Enhancing public health and safety through technology in educational settings.	Limited relevance to SDG 4 but contributes to SDG 3 (Good Health and Well-being) in school settings.	Exclusion
Near Real-Time Wildfire Management Using Distributed Satellite System Thangavel et al. [66]	Examines the use of satellite technology and AI for real-time wildfire monitoring and management.	RQ1: AI and satellite systems for disaster management; RQ2: Real-time environmental monitoring and its educational implications.	No direct relevance to SDG 4, more aligned with SDG 13 (Climate Action).	Exclusion
AI in Education: Improving Quality for Both Centralized and Decentralized Frameworks Madathil et al. [67]	Discusses the application of AI and Machine Learning (ML) in improving educational outcomes, focusing on both centralized and decentralized educational institutions. The study aims to predict student performance and	RQ1: Use of AI and ML in predicting educational outcomes; RQ2: Improving educational quality through technology in both centralized and decentralized frameworks.	High relevance to SDG 4, promoting quality education and improved learning outcomes through AI and ML.	Inclusion

Title	Key Aspects Addressed	Research Questions	Relevance to SDG 4	Inclusion / Exclusion
	enhance learning environments.			
Technology-mediated method for prediction of global government investment in education toward sustainable development and aid using machine learning and classification, Okoye [68]	Focuses on using machine learning techniques to predict global government investment in education, aiming to support sustainable development goals and improve policy decisions in education systems.	RQ1: Role of AI and machine learning in predicting educational investments; RQ2: Supporting sustainable education practices and policy decisions through technology.	Strong relevance to SDG 4, particularly related to improving education quality through data-driven decisions.	Inclusion

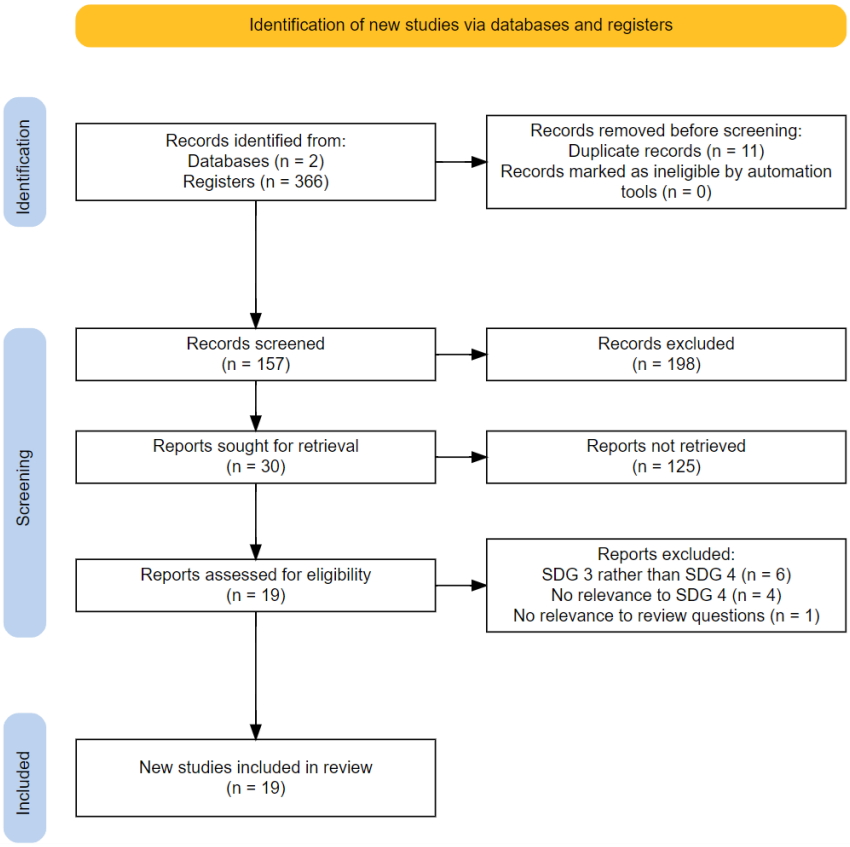

Figure 2.
Inclusion and Exclusion of Research Works.

As presented in Figure 1, two databases were utilized in the initial identification process: the IEEE database and the MU E-database. The identification process yields a total of 366 research records. After removing 11 duplicates, a screening process excluded 198 research records, leaving 158 remaining. Of these, 30 research records were sought for retrieval, leaving 125 records not retrieved. Of the retrieved records, 19 were deemed eligible after the assessment process, while 11 were excluded for the following reasons: six referred to SDG 3 rather than SDG 4, four had no relevance to SDG 4, and one had no relevance to review questions. 13 research records were included in the final review.

3.2. Description of Selected Research Works

The chosen research studies illustrate the implementation of artificial intelligence within various educational settings. As outlined in Table 2 and Figure 2, they are classified into six distinct focus areas. These focus areas furnish an extensive overview of how artificial intelligence technologies and methodologies aid in attaining the SDG 4 objectives.

Table 2.
Categorization of Selected Articles Based on Focus Areas and Methodologies.

Category	Numbers	Examples of Technologies and Approaches	Methodologies Used	Key Findings
Artificial Intelligence in Education	5	Generative AI tools, chatbots, machine learning for performance prediction	Case studies, systematic reviews	Enhanced personalized learning, equitable advising, and data-driven interventions in education.
Information Technologies Supporting Learning	6	Virtual remote platforms, STEAM education tools, digital classrooms	Quantitative and qualitative studies	Improved accessibility, inclusivity, and engagement in diverse educational contexts.
Learning / Teaching Methodologies and Assessment	4	Education 4.0 frameworks, design thinking	Structural equation modeling, ethnographic methods	Enhanced teaching frameworks, collaboration, and innovative methodologies for sustainable education.
Social Context and Learning Environments with Emerging Technologies	5	Immersive Metaverse environments, collaborative tools	Experimental research, ethnographic methods	Fostered inclusivity, equitable access, and diverse learning environments through technology.
Ubiquitous Learning	3	Mobile learning apps, cloud-based learning tools	Systematic reviews, mixed-method analysis	Enabled global reach, anytime-anywhere learning, and accessible educational resources.
Educational Data Mining	2	Predictive analytics, machine learning algorithms	Data mining techniques, systematic reviews	Identified at-risk students, enabled targeted interventions, and improved educational outcomes.

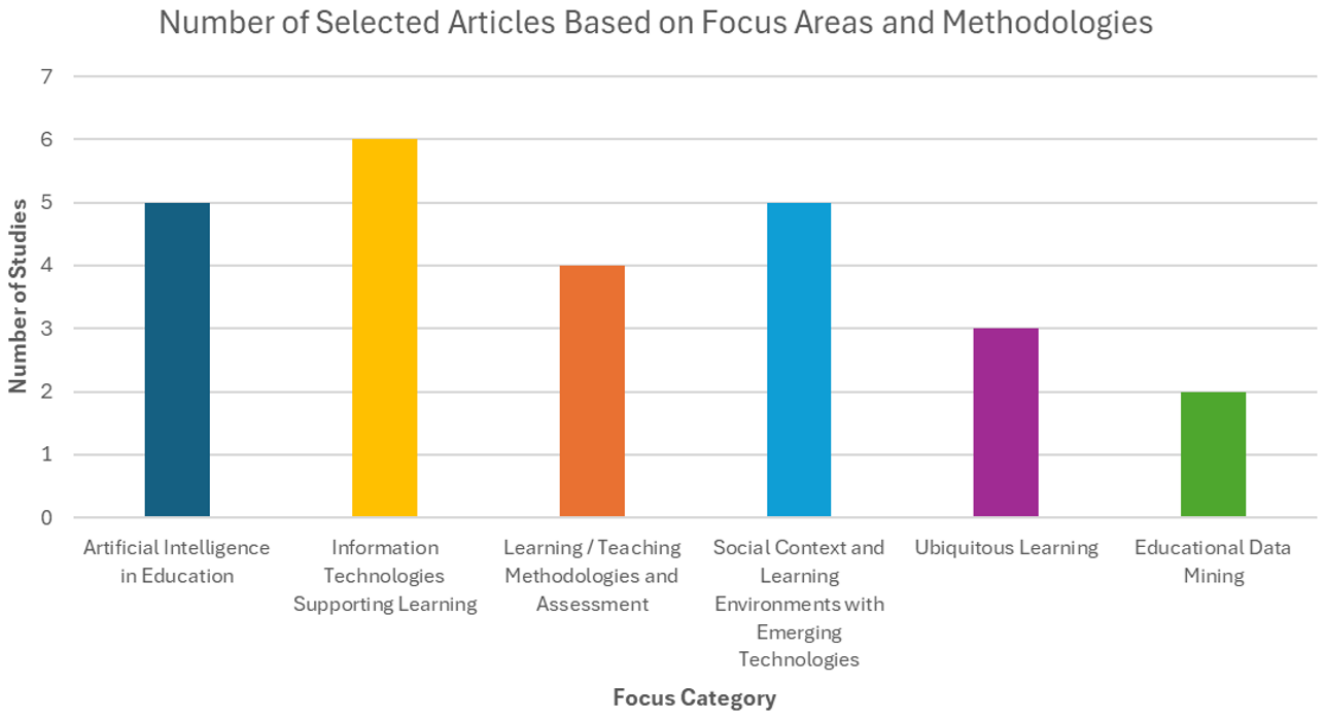

Figure 3.
Distribution of Selected Studies Across Focus Areas and Methodologies in Educational Research.

As illustrated in Figure 2, the specifics on the six areas are as follows:

- Artificial Intelligence in Education (5 studies).

This category underscores the significance of generative artificial intelligence, chatbots, and machine learning in relation to performance prediction. The analysis of case studies and systematic reviews illustrates that the integration of artificial

intelligence significantly contributes to enhancing personalized learning, providing equitable advising, and facilitating data-driven educational interventions.

- Information Technologies Supporting Learning (6 studies).

Research within this domain investigates virtual remote platforms, STEAM tools, and digital classrooms, utilizing both quantitative and qualitative methodologies. Notable findings underscore enhanced accessibility, inclusivity, and engagement within diverse and remote learning environments.

- Learning/Teaching Methodologies and Assessment (4 studies).

This discourse concentrates on frameworks such as Education 4.0 and design thinking, demonstrating that these studies utilize structural equation modeling and ethnographic methods to enhance instructional strategies. The findings underscore the significance of collaborative and innovative methodologies that align with sustainable educational objectives.

- Social Context and Learning Environments with Emerging Technologies

(5 studies).

This section explores immersive technologies, including Metaverse environments and collaborative tools, underpinned by experimental and ethnographic research. The findings of these studies illustrate how artificial intelligence promotes inclusivity, equitable access, and culturally responsive educational contexts.

- Ubiquitous Learning (3 studies).

The use of mobile technologies, such as AI-powered chatbots, virtual learning platforms, and mobile-based adaptive learning systems, enhances the accessibility and flexibility of educational resources. Research studies show that mobile applications support the personalization of learning experiences, which allows students to engage with digital content through smartphones and tablets, alongside cloud-based systems to further allow easy access to course materials, collaborative tools, and virtual classrooms, fostering an inclusive and equitable learning environment [43, 44].

Systematic reviews and mixed-method analyses emphasize how mobile AI applications bridge the digital divide, ensuring that learners from underrepresented regions can access high-quality education through cost-effective and scalable solutions [42, 47].

- Educational Data Mining (2 studies).

These studies utilize data mining techniques and systematic reviews, particularly on predictive analytics and machine learning. The findings underscore artificial intelligence's capability to identify at-risk students, enable targeted interventions, and enhance educational outcomes.

Finally, Table 2 systematically elucidates the extensive range of artificial intelligence applications, illustrating their capacity to revolutionize education through customized methodologies and specific technological interventions. These focal areas align with the tenets of SDG 4 and provide avenues towards inclusive and high-quality education.

3.3. Quality Evaluation Criteria

Each research endeavor underwent a comprehensive quality appraisal following PRISMA guidelines to ensure methodological rigor and relevance. A standardized checklist was employed to assess parameters such as research design, data analysis, and alignment with the objectives of SDG 4. The evaluation process underscores transparency and credibility, with research scores consistently reflecting high compliance with established measures. This quality appraisal framework endorses the inclusion of studies that provide valuable insights into the transformative role of artificial intelligence in education.

3.4. AI-Driven Outcomes in Education

The analysis underscores the significant influence of AI technologies on the learning process, particularly in furthering the objectives of SDG 4, which encompasses quality, accessibility, and inclusivity. The results obtained from the selected studies are classified into mechanical and transformative outcomes, each illustrating how AI contributes to educational progress while also addressing related challenges, as depicted in Table 3.

Table 3.
Categorization of Selected Articles Based on Focus Areas and Methodologies.

Outcome Type	Description	Alignment with SDG 4	Challenges Identified
Mechanical Outcomes	Adaptive Learning: Personalized pathways using AI tools.	Enhances quality education through tailored engagement and outcomes.	High implementation costs and uneven technological access.
	Performance Prediction: Data-driven insights identify at-risk students.	Reduces educational disparities through targeted interventions.	Dependence on data accuracy and privacy concerns.
	Improved Accessibility: Tools support diverse learner needs (e.g., sign language, chatbots).	Promotes inclusive education for marginalized communities.	Lack of infrastructure in underdeveloped regions.
Transformative Outcomes	Equity in Guidance: Chatbots foster fair advising processes for marginalized students.	Bridges gaps in educational equity, promoting SDG 4.	Ensuring unbiased algorithms and maintaining scalability.
	Fostering Innovation: Design thinking and Education 4.0 tools drive creative solutions.	Empowers students and educators to address real-world educational challenges.	Resistance to adopting innovative practices in traditional settings.
	Sustainability: Collaborative frameworks for sustainable education systems.	Aligns with SDG 4 by ensuring resilience and adaptability in education.	Coordination among institutions and scalability challenges in larger networks.

3.4.1. Mechanical Outcomes

- Adaptive Learning

Artificial Intelligence tools facilitate the design of customized learning pathways tailored to meet students' individual needs. They significantly enhance the quality of education by increasing student engagement and improving success rates. Nevertheless, the integration of such technologies is hindered by substantial implementation costs and disparities in access to the devices and infrastructure required for adaptive learning platforms.

- Performance Prediction

Machine learning algorithms are essential in analyzing educational data to identify at-risk students and facilitate timely interventions. This targeted methodology significantly reduces disparities by allocating resources and support to needy students, effectively aligning with SDG 4 objectives. However, the efficacy of these systems is contingent upon the accuracy of the data, and issues regarding privacy constitute a considerable challenge, given the sensitive nature of student information.

- Improved Accessibility

AI-powered tools, encompassing chatbots and assistive technologies, cater to a diverse student population, including individuals with disabilities and those from marginalized communities. These tools promote inclusivity by dismantling barriers and facilitating the participation of underrepresented groups in education. However, their implementation is constrained by inadequate infrastructure and technological support in less-developed regions, thereby limiting the scalability of these innovations.

3.4.2. Transformative Outcomes

- Equity in Guidance

AI-driven systems, such as chatbots, facilitate equitable advising processes for students from diverse socioeconomic backgrounds. It promotes fairness in educational guidance and assists in bridging equity gaps, thus supporting the objectives of SDG 4. Nevertheless, challenges emerge from the potential biases inherent in algorithms and the difficulty in scaling these systems to address the needs of larger student populations without compromising their effectiveness.

- Fostering Innovation

Artificial Intelligence tools founded on frameworks such as Design Thinking and Education 4.0 facilitate creative problem-solving, thereby empowering educators and learners to confront genuine educational challenges. These tools promote lifelong learning and innovative methodologies and contribute to advancing Sustainable Development Goal 4. Nevertheless, resistance stemming from traditional educational systems and a reluctance to embrace novel approaches present substantial obstacles to their widespread integration.

- Sustainability

AI facilitates the advancement of collaborative educational frameworks, emphasizing resilience and adaptability, promoting long-term sustainability within educational systems. These frameworks align with SDG 4 by ensuring the establishment of robust and flexible educational structures capable of withstanding evolving challenges. Nonetheless, achieving coordination among institutions and scaling these systems to encompass wider networks necessitates significant resources and introduces considerable complexity.

The results presented in Table 3 illustrate the significant potential of artificial intelligence to transform education through operational enhancements and systemic modifications. While mechanistic outcomes directly contribute to improving educational processes, transformative outcomes underscore AI's more expansive role in fostering sustainable and equitable

educational systems. Nevertheless, addressing ethical concerns, financial constraints, and infrastructural disparities remains imperative to fully harness AI's potential in advancing SDG 4.

3.5. Ethical Considerations in AI-Driven Education

Although the transformative potential of artificial intelligence in the educational process is evident, its responsible implementation necessitates careful consideration of ethical challenges. If these challenges remain unaddressed, they could jeopardize attaining the objectives outlined in SDG 4.

3.5.1. Algorithmic Bias

AI systems present considerable challenges, particularly in educational contexts. Such biases may originate from various sources, resulting in unjust advantages for specific demographics or learning styles [69]. Continuous monitoring and the execution of fairness audits are imperative to guarantee equitable educational opportunities for all students [70]. Mitigating bias involves diversifying datasets and implementing algorithmic fairness interventions, which can contribute to cultivating an ethical educational environment that benefits all learners [71].

3.5.2. Data Privacy and Security

The application of AI in education necessitates collecting and analyzing substantial quantities of student data. Although this data facilitates personalized learning experiences, it may also raise significant privacy concerns. Sensitive information, including academic records and behavioral data, could be exposed to risks if adequate safeguards are not established. Consequently, educational institutions must implement robust data regulatory measures that adhere to governance frameworks and comply with regulations such as the General Data Protection Regulation (GDPR) to protect student information.

3.5.3. Transparency and Explainability

The utilization of artificial intelligence, particularly in contexts that may influence academic outcomes or evaluations, necessitates a high degree of transparency and explicability. Educators and students must comprehend the methodologies by which AI algorithms derive their conclusions, thus ensuring that these tools are employed responsibly. Such transparency assists educators in making informed decisions while enabling students to use AI appropriately within suitable contexts and environments.

3.5.4. Ethical Guidelines and Policy Frameworks

It is imperative to establish clear ethical guidelines for educational artificial intelligence. These frameworks must delineate the best practices for data management, algorithm development, and bias mitigation. The appointment of roles such as AI Data Privacy Coordinators in the context of educational artificial intelligence can further bolster the enforcement of these guidelines.

By addressing these ethical considerations, educational institutions can promote a more responsible implementation of artificial intelligence, ensuring that technological advancements contribute to inclusive, equitable, and high-quality education for all individuals.

3.6. Enhancing Mobile AI Learning in Education

Although the transformative potential of artificial intelligence in the educational process is evident, its responsible implementation necessitates careful consideration of ethical challenges. If these challenges remain unaddressed, they could jeopardize attaining the objectives outlined in SDG 4.

3.6.1. Increasing Focus on Mobile AI Learning Applications

While AI-driven adaptive learning and data analytics have been explored, the role of mobile AI applications in education requires greater emphasis. Mobile-based learning analytics, smartphone-integrated adaptive learning, and AI-powered mobile tutoring applications offer innovative opportunities to enhance education [43, 44].

Research indicates that AI-driven mobile learning tools, such as chatbot-based educational applications and mobile-based tutoring systems, significantly improve personalized learning experiences [42, 47]. Incorporating case studies and real-world implementations of these technologies will provide a more comprehensive understanding of how AI-driven mobile learning applications contribute to accessible and flexible education.

3.6.2. Practical Implications for Interactive Mobile Learning

Educators and technology developers play a crucial role in implementing AI-driven mobile learning solutions. A strong focus on implementation strategies for AI-powered mobile learning tools can bridge this gap. Recommendations should highlight best practices for integrating AI-driven mobile learning within existing educational frameworks. For instance, case studies on mobile-based AI tutors, interactive chatbot-driven learning applications, and mobile AI-driven assessment tools would provide valuable insights into real-world applications. Such discussions can support educators in designing engaging AI-powered mobile learning environments and assist developers in creating user-friendly mobile AI applications [42, 47].

3.6.3. Expanding Future Directions for Mobile AI Learning

Future research in mobile AI learning should focus on several emerging trends that promise to reshape educational practices. These personalized lessons generated or assisted by AI can greatly enhance engagement and focus on individual learning needs [72]. Additionally, mobile AI-powered assessment tools are also set to change and improve feedback mechanisms, providing adaptive and real-time evaluations that promote higher-order thinking skills [73]. The advent of 5G technology will facilitate high-speed, interactive learning environments, enabling seamless integration of AI applications [23, 25]. Addressing ethical concerns, such as data privacy and algorithmic bias, is crucial for technologies to evolve in the correct and ethical way [73].

4. Discussion

This systematic review underscores the prospective role of Artificial Intelligence (AI)-enhanced educational technologies in furthering Sustainable Development Goal 4 (SDG 4). Following PRISMA guidelines, 19 studies were identified, concentrating on applications including adaptive learning systems, intelligent tutoring, and educational analytics. These technologies significantly enhance engagement, inclusivity, and data-informed decision-making within the academic sector. Mobile-based solutions, such as AI-driven educational apps, chatbot-based learning interactions, and cloud-based mobile platforms, further help to expand accessibility, especially in low-resource settings. Although mechanical outcomes such as personalized learning and performance prediction exhibit the potential to mitigate disparities, challenges, including substantial implementation costs, privacy issues, and unequal accessibility, persist as critical obstacles. Furthermore, socio-economic divides and infrastructural constraints exacerbate the challenges of deploying these technologies in under-resourced regions.

A significant geographical bias is evident in the studies conducted, revealing a predominant emphasis on technologically advanced regions, particularly North America, Europe, and specific East Asian areas. Although exceptions exist, such as research from Ghana and Indonesia, numerous regions remain substantially underrepresented, including vast areas of Sub-Saharan Africa, South Asia, Latin America, and Oceania. This bias raises pertinent concerns regarding the global applicability of the findings, as the distinct educational challenges present in marginalized and low-resource contexts, such as gender disparities, Indigenous education, and insufficient digital infrastructure, may be inadequately addressed. Mobile technologies help to present an opportunity to close this gap and increase access in many underserved areas. It is important to expand research efforts into these regions, engage local perspectives to tackle systemic inequities, and ensure that AI-driven solutions are inclusive and globally relevant.

In addition to mechanical enhancements, AI facilitates transformative change by addressing systemic barriers within the education sector. Instruments such as AI-powered chatbots and immersive learning environments promote equity by bridging socio-economic disparities and improving accessibility for marginalized demographics, including students with disabilities and those residing in remote locations. Mobile learning environments help improve these benefits, such as enabling real-time feedback and offline/online accessibility in regions with inconsistent internet connectivity. These innovations advance sustainability and foster innovation in educational practices, empowering educators and students to navigate real-world challenges effectively. Nevertheless, to attain widespread implementation, it is imperative to surmount resistance to change, guarantee the utilization of unbiased and context-sensitive algorithms, and scale affordable and adaptable solutions to diverse contexts. Tackling these challenges necessitates coordinated efforts across various sectors to establish equitable infrastructure and align educational advancements with broader technological transformations.

5. Conclusion

The findings of this review underscore the transformative potential of Artificial Intelligence (AI)-driven technologies in advancing Sustainable Development Goal 4 (SDG 4). Flexible learning platforms and innovative tutoring systems enhance personalization, inclusivity, and engagement, addressing educational disparities and promoting equitable opportunities. These advancements not only improve learning outcomes but also cultivate broader societal impacts through the promotion of innovation and equity. Nevertheless, challenges such as uneven access to infrastructure, ethical considerations, and resistance to AI adoption persist. Expanding mobile network access and integrating AI-driven mobile learning solutions can help mitigate some of these barriers, especially for regions with limited access. Policymakers are urged to invest in digital infrastructure, particularly in underserved regions, and to establish clear regulations governing the ethical use of AI. Furthermore, educational institutions should implement AI and mobile literacy programs to effectively equip educators with the skills necessary to integrate AI tools into teaching methodologies.

Collaboration among governmental entities, educational institutions, and technology experts is indispensable. Stakeholders can cultivate a resilient and inclusive academic environment by fostering AI literacy, designing culturally responsive tools, and addressing algorithmic bias. Using mobile technologies in AI-driven education strategies enables real-time feedback, microlearning, and offline learning capabilities, further reducing digital divides. This coordinated strategy will enable the education sector to fully leverage the potential of AI to achieve SDG 4, thereby ensuring equitable and high-quality education for all individuals. Policymakers should allocate resources toward enhancing digital infrastructure and establish regulatory frameworks to govern the ethical utilization of AI technologies. Educators are encouraged to embrace AI literacy programs and integrate AI tools to facilitate personalized and inclusive teaching methodologies. Meanwhile, technologists should concentrate on developing transparent and culturally responsive AI solutions while effectively addressing bias and safeguarding data privacy. These measures will serve to maximize the capacity of AI to enhance both educational equity and quality.

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