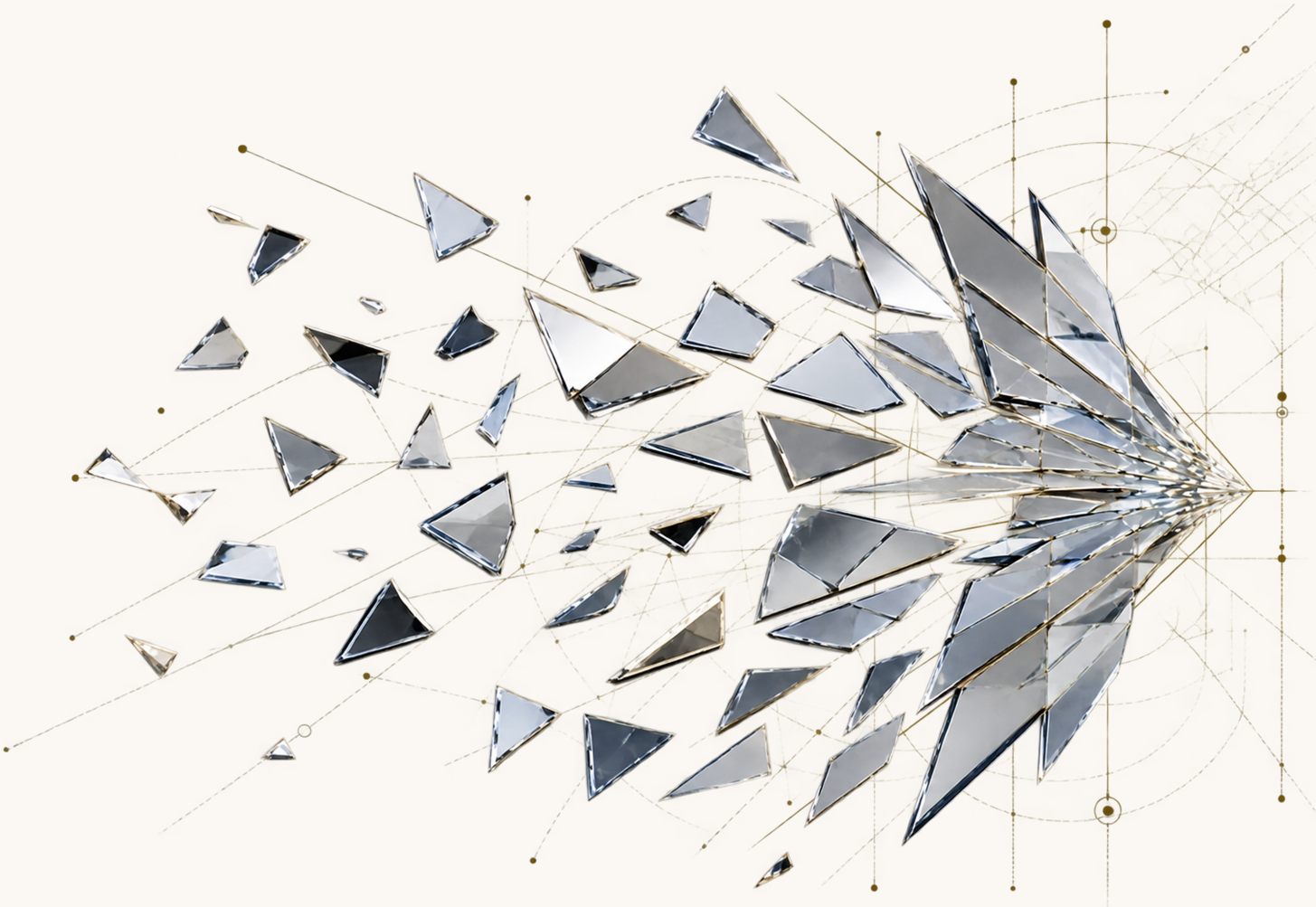
ARTIFICIAL INTELLIGENCE AND NATIONAL TECHNOLOGY REFLECTIONS



TÜRKİYE TEKNOLOJİ TAKIMI

TÜBA
TÜRKİYE BİLİMLER AKADEMİSİ
TURKISH ACADEMY OF SCIENCES

KÜMS

TÜRKİYE TEKNOLOJİ TAKIMI

TÜBA

TÜRKİYE BİLİMLER AKADEMİSİ
TURKISH ACADEMY OF SCIENCES

ARTIFICIAL INTELLIGENCE AND NATIONAL TECHNOLOGY REFLECTIONS

Editors

Prof. Dr. Hüseyin ARSLAN

Dr. Abdulkadir TAŞDELEN

Dr. Elvan KUZUCU HIDIR

Dr. Ozan Ahmet ÇETİN

Ankara, 2026

Artificial Intelligence and National Technology Reflections

© Turkish Academy of Sciences Publication, 2026

Science and Thought Series No:

ISBN: 978-625-6110-86-1

DOI: 10.53478/TUBA.978-625-6110-86-1

Editors
Prof. Dr. Hüseyin ARSLAN
Dr. Abdulkadir TAŞDELEN
Dr. Elvan KUZUCU HIDIR
Dr. Ozan Ahmet ÇETİN

Publication Advisor
Assoc. Prof. Dr. Mürsel DOĞRUL
Merve KOÇOĞLU

Secretariat
Dr. Ahmet ÖZGÜLTEKİN

Cover Design
Tarık AKIN

Graphic Design
Mustafa ALTINTEPE

The scientific responsibility for the language, scientific, ethical and legal aspects of all the articles included in the book belongs to the authors. Turkish Academy of Sciences and the editors have no responsibility.

Turkish Academy of Sciences

Vedat Dalokay Cad. No: 112 06670 Çankaya - Ankara

Tel: +90 312 442 29 03 • www.tuba.gov.tr

Publication Place and Date: Tek Ses Ofset Matbaacılık Yayıncılık • Ankara 2026

Pcs.: 2000

Artificial Intelligence and National Technology Reflections / ed. Hüseyin Arslan, Abdulkadir Taşdelen, E. Kuzucu Hıdır ve Ozan Ahmet Çetin. ¬-- Ankara : Turkish Academy of Sciences, 2026.
648 p. ; 19,5 x 27,5 cm. – (Science and Thought Series: 71)
Includes bibliographical references.

ISBN 978-625-6110-86-1
1. Artificial intelligence. 2. National Technology Initiative. 3. Technology policy. 4. AI governance and ethic. 5. Landscape Analysis

Q335 .A78 2026
006.3

This work is licensed under a Creative Commons Attribution-NonCommercial-No Derivative (BY-NC-ND) 4.0 International License.

Table of Contents

FOREWORD
Prof. Dr. Muzaffer Şeker
xi

FOREWORD
Selçuk Bayraktar
xiii

EDITORIAL NOTE
Editors
xv

PART I
GLOBAL LANDSCAPE OF ARTIFICIAL INTELLIGENCE TECHNOLOGY

The Transformation of the Science in the Age of AI
Prof. Dr. Muzaffer Şeker
3

Evolution of Artificial Intelligence from Traditional to Super Intelligence
Prof. Dr. Ercan Oztemel, Dr. M. Esad Oztemel
27

Foundations of Artificial Intelligence: Big Data, Processors and Large Language Models
Prof. Dr. Şeref Sağıroğlu
59

Geopolitics and AI: Power, Influence, and Foreign Policy
Assoc. Prof. Dr. Mürsel Doğrul, Asst. Prof. Dr. Ozan Ahmet Çetin
83

Global AI Collaboration and Innovation Networks
Prof. Dr. T. Metin Sezgin
107

AI's Impact on Global Sustainability and Labor Markets
Prof. Dr. Halit Keskin, Prof. Dr. Emel Esen
129

AI/ML for Radio Access Networks: Enabling Self-Evolving and Intelligent Connectivity
Dr. Evren Tuna, Prof. Dr. Hüseyin Arslan
151

A Review of Artificial Intelligence in Education: What is Ahead, What is Left Behind at Global Scale?
Dr. Mehmet Akın Bulut, Dr. Jeffrey Buckley
171

PART II
NATIONAL LANDSCAPE OF ARTIFICIAL INTELLIGENCE (TÜRKİYE PERSPECTIVE)

Artificial Intelligence as a Strategic Pillar of the National Technology Initiative by the Turkish Technology Team (T3) Foundation: The T3AI, TEKNOFEST, and T3 Gemstone Projects
Dr. Elvan Kuzucu Hıdır
203

Türkiye's National Artificial Intelligence Strategy
Dr. Atilla Aydın, Seda İpek Aksoy Ercan
229

National Technology Initiative and AI Integration
Prof. Dr. Orhan Aydın
247

Artificial Intelligence Regulation in Türkiye: Current Position and Future Trajectory
Asst. Prof. Dr. Osman Gazi Güçlütürk
277

AI Applications in Defence Sectors
Prof. Dr. Zafer Evis, Assoc. Dr. Onur Behzat Tokdemir
303

Integration of AI in the National Education System in Türkiye
Mustafa Canlı, Dr. Zafer Özen, Dr. Hüseyin Ulukuz, Dr. Emre Dinç
327

The Use of Artificial Intelligence in the Public Sector and Government Institutions
Prof. Dr. Çetin Elmas
355

Türkiye's AI Ecosystem: Key Actors, Research Institutes, Startups, and Collaborations
Dr. Mehmet Haklıdır
381

Artificial Intelligence Startup Ecosystem of Türkiye: Opportunities and Challenges
Yasemin Tavlaşoğlu
413

PART III
FUTURE LANDSCAPE OF ARTIFICIAL INTELLIGENCE

Technology as a Cultural Form: an Attempt at Reconciliation
Abdullah Eren
441

Governance of Artificial Intelligence and its Impact on the Transformation of Societies
Prof. Dr. Mehmet Yildiz
457

Artificial General Intelligence (AGI) and Emerging Technologies (Quantum Tech.)
Prof. Dr. Berk Canberk, Res. Asst. Yağmur Yiğit
481

Human-AI Collaboration and the Future of the Workforce
Dr. Muhammed Yusuf Kocyigit
503

Governance, Accreditation, Ethics, and Trust in Future AI Systems
Asst. Prof. Dr. Abdulkadir Taşdelen
527

Future Threats and Risks - I: Deepfakes, Autonomous Weapons, and AI Safety
Dr. Yasir Atalan
559

Future Threats and Risks - II: Environmental Impacts of AI (Energy and Water)
Dr. Don Liyanage, Prof. Dr. Mehmet Emin Aydın
583

Artificial Intelligence Optimization Techniques, Artificial Bee Colony (ABC) Algorithm and its Global Reflections
Prof. Dr. Derviş Karaboğa, Prof. Dr. Bahriye Akay
599

Index
621

ABBREVIATIONS

5G	Fifth-Generation (mobile network)
6G	Sixth-Generation (mobile network)
AAAI	Association for the Advancement of Artificial Intelligence
AASSA	Association of Academies and Societies of Sciences in Asia
ACL	Association for Computational Linguistics
ACM	Association for Computing Machinery
AGI	Artificial General Intelligence
AI	Artificial Intelligence
AI2	Allen Institute for AI
AIA	Artificial Intelligence Act
AIC	Artificial Intelligence Center
AI/ML	Artificial Intelligence / Machine Learning
AIMS	Artificial Intelligence Management System
AIPA	Artificial Intelligence Policies Association
ALLEA	All European Academies
AMD	Advanced Micro Devices
ANAB	ANSI-ASQ National Accreditation Board
API	Application Programming Interface
ASELSAN	Military Electronics Industries (Askeri Elektronik Sanayi)
ASI	Artificial Super Intelligence
ATP	Academic Thesis Program
AWS	Amazon Web Services
BERT	Bidirectional Encoder Representations from Transformers
BPU	Brain Processing Unit
BS	Base Station
BTYPK	Science, Technology and Innovation Policies Board
CAGR	Compound Annual Growth Rate
CBDDO	Digital Transformation Office of the Presidency
CCO	Coverage and Capacity Optimization
CCW	Convention on Certain Conventional Weapons
CDL	Creative Destruction Lab
CE	Circular Economy
CEFR	Common European Framework of Reference for Languages
Cfpd	Critical Foreign Policy Decisions
CMU	Carnegie Mellon University
CN	Core Network
CNN	Convolutional Neural Networks
COMPAS	Correctional Offender Management Profiling for Alternative Sanctions
COVID-19	Coronavirus Disease 2019
CPU	Central Processing Unit
CSCW	Computer Supported Cooperative Work
CSI	Channel State Information

CV	Computer Vision
CVC	Corporate Venture Capital
CVPR	Conference on Computer Vision and Pattern Recognition
DARB	Data and AI Review Board
DCAF	Geneva Centre for Security Sector Governance
DCV	Dynamic Capabilities View
DE	Differential Evolution
DIB	Defence Industrial Base
DL	Deep Learning
DoD	Department of Defense
DOI	Digital Object Identifier
DPU	Data Processing Units
DRC	Democratic Republic of Congo
DTO	Digital Transformation Office
EBA	Educational Informatics Network
ECHR	European Convention on Human Rights
EDIH	European Digital Innovation Hubs
EEG	Electroencephalography
EPRS	European Parliamentary Research Service
ERC	European Research Council
EU	European Union
FAT	Fairness, Accountability, and Transparency
FDA	Food and Drug Administration
FHEA	Fellow of the Higher Education Academy
FLI	Future of Life Institute
FPV	First-person-view
G20	Group of Twenty
GA	Genetic Algorithm
GAN	Generative Adversarial Network
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GII	Global Innovation Index
GP	Genetic Programming
GPAI	Global Partnership on Artificial Intelligence
GPS	General Problem Solver
GPT	Generative Pre-trained Transformer
GPU	Graphics Processing Unit
GRU	Gated Recurrent Unit
HAMLE	Technology-Oriented Industry Initiative
HAVELSAN	Air Electronic Industries (Hava Elektronik Sanayi)
HPC	High-Performance Computing
HRW	Human Rights Watch
HTR	Handwritten Text Recognition
IAP	InterAcademy Partnership
IBM	International Business Machines
ICAIE	International Conference on Artificial Intelligence and Education

ICCR	International Conference on Cyber Resilience
ICLR	International Conference on Learning Representations
ICML	International Conference on Machine Learning
ICTON	International Conference on Transparent Optical Networks
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIUM	International Islamic University Malaysia
IJAET	International Journal of Adult Education and Technology
ILO	International Labour Organization
IMF	International Monetary Fund
IMT	International Mobile Telecommunications
IMT-2030	International Mobile Telecommunications 2030
IoT	Internet of Things
ISBN	International Standard Book Number
ISO	International Organization for Standardization
ITS	Intelligent Tutoring Systems
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
IUI	Intelligent User Interfaces
KVKK	Personal Data Protection Law (Kişisel Verilerin Korunması Kanunu)
LAWS	Lethal Autonomous Weapons Systems
LLM	Large Language Model
LSTM	Long Short-Term Memory
LTA	Land Transport Authority
LTE	Long Term Evolution
MAC	Medium Access Control
MEB (MoNE)	Ministry of National Education
MEMS	Micro-Electro-Mechanical Systems
METU	Middle East Technical University
MIT	Massachusetts Institute of Technology
ML	Machine Learning
MMA	Matrix Multiply Accelerator
MOIT	Ministry of Industry and Technology
MOOC	Massive Open Online Course
MRI	Magnetic Resonance Imaging
MTYZGM	Directorate General for National Technology and Artificial Intelligence
MÜSİAD	Independent Industrialists' and Businessmen's Association Müstakil Sanayici ve İşadamları Derneği
NAIS	National Artificial Intelligence Strategy
NATO	North Atlantic Treaty Organization
NBER	National Bureau of Economic Research
NGO	Non-Governmental Organization
NISQ	Noisy Intermediate-Scale Quantum
NIST	National Institute of Standards and Technology
NLP	Natural Language Processing

OECD	Organisation for Economic Co-operation and Development
ORCID	Open Researcher and Contributor ID
OTS	Organization of Turkic States
PD	Presidential Decree
PDR	Preliminary Design Report
PQC	Post-Quantum Cryptography
PSO	Particle Swarm Optimization
PUE	Power Usage Effectiveness
Q&A	Question and Answer
QAOA	Quantum Approximate Optimisation Algorithm
QKD	Quantum Key Distribution
QPU	Quantum Processing Units
QSDC	Quantum Secure Direct Communication
QUBO	Quadratic Unconstrained Binary Optimisation
RAM	Readiness Assessment Methodology
RAN	Radio Access Network
R&D	Research and Development
RL	Reinforcement Learning
RMF	Risk Management Framework
RNN	Recurrent Neural Network
RPA	Robotic Process Automation
RRM	Radio Resource Management
SAIL	Stanford Artificial Intelligence Laboratory
SAYZEK	Defense Industry Artificial Intelligence Cluster
SDG	Sustainable Development Goals
SI	Swarm Intelligence
SIGAI	Special Interest Group on Artificial Intelligence
SME	Small and Medium-sized Enterprise
SRI	Stanford Research Institute
SSB	Presidency of Defense Industries (Savunma Sanayii Başkanlığı)
STB	Ministry of Industry and Technology (Sanayi ve Teknoloji Bakanlığı)
STEAM	Science, Technology, Engineering, Arts, and Mathematics
STEM	Science, Technology, Engineering, and Mathematics
SVM	Support Vector Machines
T3	Turkish Technology Team (Türkiye Teknoloji Takımı)
T3AI	T3 Foundation Artificial Intelligence (large language model)
TBV	Turkish Informatics Foundation
TEKNOFEST	Aerospace and Technology Festival (Teknoloji Festivali)
TOPS	Trillion Operations Per Second
TPU	Tensor Processing Unit
TRAI	Turkish Artificial Intelligence Initiative
TRL	Technology Readiness Level
TSA	Tabu Search Algorithm
TSMC	Taiwan Semiconductor Manufacturing Company
TUBITAK	Scientific and Technological Research Council of Türkiye
TÜBA	Turkish Academy of Sciences

UAE	United Arab Emirates
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UGV	Unmanned ground vehicles
UIST	User Interface Software and Technology
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Program
UNESCO	United Nations Educational Scientific and Cultural Organization
US	United States
USA	United States of America
USV	Unmanned surface vehicles
VC	Venture Capital
VDK	Vergi Denetim Kurulu
WEF	World Economic Forum
WIPO	World Intellectual Property Organization
WUE	Water Usage Effectiveness
XAI	Explainable Artificial Intelligence
YÖK (CoHE)	The Council of Higher Education
YZE	Artificial Intelligence Institute
YZF	Artificial Intelligence Factory

10.53478/TUBA.978-625-6110-86-1.ch08

A REVIEW OF ARTIFICIAL INTELLIGENCE IN EDUCATION: WHAT IS AHEAD, WHAT IS LEFT BEHIND AT GLOBAL SCALE?

Dr. Mehmet Akın Bulut
CILT-AI Education Center, Ibn Haldun University

Dr. Jeffrey Buckley
University of the Shannon

Abstract

This narrative review synthesizes recent research on artificial intelligence (AI) in education to address gaps in understanding its diverse roles, integration strategies, and pedagogical implications. The review aims to evaluate AI integration within curricula and instructional practices, examine AI literacy development, identify inclusive pedagogical strategies, compare adoption challenges including ethics and equity, and analyze AI's role in fostering critical thinking and creativity. Literature published between 2020 and 2025 was identified through searches of the Scopus, Web of Science, PubMed/MEDLINE, and arXiv databases, supplemented by AI-assisted semantic search, and a purposively selected body of 86 sources comprising peer-reviewed journal articles, books, conference proceedings, and preprints was retained as representative evidence for critical synthesis. A thematic analysis of empirical and theoretical studies across global K-12, higher education, and professional contexts was conducted, focusing on AI literacy and educator preparedness, curriculum design, pedagogical effectiveness, inclusivity, and ethics. Findings reveal that AI-enabled personalized and adaptive learning can significantly enhance student engagement and outcomes while supporting diverse learner needs; however, equitable access and infrastructure disparities limit inclusivity. Curriculum frameworks emphasize interdisciplinary AI literacy integrating ethical and technical competencies, yet standardization and comprehensive coverage remain insufficient. Educator readiness is critical but hindered by knowledge gaps and limited professional development, affecting effective AI adoption. Ethical concerns, including data privacy and algorithmic bias, are widely recognized but inadequately addressed in practice. Collectively, these findings underscore AI's transformative potential in education contingent on balanced curriculum design, ethical integration, and robust teacher support. The review informs educators, policymakers, and researchers on effective AI embedding strategies to prepare learners for an AI-driven future.

Keywords

Artificial Intelligence, Educational Technology, Techno-Pedagogy, AI Ethics, AI Literacy

1. Introduction

1.1. Context

Research on artificial intelligence (AI) in education has emerged as a critical area of inquiry due to its transformative potential in reshaping both technology teaching, e.g., thinking and teaching about AI as a technology, and educational technology, using AI to support learning processes across educational levels more generally (Stolpe and Hallström, 2024; Xiao et al., 2025). The evolution of AI integration in education spans from early computational literacy initiatives to the current emphasis on AI literacy and adaptive learning systems (Casal-Otero et al., 2023; Yue et al., 2022). This progression reflects growing societal and economic demands for AI competencies, with AI literacy increasingly recognized as an essential technological competency for preparing students for future societal challenges (Wang & Lester, 2023; Zhao, 2025). Notably, AI-driven personalized learning platforms and intelligent tutoring systems have demonstrated improvements in student engagement and academic outcomes, underscoring the practical significance of AI in education (Deckker et al., 2025; Salendab et al., 2026). However, though statistics reveal a rapid increase in AI adoption in educational institutions, there are disparities in access highlighting equity concerns (Li et al., 2024; Westover, 2025).

Despite these advances, a specific problem persists in effectively integrating AI into education curricula, particularly in K-12 and higher education contexts (Dubey & Crevar, 2025). There is a notable knowledge gap regarding standardized frameworks for AI literacy, pedagogical strategies, and teacher preparedness to deliver AI content effectively (Fissore et al., 2024; Yau et al., 2023; Yue et al., 2024). Competing perspectives exist: some advocate for AI as a tool to enhance personalized learning and administrative efficiency, while others caution against overreliance on AI, emphasizing ethical challenges and the preservation of human-centered pedagogy (Yadav, 2024). The consequences of this gap include inconsistent AI education quality, limited teacher confidence, and potential exacerbation of educational inequities (Addo, 2023; Familoni & Onyebuchi, 2024).

The conceptual framework for this review defines AI literacy as encompassing knowledge of AI technologies, skills to interact with AI systems, and ethical understanding of AI's societal impacts (Chiu et al., 2024; Tadimalla & Maher, 2024). This framework situates AI literacy within technological literacy and computational thinking, emphasizing the integration of technical, socio-ethical, and reflective competencies (Stolpe & Hallström, 2024; Weng et al., 2024). The relationships among these concepts guide the examination of AI's role in curriculum design, instructional methods, and teacher education (Black et al., 2024; Lim, 2024).

The purpose of this review is to synthesize current research on AI integration in education, focusing on curriculum development, pedagogical approaches, and teacher readiness (Garzón et al., 2025; Yue et al., 2024). This review aims to fill the identified gaps by providing a comprehensive analysis that informs educators, policymakers, and researchers on effective AI literacy implementation across educational contexts (Lin & Van Brummelen, 2021). The value added lies in consolidating interdisciplinary perspectives and highlighting best practices and challenges to support equitable and ethical AI education (Tahura et al., 2026; Yadav, 2024).

Analytical frameworks incorporate thematic synthesis and conceptual mapping to organize findings on AI literacy components, curriculum models, and instructional strategies (Heo, 2025; Rüütmann & Läänemets, 2025). The review is structured to first contextualize AI in education, then explore curriculum integration, followed by customized learning, intelligent tutoring systems, teacher preparation and pedagogical innovations, concluding with recommendations for future research and practice (Lin & Van Brummelen, 2021; Stolpe & Hallström, 2024).

1.2. Purpose and Objectives of the Review

The objective of this report is to examine the existing research on "AI in education" in order to elucidate the multifaceted roles, integration strategies, customized learning, intelligent tutoring systems and pedagogical implications of artificial intelligence in education frameworks. This review is important as AI technologies increasingly permeate educational environments, reshaping curriculum design, instructional methodologies, and learner engagement. By synthesizing current knowledge, the report aims to provide a comprehensive understanding of how AI contributes to technological literacy, fosters inclusivity, and addresses challenges such as ethical considerations and equitable access. Ultimately, the review seeks to inform educators, policymakers, and researchers about effective approaches to embedding AI in education, thereby preparing learners for an AI-driven future.

Specific objectives:

1) To evaluate current knowledge on AI integration into education curricula and instructional practices.
2) Benchmarking of existing approaches to AI literacy development in education across diverse educational levels.
3) Identification and synthesis of pedagogical strategies that leverage AI to enhance inclusivity and personalized learning.
4) To compare challenges and opportunities reported in AI adoption for education, including ethical and equity concerns.
5) To deconstruct the role of AI tools in fostering critical thinking, creativity, and problem-solving in education.

2. Methodology

2.1. Review Approach and Rationale

This chapter adopts a narrative (traditional) review design with a thematically organized synthesis, consistent with the aims and format of a book chapter intended to orient readers to the field. This methodological choice also reflects the character of the field itself. Research on AI in education is expanding rapidly, is terminologically heterogeneous (spanning labels such as "AI literacy," "intelligent tutoring systems," "adaptive learning," and "machine learning education"), and is distributed across diverse publication venues, disciplines, and educational contexts. The aim of this review is not an exhaustive quantitative mapping of every published study, but a critical, interpretive synthesis that identifies conceptual themes, tensions, and gaps across the literature and connects them to implications for curriculum design, pedagogy, equity, and policy.

For this purpose, a narrative review offers distinct advantages over systematic or scoping designs. It permits the integration of methodologically diverse contributions such as empirical studies, theoretical and conceptual papers, policy-oriented analyses, and emerging preprints that would be difficult to synthesize under a single appraisal framework, and it allows the researchers' domain expertise to guide the selection of the most conceptually significant works rather than constraining synthesis to what standardized search strings happen to retrieve. Narrative reviews are widely recognized as an appropriate design when the goal is interpretation, theory development, and agenda-setting in a fast-moving and conceptually fragmented field, as is the case for AI in education (Grant & Booth, 2009; Greenhalgh et al., 2018).

2.2. Literature Identification and Selection

To identify relevant literature published between January 2020 and December 2025, searches were conducted in the Scopus, Web of Science (WoS), PubMed/MEDLINE, and arXiv databases, using combinations of AI-related terms ("artificial intelligence," "machine learning," "deep learning," "natural language processing," "intelligent tutoring systems") with education-focused terms ("education," "learning," "teaching," "pedagogy"). These database searches were supplemented by AI-assisted semantic search (SciSpace), which complements Boolean keyword matching by surfacing conceptually related work across the field's heterogeneous vocabulary. All sources ultimately included in the review were verified by the authors against their original records, and all relevance judgments were made by the researchers rather than delegated to the tool.

From the retrieved literature, sources were selected purposively rather than exhaustively, following the logic of information-rich case selection appropriate to narrative synthesis. Four criteria guided inclusion: (1) substantive relevance: the source directly addressed at least one of the review's guiding questions (AI integration in curricula and instruction, AI literacy and educator preparedness, personalized and adaptive learning, inclusivity and equity, or ethical challenges of AI adoption); (2) conceptual or empirical contribution: the source offered original findings, a distinct theoretical framing, or a synthesis that advanced understanding beyond studies already selected, such that redundant confirmations of already-represented findings were not added; (3) contextual breadth: sources were deliberately balanced to cover K-12, higher education, and vocational settings across diverse geographic regions, so that no theme rested on a single context; and (4) quality and recency: priority was given to peer-reviewed journal articles published between 2020 and 2025, with books, conference proceedings, and preprints admitted only where they offered significant contributions not yet represented in the journal literature. Sources were excluded if they were not substantively concerned with AI in educational settings or fell outside this window. Selection continued until thematic saturation was reached, that is, until additional sources no longer introduced new themes or materially altered existing ones, yielding a final corpus of 86 sources spanning global K-12, higher education, and professional contexts, which constitutes the evidence base cited throughout this chapter.

2.3. Analysis and Synthesis

The selected sources were read in full and analyzed thematically. An inductive coding of key findings, arguments, and recommendations was carried out and iteratively grouped into the organizing themes of the review: (1) AI literacy and educator preparedness, (2) curriculum design and integration, (3) pedagogical effectiveness of personalized and adaptive learning, (4) inclusivity and equity, and (5) ethics and governance. Within each theme, findings were compared across educational levels and geographic contexts to surface convergences, contradictions, and underexplored areas. Consistent with the narrative review design, the synthesis is interpretive and critical rather than tabulative: the discussion foregrounds representative and conceptually significant evidence for each theme and uses it to articulate research trends, gaps, and future directions in the field of AI in education.

3. A Comprehensive Review of AI in Education

This chapter reviews the literature on AI in education through a thematically structured synthesis, preceded by a brief qualitative chronological descriptive overview that situates the evolution of the field. The chapter adopts thematic analysis (Braun & Clarke, 2012) as the primary analytical contribution, allowing findings

across educational levels, regions, and methodologies to be integrated into a coherent narrative, while the initial chronological review provides supplementary historical context. The thematic analysis is followed by an overview of strengths and weaknesses of AI integration in education discussed throughout the reviewed literature, and finally an overview of ongoing discussions in contemporary works.

3.1. Chronological Review of the Literature

The chronological development of literature on AI in education reveals a gradual shift from early curriculum conceptualization toward systemic, ethical, and adaptive implementations. Early work focused on defining AI concepts and integrating them into computing curricula, while later studies expanded toward interdisciplinary approaches, K–12 inclusion, teacher preparation, and ethical governance. Most recent research emphasizes generative AI, adaptive learning systems, inclusivity, and responsible innovation. While the 'Pre-2000' era belongs to the history of computer science philosophy, the 'Post-2000' era belongs to the history of functional technology. Starting at 2000 filters out the 'AI Winters' and focuses the reader on the specific evolutionary path that led directly to the current generative AI boom. By anchoring the chronology in the year 2000, we focus the narrative on the definitive shift from the rigid, rule-based logic of the 20th century to the modern era of applied machine learning, capturing the precise historical juncture where the convergence of massive internet-scale datasets, statistical modeling, and high-performance GPU hardware transformed artificial intelligence from a lab-bound academic theory into the scalable, functional powerhouse that directly fuels today's generative revolution. Table 1 summarizes this chronological development of the literature across six periods.

Table 1

Chronological Review of Literature

Year Range	Research Direction	Description
2001–2010	Foundations and Early Curriculum Development	Early studies concentrated on developing integrated AI curricula and exploring AI concepts for learners, focusing on foundational knowledge and pedagogical frameworks in computing education. Emphasis was placed on motivating students through AI-related projects and integrating AI as a disciplinary subject.
2011–2015	Expansion of AI in Computer Science Education	Research expanded to include machine learning and interdisciplinary approaches within computer science curricula. Efforts began addressing the inclusion of AI in software engineering education and exploring early-stage AI literacy tools.
2016–2019	Growing Interest in K-12 AI Literacy and Pedagogical Models	A surge in AI education initiatives targeted K-12 levels, with exploration of pedagogical designs, teacher readiness, and the inclusion of ethical considerations. Studies investigated hands-on learning, project-based activities, and the integration of AI across subjects, recognizing the need for interdisciplinary and critical approaches.
2020–2021	Establishing AI Literacy Frameworks and Teacher Preparation	Literature focused on defining AI literacy competencies, developing sustainable curricula, and preparing educators through professional development programs. Early implementations of AI education were studied, highlighting challenges in content delivery and the importance of human-centered AI pedagogy.
2022–2023	Advancements in AI Curriculum Design and Ethical Integration	Research emphasized curriculum reform with AI integration across educational levels, including adaptive, customized learning systems and intelligent tutoring. Ethical challenges such as algorithmic bias, data privacy, and equitable access became prominent. Teacher perspectives and readiness studies informed curriculum development and instructional strategies.
2024–2025	Personalized, Inclusive, and Generative AI in Education	Recent studies explore AI-driven adaptive learning platforms, generative AI tools like ChatGPT, and their impact on personalization, inclusivity, and engagement. Emphasis is placed on ethical frameworks, equitable access, teacher training, and integrating AI across interdisciplinary curricula. Innovations in AI-powered curriculum design and assessment are highlighted as transformative for future education.

3.2. Thematic Summary of the Studies

This section thematically maps the research landscape of the literature on AI in education, encompassing a diverse range of studies that explore AI education across K-12, higher education, and vocational contexts. The reviewed works employ various methodologies including systematic reviews, empirical studies, curriculum design, and qualitative analyses, with geographic representation spanning multiple continents. The comparison addresses critical dimensions such as curriculum integration, pedagogical effectiveness, inclusivity, ethical considerations, and educator preparedness, providing a comprehensive understanding relevant to the research questions on AI's role and impact in education.

Across the listed studies, AI curriculum integration is shifting from "add-on tools" toward systemic curriculum design, with most papers arguing that *AI literacy* should be treated as a foundational competence (not only a technical topic) and be embedded across subjects, assessment, and teacher education. Recurring threads appear across the various themes relating to curriculum integration depth (where and how AI is embedded), pedagogical effectiveness (what learning gains are reported or expected), and the "conditions of implementation," dominated by inclusivity/access, ethics/equity, and educator readiness. Table 2 presents the five overarching themes identified in the thematic analysis, together with their descriptions.

Table 2

Thematic Summary of the Studies

Theme	Theme Description
AI Literacy, educator preparedness and perceptions	AI literacy is broadly recognized as a critical competency for students, encompassing technical knowledge, ethical understanding, and responsible use of AI technologies. Curricula and programs emphasize interdisciplinary and age-appropriate AI education, aiming to equip learners with conceptual and applied skills to navigate an AI-driven future. Research indicates that AI literacy fosters motivation, ethical reflection, and problem-solving abilities, but also reveals gaps in assessment and educator preparedness. Teachers' attitudes, competency, and readiness significantly impact AI adoption in classrooms. Professional development programs and co-design initiatives support educators in understanding AI content and integrating AI tools effectively, while addressing concerns about workload, ethics, and instructional strategies. Collaborative frameworks foster teacher agency and adaptability across STEM and non-STEM disciplines.
Curriculum integration depth	AI integration in curricula spans from standalone AI courses to embedding AI concepts across subjects, promoting interdisciplinary approaches and project-based learning. Frameworks and models for AI curriculum development address content sequencing, competency frameworks, and contextual adaptation to diverse educational levels. Innovations include AI-assisted curriculum creation and personalized content generation, emphasizing the need to balance technological advances with pedagogical goals and human agency.
Pedagogical effectiveness	AI is explored both as an educational content area and as a tool to enhance teaching and learning processes. Applications include intelligent tutoring systems, automated assessments, AI-enhanced content creation, and facilitation of collaborative and active learning environments. This dual role requires pedagogical innovation and critical examination of AI's impact on teaching roles and student engagement.
Inclusivity and accessibility	AI-powered systems enable personalized learning experiences through adaptive platforms, intelligent tutoring, and real-time feedback, enhancing student engagement and academic outcomes. Studies demonstrate AI's role in tailoring instruction to individual needs and supporting diverse learners, including in STEAM and vocational education contexts. Despite benefits, challenges such as data privacy, algorithmic bias, and digital divides affect equitable implementation. Research highlights diverse AI education initiatives and challenges across countries and regions, reflecting variations in curriculum development, resource availability, and cultural contexts. Comparative studies inform adaptive strategies and underscore the need for context-sensitive frameworks that address local educational needs and global AI literacy standards. Efforts in developing countries emphasize capacity building, infrastructure development, and culturally relevant pedagogy.
Ethical and equity considerations	Ethical concerns including algorithmic bias, data privacy, and transparency are recurrent in AI education literature, alongside issues of equitable access and digital infrastructure disparities. Strategies for ethical AI integration emphasize inclusive design, governance frameworks, and policy development to mitigate risks and promote fairness. Addressing these challenges is crucial for sustainable and responsible AI use in education.

3.2.1. AI Literacy, Educator Preparedness and Perceptions: Training as the Dominant Implementation Bottleneck

The literature offers multiple integration frameworks emphasizing interdisciplinary design, alignment with existing curricula, and AI literacy as a multiliteracy spanning technical, conceptual, and socio-ethical competencies (Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). In harmony, teacher capacity is consistently presented as the main constraint on sustainable AI integration. Multiple sources explicitly call for professional development, competency frameworks, and teacher education redesign (Adıgüzel et al., 2023), often emphasizing that AI literacy requires both technical familiarity and socio-ethical facilitation skills (Black et al., 2024; Bulut et al., 2025; Bulut, 2026; Suna et al., 2025). Where educator perceptions are studied, findings tend to show interest and openness mixed with uncertainty, highlighting gaps in confidence, knowledge, and institutional support (Annuš, 2024; Karanfiloğlu & Bulut, 2025; Yue et al., 2024).

Teacher education-focused frameworks emphasize culturally responsive, equity-centered preparation and "community-wide" supports (Black et al., 2024; Bulut et al., 2026), while other studies stress digital competencies and practical pedagogical supports for classroom integration. Several works also argue that teachers' roles evolve toward orchestration, ethical guidance, and design leadership in hybrid human–AI learning environments (Han, 2026; Ramakrishnan et al., 2024).

3.2.2. Curriculum Integration Depth: From Discrete Modules to Cross-Curricular Architectures

Several studies propose frameworks that treat AI literacy as a curriculum-level construct rather than a single unit or elective. For example, work in education emphasizes embedding AI literacy within established curricular aims so that students learn AI as part of broader "technological literacy" and socio-technical understanding (Stolpe & Hallström, 2024). Related frameworks place AI within interdisciplinary socio-technical curricula that intentionally balance technical concepts (data, models, automation) with non-technical competencies (ethical reasoning, civic understanding, human agency) (Tadimalla & Maher, 2024).

A second integration pattern is AI as an educational technology engine of curriculum redesign, using AI to support adaptive pathways, competency-based progression (Birgili et al., 2025), and customized flexible learning structures (Anbumaheshwari et al., 2026). These studies align AI integration with outcome-based education and assessment modernization, emphasizing alignment between competencies, evidence of learning, and adaptive feedback loops.

A third pattern is contextual and system-level integration, including national/regional initiatives, guideline alignment (e.g., with UNESCO/SDGs), and infrastructural investment as prerequisites for equitable adoption (Li et al., 2024; Zhou et al., 2022). Across these, "integration depth" is framed less as a pedagogical choice and more as a governance and capacity-building agenda (Li et al., 2024). Overall, integration depth trends go toward cross-curricular AI literacy, adaptive/competency-based redesign and policy/infrastructure alignment (Li et al., 2024; Stolpe & Hallström, 2024).

3.2.3. Pedagogical Effectiveness: Gains Are Reported, but Often Conditionally

A consistent claim is that AI-supported curricula can strengthen problem-solving, creativity, critical thinking, engagement, and retention, particularly when learning is active (e.g., project-, inquiry-, game-, customized-, personalized- or design-based learning) (Dai, 2024; Ruth & İbrahim, 2025). Many K–12 based works emphasize hands-on experiences (camps, workshops, robotics, unplugged activities) as effective for building understanding and attitudes toward AI. Evidence syntheses generally report positive or moderate effects on learning outcomes and/or motivation, while also noting variability by tools, activity types, and evaluation methods (Garzón et al., 2025; Kim & Kwon, 2025).

At higher education and teacher education levels, AI is frequently portrayed as improving instructional efficiency, feedback, and personalization, yet several studies caution that benefits depend on teacher capability, curriculum coherence, and assessment integrity (Adıgüzel et al., 2026; Çela et al., 2025; Dubey & Crevar, 2025). Where AI is positioned as a curriculum co-designer (including generative AI), effectiveness is paired with warnings about hallucination/accuracy, plagiarism, and the need for human oversight (Bektik et al., 2024). In brief, pedagogical gains are commonly reported, especially for engagement and higher-order skills, but are repeatedly described as contingent on equity of access, ethical safeguards, and teacher preparedness (Bektik et al., 2024; Ruth & İbrahim, 2025).

3.2.4. Inclusivity and Accessibility: Equity as Both a Goal and a Constraint

Across the reviewed literature, AI-inclusivity is treated in two ways: first as an inclusion enabler through personalization, accessibility supports, Universal Design for Learning alignment, flexible pacing, and assistive affordances (Han, 2026; Tahura et al., 2026; Kohnke & Zaugg, 2025), and second as an equity risk due to digital divides, uneven infrastructure, cost barriers, and differential teacher readiness (Juyal et al., 2025; Li et al., 2024; Xiao et al., 2025).

Many papers explicitly highlight the digital divide (devices, connectivity, data access) as a core limiter of equitable AI literacy, cautioning that AI integration can magnify existing inequalities unless addressed through policy and investment (Juyal et al., 2025; Li et al., 2024; Xiao et al., 2025). Others extend equity beyond access to include cultural relevance, decolonization, and epistemic justice, arguing curriculum should reflect local contexts and diverse identities (Westover, 2025). To sum, inclusivity is widely positioned as non-negotiable, but most studies imply it requires system supports (infrastructure, governance, training, accessible design) rather than relying only on classroom-level good intentions (Li et al., 2024; Tahura et al., 2026; Westover, 2025).

3.2.5. Ethical and Equity Considerations: Privacy, Bias, Integrity, and Human Agency

Ethics appears as a unifying thread, though also standing out as a theme in its own right. Common focal points include:

- Data privacy/ownership and student protection (Baek & Wilson, 2024; Boumediene & Bouakkaz, 2025).
- Algorithmic bias and fairness plus mitigation strategies (Deckker et al., 2025; Kohnke & Zaugg, 2025; Ruth & İbrahim, 2025; Zhu & Fu, 2025).
- Academic integrity and transparency, especially in AI-driven assessment and generative AI use (Bektik et al., 2024).
- Human-centered AI and agency, emphasizing students' role in questioning, contextualizing, and governing AI use (Stolpe & Hallström, 2024).

A notable pattern is that ethics is rarely framed as a standalone unit. Many studies argue for ethics-infused pedagogy embedded in projects, dilemmas, reflective practice, and socio-technical reasoning (Tadimalla & Maher, 2024). In this framing, ethical competence is part of "what it means" to be AI literate (Casal-Otero et al., 2023; Chiu et al., 2024; Wang & Lester, 2023). Briefly stated, the ethical agenda is converging on privacy, bias/fairness, integrity and human-centered governance, with repeated calls for clear policies, transparency, and responsible implementation (Baek & Wilson, 2024; Zhu & Fu, 2025).

3.3. Strengths and Weaknesses of AI in Education

3.3.1. Personalized Learning and Adaptive Instruction

Across K–12 and higher education, AI-enabled adaptive platforms and intelligent tutoring systems are consistently associated with better tailoring of content and pacing, higher engagement, and improved performance, with added inclusivity benefits for varied learning styles and abilities (Deckker et al., 2025; Juyal et al., 2025; Ruth & İbrahim, 2025; Salendab et al., 2026; Xiao et al., 2025). However, benefits can be uneven where infrastructure and affordability constrain access, risking widened

disparities; there are also concerns that heavy dependence on AI may reduce human interaction and weaken critical thinking if pedagogy becomes "automation-led" rather than teacher-guided (Li et al., 2024; Zhu & Fu, 2025).

3.3.2. Curriculum Design and Integration Frameworks

The literature offers multiple integration frameworks emphasizing interdisciplinary design, alignment with existing curricula, and AI literacy as a multiliteracy spanning technical, conceptual, and socio-ethical competencies (Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). That said, many curriculum efforts remain fragmented, that's, lacking standardization, consistent thematic coverage, and sufficient treatment of societal/ethical implications. Disagreement (or absence) around shared AI literacy definitions and competency benchmarks continues to impede coherent curriculum development and comparability across contexts (Casal-Otero et al., 2023; Chiu et al., 2024; Michaeli et al., 2022).

3.3.3. Educator Preparedness and Professional Development

Studies repeatedly identify teacher learning (e.g., strengthening TPACK and assessment/pedagogy for AI) as pivotal for successful implementation, with well-designed programs improving educators' capacity to teach AI concepts and facilitate ethical discussion (Black et al., 2024; Fissore et al., 2024; Suna et al., 2025; Yau et al., 2023). However, a persistent skills-confidence-resource gap remains; many teachers report limited AI knowledge, insufficient instructional materials, and weak institutional support, particularly where infrastructure and professional learning ecosystems are underdeveloped (Addo, 2023).

3.3.4. Ethical Considerations and Equity

Ethical issues such as privacy, bias, fairness, and responsible use are widely recognized as essential curriculum content, with growing attention to embedding ethical reasoning and critical awareness into AI learning experiences (Krakowski et al., 2022; Stolpe & Hallström, 2024; Tahura et al., 2026; Yadav, 2024). Unfortunately, implementation lags behind aspiration: many educational AI systems remain opaque, insufficiently inclusive, and vulnerable to reproducing bias. Governance and policy frameworks for ethical AI in education are often described as incomplete or immature, limiting enforceable safeguards and accountability (Li et al., 2024; Yadav, 2024; Zhu & Fu, 2025).

3.3.5. Impact on Critical Thinking, Creativity, and Problem-Solving

Evidence suggests AI can support higher-order skills, especially when used in project-based learning, simulations, and STEAM/technology education contexts that require authentic inquiry and iterative design (Espinoza, 2026; Kotsari & Smyrnaiou, 2025; Ruth & İbrahim, 2025). The same tools though may erode these skills if used

uncritically (e.g., substituting AI output for reasoning), encouraging passive consumption and shallow engagement rather than student-led inquiry and creative struggle (Deckker et al., 2025; Zhu & Fu, 2025).

3.3.6. Methodological Rigor and Research Gaps

The evidence base is methodologically diverse (systematic reviews, empirical studies, case analyses), with some work providing robust quantitative indicators of positive effects on learning outcomes (Familoni & Onyebuchi, 2024). Common limitations include small samples, short interventions, limited longitudinal tracking, and reliance on self-reported outcomes, which constrains generalizability and makes long-term impact claims uncertain, thereby supporting calls for larger-scale, longer-term, and more rigorous designs (Animashaun et al., 2024; Kim & Kwon, 2025; Okolo, 2024; Rizvi et al., 2023).

3.3.7. Technological Tools and Resources

A broad ecosystem of tools (tutors, chatbots, adaptive systems, analytics) is reported to improve efficiency, feedback quality, and personalization, often positioned as support for diverse learners and teachers' workload management (Kwid et al., 2024). Tool integration though is frequently hindered by interoperability issues, technical constraints, and insufficient teacher support; equity problems persist because infrastructure gaps limit deployment and sustained use, especially in under-resourced contexts (Li et al., 2024; Perse, 2025).

3.4. Ongoing Discussions on AI in Education

Most studies concur on the importance and benefits of integrating AI into education, highlighting its role in enhancing personalized learning, inclusivity, and adaptive curriculum design. There is broad consensus that ethical considerations and teacher preparedness are critical challenges to address for successful AI adoption. However, divergences exist regarding the depth of AI integration in curricula, with some studies emphasizing technical skills while others advocate for interdisciplinary and socio-ethical approaches. Disparate contexts, educational levels, and methodological focuses contribute to variations in reported challenges and implementation strategies. Below is a summary list of contemporary areas of discussion pertaining to the AI integration in education.

3.4.1. AI Literacy, Educator Preparedness and Perceptions

Teacher readiness, confidence, and attitudes are consistently identified as decisive for successful AI integration; professional development and scaffolded support are repeatedly recommended (Addo, 2023; Black et al., 2024; Fissore et al., 2024; Suna et al., 2025; Yue et al., 2024). Other work highlights substantial gaps in AI knowledge and confidence that can contribute to resistance or superficial/ineffective use, with

perceived workload and technology acceptance varying across contexts (Masih et al., 2025). Differences are plausibly driven by variability in teacher education programs, institutional resourcing and infrastructure, and cultural norms shaping technology adoption and workload expectations.

3.4.2. Curriculum Integration Depth

Many studies support embedding AI literacy and tools in education, explicitly pairing technical learning with ethical understanding, and using either cross-curricular integration or standalone AI subject structures to build computational thinking and problem-solving (Casal-Otero et al., 2023; Heo, 2025; Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024; Weng et al., 2024). Some papers prioritize AI as a discrete technical discipline (often CS/higher education), while others foreground socio-technical, interdisciplinary integration (Aliabadi et al., 2023; Michaeli et al., 2022; Mishra & Siy, 2020; Tadimalla & Maher, 2024). Differences are largely attributable to educational level (K–12 vs higher education), regional policy expectations, and disciplinary traditions (technical specialization vs interdisciplinary literacy).

3.4.3. Pedagogical Effectiveness

AI is frequently reported to improve engagement and learning outcomes via adaptive/personalized platforms and project-based, collaborative learning designs; hands-on, scaffolded, and human–AI collaboration approaches are repeatedly positioned as effective (Dai, 2024; Deckker et al., 2025; Ruth & İbrahim, 2025). Some studies warn that uncritical or heavy reliance on AI may weaken critical thinking/creativity, and others flag implementation issues such as insufficient formative feedback or instructional fit (Akram et al., 2022; Masih et al., 2025). Reported effectiveness varies with pedagogical design quality, duration/intensity of interventions, and the measures used to assess learning (e.g., short-term performance vs deeper reasoning outcomes). On the other hand, it should be noted that studies with counter arguments imply critical insights. Contrary to the 'cognitive atrophy' hypothesis, emerging research suggests that when AI is integrated as a 'digital scaffold,' it actually catalyzes higher-order critical thinking by automating procedural redundancies and providing real-time, personalized formative feedback that encourages students to move beyond rote memorization into complex, iterative problem-solving (Gerlich, 2025; Magwa, 2026; Patrick et al., 2025; Yang & Niu, 2026).

3.4.4. Inclusivity and Accessibility

Many sources frame AI as a lever for inclusion, that is, supporting diverse learners, accessibility needs, and equity goals, often recommending Universal Design for Learning-aligned approaches (Han, 2026; Kohnke & Zaugg, 2025; Motta et al., 2025; Tahura et al., 2026). Persistent evidence of uneven access and digital divides,

particularly in under-resourced schools and developing regions, challenges equitable implementation (Li et al., 2024; Masih et al., 2025; Westover, 2025). Socioeconomic conditions, infrastructure and connectivity constraints, and policy/investment gaps shape whether AI inclusion benefits are realized at scale.

3.4.5. Ethical and Equity Considerations

Ethical issues such as privacy, bias, transparency, and responsible use are treated as central to AI adoption, with broad support for integrating ethics alongside technical instruction (Boumediene & Bouakkaz, 2025; Krakowski et al., 2022; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024; Yadav, 2024). Some studies argue ethics remains under-implemented in practice, and others emphasize that teacher capacity to facilitate ethical discussion is a limiting factor (Suna et al., 2025). Variation reflects differing policy maturity and governance, uneven educator preparation, and whether a study focuses on ethical ideals/frameworks versus classroom enactment.

4. Discussion

4.1. Theoretical and Practical Implications

4.1.1. Theoretical Implications

The integration of AI into education supports the evolving conceptualization of technological literacy as a multiliteracy that includes technical skills, technological scientific knowledge, and socio-ethical understanding. This aligns with frameworks emphasizing AI literacy as encompassing both technical competencies and ethical considerations (Casal-Otero et al., 2023; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). AI's role in fostering critical thinking, creativity, and problem-solving within STEAM and STEM education confirms constructivist and learner-centered pedagogical theories, highlighting AI as a tool that enables personalized and adaptive learning experiences (Espinoza, 2026; Kotsari & Smyrnaiou, 2025; Ruth & İbrahim, 2025).

The findings underscore the necessity of a transdisciplinary and holistic approach to AI education, integrating AI concepts across curricula rather than isolating them as standalone subjects. This challenges traditional disciplinary boundaries and supports theories advocating for interdisciplinary learning to address complex real-world problems (Aliabadi et al., 2023; Casal-Otero et al., 2023; Michaeli et al., 2022). Ethical considerations and equity issues in AI adoption emphasize the importance of embedding responsible AI principles within educational frameworks, supporting theoretical models that advocate for fairness, transparency, and inclusivity in technology-enhanced learning (Revolusi & Febriandy, 2025; Tian, 2024).

The evolving role of educators in AI-enhanced classrooms, shifting from knowledge transmitters to facilitators and ethical guides, aligns with socio-constructivist theories and highlights the importance of teacher agency in mediating AI's impact on learning (Grubaugh & Levitt, 2023; Ramakrishnan et al., 2024). The limited empirical assessment of AI learning outcomes, especially in K-12 settings, points to a theoretical gap in understanding how AI literacy develops cognitively and affectively, suggesting a need for more rigorous, longitudinal research designs (Bulut et al., 2026; Casal-Otero et al., 2023; Rizvi et al., 2023; Yue et al., 2022).

4.1.2. Practical Implications

AI integration in education necessitates comprehensive teacher professional development programs that enhance AI literacy, pedagogical skills, and ethical awareness to ensure effective curriculum implementation and instructional practices (Black et al., 2024; Fissore et al., 2024; Yue et al., 2024). Policymakers and educational institutions should prioritize equitable access to AI technologies and infrastructure to mitigate digital divides and ensure all learners benefit from AI-enhanced personalized learning environments (Li et al., 2024; Masih et al., 2025; Westover, 2025). An elaboration-worthy point also lies in teacher position (teacher agency) and defining, measuring and assessing learning outcomes. As artificial intelligence increasingly assumes the burden of content delivery and procedural feedback, the teacher's necessity is reaffirmed not as a distributor of information but as a pedagogical orchestrator and socio-emotional anchor who provides the ethical mentorship and diagnostic intervention that machines cannot replicate, thereby necessitating a radical shift in educational assessment from the measurement of static, AI-reproducible final products toward the evaluation of the iterative, process-based competencies and critical literacies essential for navigating an automated world (OECD, 2026).

Curriculum designers are encouraged to adopt adaptive, learner-centered frameworks that leverage AI-driven tools for personalized content delivery, real-time feedback, and formative assessment, thereby improving student engagement and academic outcomes (Anbumaheshwari et al., 2026; Animashaun et al., 2024). The co-design of AI curricula with educators across disciplines fosters relevance, inclusivity, and practical applicability, supporting scalable and context-sensitive AI education models that address diverse learner needs (Li et al., 2024; Lin & Van Brummelen, 2021). Ethical guidelines and governance frameworks must be established to address data privacy, algorithmic bias, and academic integrity concerns, ensuring responsible AI use in educational settings and maintaining trust among stakeholders (Baek & Wilson, 2024; Revolusi & Febriandy, 2025; Yadav, 2024). Industry-academia collaborations and mentorship programs can enhance AI education by providing real-world applications, resources, and support, thereby bridging the gap between educational outcomes and workforce demands (Chklovski et al., 2021; Crevar et al., 2026; Saddam & Hasan, 2024).

4.2. Summary of Research Limitations and Future Priorities

4.2.1. Limitations

Research in AI-in-education faces several interconnected challenges that limit the generalizability and depth of current findings. Methodologically, many studies suffer from small sample sizes that reduce statistical power and confidence in replication (Alvarez et al., 2022; Rizvi et al., 2023; Yue et al., 2022), a lack of longitudinal data to track long-term impacts (Deckker et al., 2025; Leddy & Creanor, 2024; Masih et al., 2025), and an insufficient assessment of learning outcomes that relies too heavily on self-reported or qualitative data rather than objective measures (Casal-Otero et al., 2023; Rizvi et al., 2023; Yue et al., 2022). These issues are compounded by geographic bias and technological infrastructure gaps, which concentrate evidence in well-resourced regions and hinder global transferability (Casal-Otero et al., 2023; Heo, 2025; Li et al., 2024; Masih et al., 2025; Song et al., 2022). Furthermore, implementation is often hampered by under-addressed teacher preparedness (Fissore et al., 2024; Motta et al., 2025; Suna et al., 2025; Yue et al., 2024) and a lack of standardized curriculum frameworks, making it difficult to compare results across fragmented literacy definitions (Casal-Otero et al., 2023; Lee & Kwon, 2024; Zhou et al., 2022). Finally, the field must contend with inconsistently treated ethical considerations (Deckker et al., 2025; Revolusi & Febriandy, 2025; Xiao et al., 2025; Yadav, 2024), concerns regarding learner passivity and overreliance on AI tools (Leddy & Creanor, 2024; Masih et al., 2025), and limited interdisciplinary approaches that often isolate research within computer science at the expense of holistic socio-ethical integration (Aliabadi et al., 2023; Mishra & Siy, 2020; Tadimalla & Maher, 2024).

4.2.2. Future Priorities

To advance AI education, researchers and practitioners must bridge several critical gaps by prioritizing the standardization of AI literacy frameworks to create validated, interdisciplinary competencies across K–12 and higher education (Casal-Otero et al., 2023; Chiu et al., 2024; Stolpe & Hallström, 2024). This effort requires addressing educator preparedness through scalable, context-sensitive professional development (Black et al., 2024; Chiu et al., 2024; Fissore et al., 2024; Yue et al., 2024) and moving beyond theoretical discussions of ethical AI integration to implement practical governance and pedagogical models for bias mitigation (Baek & Wilson, 2024; Krakowski et al., 2022; Tadimalla & Maher, 2024; Yadav, 2024). Bridging the digital divide to ensure equitable access necessitates longitudinal tracking of infrastructure disparities and the development of low-cost tools (Juyal et al., 2025; Kohnke & Zaugg, 2025; Li et al., 2024; Perse, 2025), while shifting away from short-term studies toward longitudinal research that measures cognitive and affective outcomes across diverse

populations (Kim & Kwon, 2025; Okolo, 2024; Rizvi et al., 2023). Future work should also foster interdisciplinary integration that embeds AI across the humanities and sciences (Aliabadi et al., 2023; Mertala et al., 2024; Tadimalla & Maher, 2024) while maintaining a human-centered pedagogy that protects critical thinking and social-emotional learning from AI overreliance (Asy'ari & Sharov, 2024; Masih et al., 2025; Zhu & Fu, 2025). Furthermore, it is essential to adapt curricula for diverse and marginalized learners using inclusive design (Albert & Son, 2026; Han, 2026; Kohnke & Zaugg, 2025; Tahura et al., 2026), resolve usability and integration challenges through user-centered design (Annuš, 2024; Kwid et al., 2024; Lin & Van Brummelen, 2021), and develop robust AI-enabled assessment and feedback mechanisms to support real-time instructional decision-making (Akram et al., 2022; Dai, 2024; Okolo, 2024).

Conclusion and Overall Synthesis

The collective body of literature illustrates that integrating artificial intelligence into education fundamentally transforms curricular design, pedagogical approaches, and learner engagement across educational levels. AI's capacity to enable personalized, adaptive, and learner-centric instruction emerges as a central theme, effectively enhancing student motivation, critical thinking, creativity, and problem-solving skills. This tailored approach not only addresses diversity in learner cognition but also promotes inclusivity by supporting marginalized groups and learners with disabilities. However, the promise of personalization is tempered by persistent challenges related to digital equity, infrastructure limitations, and varying degrees of educator preparedness, which may inadvertently widen educational disparities if unaddressed.

Curriculum integration of AI is recognized as a multifaceted endeavor, requiring interdisciplinary frameworks that encompass technical competencies, socio-ethical understanding, and conceptual AI literacy. The literature underscores the importance of embedding ethics education alongside technical content to foster responsible AI use and critical societal awareness. Although several curriculum models and frameworks have been proposed, the lack of standardization and modular, scalable AI curricula remains a significant obstacle to widespread and coherent adoption. Teacher involvement in curriculum co-design is identified as essential to ensure curricular relevance, adaptability across disciplines, and effective pedagogy.

Educator readiness is another critical factor shaping AI integration success. While teachers generally express positive attitudes toward AI's educational potential, many report insufficient knowledge, skills, and access to resources needed for effective implementation. Professional development programs that build technological pedagogical content knowledge and ethical awareness are imperative for

empowering educators as facilitators of AI literacy and ethical instruction. Collaborative and sustained training initiatives, coupled with institutional support, are necessary to bridge these gaps.

Ethical and equity concerns permeate the discourse around AI in education. Issues such as data privacy, algorithmic bias, transparency, and fairness require systematic attention through policy development and curriculum design to prevent exacerbation of existing inequalities. Human-centered AI approaches and inclusivity principles, including Universal Design for Learning, are advocated to guide ethical AI deployment in educational contexts.

Overall, AI's integration into education holds transformative potential, fostering dynamic, personalized, and equitable learning experiences. Realizing this potential demands comprehensive frameworks that harmonize curriculum innovation, educator preparedness, ethical safeguards, and infrastructural equity. Future research should focus on longitudinal impacts, scalable implementation strategies, and nuanced assessments to deepen understanding and optimize AI's role in preparing learners for an AI-driven future.

References

Addo, S. A. (2023). Are you ready to teach AI in schools? Teachers' perspectives of teaching AI in K-12 settings. In *Proceedings of the 2023 conference on United Kingdom & Ireland computing Education research, Ukicer 2023.* https://doi.org/10.1145/3610969.3610973

Adiguzel, T., Kaya, M. H., Bulut, M. A., Mete, S. E., & Nalkesen-Akin, Y. (2023). Integrating cognitive presence strategies: A professional development training for K-12 teachers. *Contemporary Educational Technology*, *15*(2), ep417. https://doi.org/10.30935/cedtech/12987

Adıgüzel, T., Aşık, G., Bulut, M. A., Kaya, M. H., & Özel, S. (2023). Teaching self-regulation through role modeling in K-12. In *Frontiers in education*. *Frontiers Media SA*, *8*, 1105466. https://doi.org/10.3389/feduc.2023.1105466

Adıgüzel, T., Kaya, M.H., Bulut, M.A. (2026). Artificial Intelligence and Educational Leadership: A Bibliometric Analysis (2004-2024) and Global Policy Review. *Revísta Espanola de Pedagogía*. 1-43

Akram, B., Yoder, S., Tatar, C., Boorugu, S., Aderemi, I., & Jiang, S. (2022). Towards an AI-Infused Interdisciplinary Curriculum for Middle-Grade Classrooms. *Proceedings of the AAAI Conference on Artificial Intelligence*, *36*(11), 12681–12688. https://doi.org/10.1609/aaai.v36i11.21544

Albert, L. R. & Son, K. (2026). Culturally Sustaining Pedagogy and Artificial Intelligence: Reimagining Mathematical Curriculum Knowledge. In K. Terrell & D. Silva Pimentel (Eds.), *Culturally Sustaining Pedagogies in Mathematics and Technology Education: Research, Practices, and Critical Reflections* (pp. 95-122). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-5337-1.ch004

Aliabadi, R., Singh, A., & Wilson, E. (2023). Transdisciplinary AI education: The confluence of curricular and community needs in the instruction of artificial intelligence. In *International conference on artificial intelligence in education technology* (pp. 137-151). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-7947-9_11

Alvarez, L., Gransbury, I., Cateté, V., Barnes, T., Ledeczi, A., & Grover, S. (2022). A socially relevant focused AI curriculum designed for female high school students. *Proceedings of the... AAAI Conference on Artificial Intelligence*, 36 (11), 12698-12705. https://doi.org/10.1609/aaai.v36i11.21546

Anbumaheshwari, K., Jayalakshmi, J., & Pavunraj, D. (2026). AI-Driven Curriculum Innovation for Adaptive and Learner-Centric Education. In A. Asrifan (Ed.), *Advancing Society 5.0 Through AI-Driven Curriculum Innovation* (pp. 99-132). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-1062-6.ch004

Animashaun, E. S., Familoni, B. T., & Onyebuchi, N. C. (2024). Advanced machine learning techniques for personalising technology education. *Computer Science & IT Research Journal*, *5*(6), 1300-1313. https://doi.org/10.51594/csitrj.v5i6.1198

Annuš, N. (2024). Education in the age of artificial intelligence. *TEM Journal*, *13*(1), 404-413. https://doi.org/10.18421/tem131-42

Asy'ari, M., & Sharov, S. (2024). Transforming Education with ChatGPT: Advancing Personalized Learning, Accessibility, and Ethical AI Integration. *International Journal of Essential Competencies in Education*, *3*(2), 119-157. https://doi.org/10.36312/ijece.v3i2.2424

Baek, E. O. & Wilson, R. V. (2024). An Inquiry Into the Use of Generative AI and Its Implications in Education: Boon or Bane. *International Journal of Adult Education and Technology (IJAET), 15*(1), 1-14. https://doi.org/10.4018/IJAET.349233

Bektik, D., Ullmann, T. D., Edwards, C., Herodotou, C., & Whitelock, D. (2024). AI-Powered curricula: unpacking the potential and progress of generative technologies in education. *Ubiquity Proceedings*, *4*(1). https://oro.open.ac.uk/98012/

Birgili, B., Bulut, M. A., Gülünay, O., Koçoğlu, M., & Baş, F. R. (2025). Technology-enhanced GipSci approach in developing contexts performs well at interest and curiosity, yet, needs reinforcing at inquiry level. *Research in Science & Technological Education*, 1–38. https://doi.org/10.1080/02635143.2025.2578303

Black, N. B., George, S., Eguchi, A., Dempsey, J. C., Langran, E., Fraga, L., … Howard, N. (2024). A Framework for Approaching AI Education in Educator Preparation Programs. *Proceedings of the AAAI Conference on Artificial Intelligence*, *38*(21), 23069–23077. https://doi.org/10.1609/aaai.v38i21.30351

Boumediene, H. & Bouakkaz, M. (2025). Artificial Intelligence in Education: Emerging Trends, Ethical Considerations, and Future Directions. In E. Cela, N. Vajjhala, & M. Fonkam (Eds.), *Next-Generation AI Methodologies in Education* (pp. 407-438). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-7220-3.ch014

Braun, V., & Clarke, V. (2012). Thematic analysis. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological* (pp. 57–71). American Psychological Association. https://doi.org/10.1037/13620-004

Bulut, M. A., Adıgüzel, T., & Kaya, M. H. (2025). Exploring views and experiences of faculty members' participation in an asynchronous online program: Using a micro-learning format and cop framework. *Innovations in Education and Teaching International*, 1–17. https://doi.org/10.1080/14703297.2025.2532056

Bulut, M. A., Koçoğlu, M., Baş, F. R., Gülünay, O., & Birgili, B. (2026). Techno-philosophical and techno-pedagogical implications of a nonformal technology and design education model to empower youth: T3 foundation's DENEYAP technology workshops program. *International Journal of Technology and Design Education*, *36*, 1047–1082. https://doi.org/10.1007/s10798-025-10055-6

Bulut, M. A. (2026). "Aidemics" examined analytically through the connectivist theory: institutional AI-Mediation in higher education via an artificial intelligence center (CILT-AI). *Interactive Learning Environments*, *34*(2), 972–1001. https://doi.org/10.1080/10494820.2026.2647982

Bulut, M. A., Kaya, N., Ortak, A., & Akan Baghirli, S. N. (2026). Yapay Zeka Sistemleri ve İnsan İşbirliğinin Psikolojik, Sosyal ve Eğitsel Etkileri. *Erzurum Teknik Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *25*, 92-106. https://doi.org/10.29157/etusbed.1794583

Çela, E., Fonkam, M. M., Vajjhala, N. R., & Vedishchev, A. (2025). Artificial Intelligence in Education: Foundations, Trends, and Implications. In E. Cela, N. Vajjhala, & M. Fonkam (Eds.), *Next-Generation AI Methodologies in Education* (pp. 1-20). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-7220-3.ch001

Casal-Otero, L., Catala, A., Fernández-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023). AI literacy in K-12: a systematic literature review. *International Journal of STEM Education*, *10*(1), 29. https://doi.org/10.1186/s40594-023-00418-7

Chiu, T. K., Ahmad, Z., Ismailov, M., & Sanusi, I. T. (2024). What are artificial intelligence literacy and competency? A comprehensive framework to support them. *Computers and Education Open*, *6*, 100171. https://doi.org/10.1016/j.caeo.2024.100171

Chklovski, T., Jung, R., Anderson, R., & Young, K. (2021). Comparing 2 years of empowering families to solve real-world problems with AI. *KI-Künstliche Intelligenz*, *35*(2), 207-219. https://doi.org/10.1007/S13218-021-00738-2

Crevar, A. R., Dubey, P. K., & Rischard, M. (2026). Artificial Intelligence and the Transformation of Career Technical Education. In V. Wang (Ed.), *AI Applications and Pedagogical Innovation* (pp. 49-76). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-5092-9.ch002

Dai, Y. (2024). Dual-contrast pedagogy for AI literacy in upper elementary schools. *Learning and Instruction*, *91*, 101899. https://doi.org/10.1016/j.learninstruc.2024.101899

Deckker, D., Sumanasekara, S., & Fakhrou, A. (2025). AI-Powered Personalised Learning: Promise and Pitfalls. *World Journal of Advanced Research and Reviews*, *26*(3), 2081-2095. https://doi.org/10.30574/wjarr.2025.26.3.2425

Dubey, P. K. & Crevar, A. R. (2025). Integrating Artificial Intelligence in Higher Education: Enhancing Pedagogy, Instruction, and Administration. In V. Wang (Ed.), *AI Integration Into Andragogical Education* (pp. 181-208). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-0502-8.ch008

Espinoza, M. (2026). AI and the Future of STEM Education: Transforming Pedagogy, Curriculum, and Workforce Readiness. In V. Wang (Ed.), *AI, Personalization, Equity, and the Future of Learning* (pp. 237-264). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-5097-4.ch008

Familoni, B. T., & Onyebuchi, N. C. (2024). Advancements and challenges in AI integration for technical literacy: A systematic review. *Engineering Science & Technology Journal*, *5*(4), 1415-1430. https://doi.org/10.51594/estj.v5i4.1042

Fissore, C., Floris, F., Conte, M. M., & Sacchet, M. (2024). Teacher training on artificial intelligence in education. In *Smart learning environments in the post pandemic era: Selected papers from the CELDA 2022 conference* (pp. 227-244). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-54207-7_13

Garzón, J., Patiño, E., & Marulanda, C. (2025). Systematic Review of Artificial Intelligence in Education: Trends, Benefits, and Challenges. *Multimodal Technologies and Interaction*, *9*(8), 84. https://doi.org/10.3390/mti9080084

Gerlich, M. (2025). AI Tools in Society: Impacts on Cognitive Offloading and the Future of Critical Thinking. *Societies*, *15*(1), 6. https://doi.org/10.3390/soc15010006

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health information & libraries journal*, *26*(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Greenhalgh, T., Thorne, S., & Malterud, K. (2018). Time to challenge the spurious hierarchy of systematic over narrative reviews?. *European journal of clinical investigation*, *48*(6), e12931. https://doi.org/10.1111/eci.12931

Grubaugh, S., & Levitt, G. (2023). Artificial intelligence and the paradigm shift: Reshaping education to equip students for future careers. *International Journal of Social Sciences and Humanities Invention*, *10*(6), 7931-7941. https://doi.org/10.18535/ijsshi/v10i06.02

Han, P. (2026). Artificial Intelligence in Education: Supporting Diverse Learning Styles and Addressing Ethical Considerations. In V. Wang (Ed.), *Emerging Trends, Global Perspectives, and Systemic Transformation in AI* (pp. 387-408). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-5102-5.ch014

Heo, J. (2025). Exploring Research Trends For Proposing Ai-Based Curriculum Development Models. *Educational Research*, *44*(3), 811-837. https://doi.org/10.34245/Jed.44.3.837

Juyal, P., Gundecha, A., Singh, M., Tiwari, A. K., Singh, R. P., & Rani, R. (2025). Transforming education through AI: Adaptive learning for a personalized digital future. *International journal of environmental sciences*, 818-824. https://doi.org/10.64252/9v2y4r84

Karanfiloğlu, M., & Bulut, M. A. (2025). Techno-pedagogical communication, ed-tech and media professionals: Crossroads for enhancing instructional quality. *Interactive Learning Environments, 33*(7), 4193–4217. https://doi.org/10.1080/10494820.2025.2459180

Kim, K., & Kwon, K. (2025). A systematic review of the evaluation in K-12 artificial intelligence education from 2013 to 2022. *Interactive Learning Environments*, *33*(1), 103-131. https://doi.org/10.1080/10494820.2024.2335499

Kohnke, S., & Zaugg, T. (2025). Artificial Intelligence: An Untapped Opportunity for Equity and Access in STEM Education. *Education Sciences*, *15*(1), 68. https://doi.org/10.3390/educsci15010068

Kotsari, K., & Smyrnaiou, Z. (2025). Fostering Creativity and Inclusion: Integrating Constructionist Learning with Artificial Intelligence for Special Education. In *Constructionism Conference Proceedings* (Vol. 8, pp. 543-545). https://doi.org/10.21240/constr/2025/116.x

Krakowski, A., Greenwald, E., Hurt, T., Nonnecke, B., & Cannady, M. (2022). Authentic Integration of Ethics and AI through Sociotechnical, Problem-Based Learning. *Proceedings of the AAAI Conference on Artificial Intelligence*, *36*(11), 12774–12782. https://doi.org/10.1609/aaai.v36i11.21556

Kwid, G., Sarty, N., & Yang, D. (2024). A Review of AI Tools: Definitions, Functions, and Applications for K-12 Education. AI, Computer Science and Robotics Technology, 3. https://doi.org/10.5772/acrt.20240048

Leddy, M., & Creanor, N. M. (2024). Exploring how education can leverage artificial intelligence for social good. *Proceedings of the European Conference on Innovation and Entrepreneurship, ECIE*, 19 (1), 1041-1048. https://doi.org/10.34190/ecie.19.1.2906

Lee, S. J., & Kwon, K. (2024). A systematic review of AI education in K-12 classrooms from 2018 to 2023: Topics, strategies, and learning outcomes. *Computers and Education: Artificial Intelligence*, *6*, 100211. https://doi.org/10.1016/j.caeai.2024.100211

Li, L., Yu, F., & Zhang, E. (2024). A systematic review of learning task design for K-12 AI education: Trends, challenges, and opportunities. *Computers and Education: Artificial Intelligence*, *6*, 100217. https://doi.org/10.1016/j.caeai.2024.100217

Lim, M. (2024). Developing a Framework for the Integration of Artificial Intelligence in Technology Education: Enhancing Learning and Innovation. *Tehnički glasnik, 18* (2), 229-233. https://doi.org/10.31803/tg-20231212055714

Lin, P., & Van Brummelen, J. (2021). Engaging teachers to co-design integrated AI curriculum for K-12 classrooms. In *Proceedings of the 2021 CHI conference on human factors in computing systems* (pp. 1-12). https://doi.org/10.1145/3411764.3445377

Magwa, L. (2026). Artificial intelligence as a scaffolding tool for self-directed learning in ODeL environments: an instrumental case study of Zimbabwe Open University. In *Frontiers in Education* (Vol. 11, p. 1793940). Frontiers Media SA. https://doi.org/10.3389/feduc.2026.1793940

Masih, M., Suleman, S., Khan, M. H., Sahito, D. Z., & Shahid, D. S. (2025). The Future Classroom: Integrating AI and Social Media for Adaptive Learning. *Inverge Journal of Social Sciences*, *4*(3), 98–111. https://doi.org/10.63544/ijss.v4i3.150

Mertala, P., Fagerlund, J., & Dufva, T. S. (2024). Rethinking the A in STEAM: Insights from and for AI Literacy Education. *arXiv preprint arXiv:2405.18179*. https://doi.org/10.48550/arxiv.2405.18179

Michaeli, T., Romeike, R., & Seegerer, S. (2022). What students can learn about artificial intelligence–recommendations for K-12 computing education. In *IFIP World Conference on Computers in Education* (pp. 196-208). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-43393-1_19

Mishra, A., & Siy, H. (2020). An interdisciplinary approach for teaching artificial intelligence to computer science students. In *Proceedings of the 21st annual conference on information technology education* (pp. 344-344). https://doi.org/10.1145/3368308.3415440

Motta, N. B., Chiappe, A., & Sáez-Delgado, F. (2025). Bridging the gap: ai and teacher training for inclusive education 4.0. *Journal of Research in Special Educational Needs*. *25*(4), 1101-1115. https://doi.org/10.1111/1471-3802.70033

OECD (2026), *OECD Digital Education Outlook 2026: Exploring Effective Uses of Generative AI in Education*, OECD Publishing, Paris, https://doi.org/10.1787/062a7394-en.

Okolo, C. T. (2024). Beyond AI hype: A hands-on workshop series for enhancing AI literacy in middle and high school students. In *Proceedings of the 2024 on RESPECT Annual Conference* (pp. 86-93). https://doi.org/10.1145/3653666.3656075

Patrick, P. M., Yip, S. Y., & Campbell, C. (2025). Artificial Intelligence and Higher-Order Thinking: A Systematic Review of Educator and Student Experiences and Perspectives in Higher Education. *Higher Education Quarterly*, *79*(4), e70069. https://doi.org/10.1111/hequ.70069

Perse, R. J. P. (2025). Using Artificial Intelligence in High School Education: A Review. Preprints. https://doi.org/10.20944/preprints202504.1727.v1

Ramakrishnan, S., Bishnoi, M. M., Joghee, S., Jijitha, S., & Kumar, A. (2024). Social engineering: role of teachers in cohabitation of AI with education. In *2024 2nd International Conference on Cyber Resilience (ICCR)* (pp. 1-6). IEEE. https://doi.org/10.1109/iccr61006.2024.10532897

Revolusi, P., & Febriandy, R. K. (2025). Human-AI Educational Collaboration: Facing Learning Challenges in the Digital Age. *International Journal of Management, Entrepreneurship, Social Science and Humanities*, *8*(2), 289–312. https://doi.org/10.31098/ijmesh.v8i2.3229

Rizvi, S., Waite, J., & Sentance, S. (2023). Artificial Intelligence teaching and learning in K-12 from 2019 to 2022: A systematic literature review. *Computers and Education: Artificial Intelligence*, *4*, 100145. https://doi.org/10.1016/j.caeai.2023.100145

Ruth, S. I., & İbrahim, D. (2025). Enhancing steam education in the era of AI: Integrating artificial intelligence to improve critical thinking, creativity and problem-solving skills. *International Journal of Educational Research and Library Science*, *8*(8). https://doi.org/10.70382/tijerls.v08i8.052

Rüütmann, T., & Läänemets, U. (2025). Generating curricula: A human-centred perspective in the era of artificial intelligence. In *International Baltic Symposium on Science and Technology Education*. https://doi.org/10.33225/balticste/2025.180

Saddam, H. M. I., & Hasan, G. A. (2024). The best of way of using AI technology in designing technical education curriculum in meeting future industry demands: Smart way. *2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, Greater Noida, India, 2024, pp. 1403-1406. https://doi.org/10.1109/icacite60783.2024.10617225

Salendab, F. A., Cogo, D. A., Catipay, A. Z., & Millendez, G. J. T. (2026). The Role of Artificial Intelligence (AI) in Personalized Learning and Adaptive Assessments. In J. Moore, S. Gupta, M. Sharma, A. Garg, & H. Josephine V. L. (Eds.), *Transforming Education With Data Science in the AI Era* (pp. 93-122). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-2185-1.ch004

Song, J., Zhang, L., Yu, J., Peng, Y., Ma, A., & Lu, Y. (2022). Paving the Way for Novices: How to Teach AI for K-12 Education in China. *Proceedings of the AAAI Conference on Artificial Intelligence*, *36*(11), 12852–12857. https://doi.org/10.1609/aaai.v36i11.21565

Stolpe, K., & Hallström, J. (2024). Artificial intelligence literacy for technology education. *Computers and Education Open*, *6*, 100159. https://doi.org/10.1016/j.caeo.2024.100159

Suna, G., Suchismita, S., & Das, T. (2025). Integrating artificial intelligence in teacher education: A systematic analysis. *International Journal of Current Science Research and Review*, *8*(1), 33. https://doi.org/10.47191/ijcsrr/v8-i1-33

Tadimalla, S. Y., & Maher, M. L. (2024). AI literacy for all: Adjustable interdisciplinary socio-technical curriculum. In *2024 IEEE frontiers in education conference (FIE)* (pp. 1-9). IEEE. https://doi.org/10.48550/arxiv.2409.10552

Tahura, S., Kalaiyarasan, G., & Sarkar, S. R. (2026). From Exclusion to Inclusion AI as a Catalyst for Equal Access to Education. In R. Awashreh (Ed.), *Democratizing Education With AI and the Future of Personalized Learning* (pp. 29-66). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-2302-2.ch002

Tian, S. (2024). The Impact and Reconstruction of Computational Thinking on Educational Models in the Era of Artificial Intelligence. *International Journal of Education and Humanities*, *14*(3), 47-50. https://doi.org/10.54097/e2s41q04

Wang, N., & Lester, J. (2023). K-12 Education in the Age of AI: A Call to Action for K-12 AI Literacy. *International journal of artificial intelligence in education*, *33*(2), 228-232. https://doi.org/10.1007/s40593-023-00358-x

Weng, X., Ye, H., Dai, Y., & Ng, O. L. (2024). Integrating artificial intelligence and computational thinking in educational contexts: A systematic review of instructional design and student learning outcomes. *Journal of Educational Computing Research*, *62*(6), 1420-1450. https://doi.org/10.1177/07356331241248686

Westover, J. H. (2025). Digital Transformation, AI, and Inclusive Education: Creating Equitable Learning Ecosystems. Preprints. https://doi.org/10.20944/preprints202507.1274.v1

Xiao, N., Pei, Y., Yuan, C., Bu, Y., & Cai, Z. (2025). Transforming Education with Artificial Intelligence: A Comprehensive Review of Applications, Challenges, and Future Directions. *International Theory and Practice in Humanities and Social Sciences*, *2*(1), 337–356. https://doi.org/10.70693/itphss.v2i1.211

Yadav, D. S. (2024). Navigating the landscape of AI integration in education: opportunities, challenges, and ethical considerations for harnessing the potential of artificial intelligence (AI) for teaching and learning. *BSSS Journal of Computer*, *15*(1), 38-48. https://doi.org/10.51767/jc1503

Yang, J., & Niu, T. (2026). Exploring of the impact of AI feedback on college students' critical thinking: a intervention experiment based on design discipline. *Frontiers in Psychology*, *17*, 1806913. https://doi.org/10.3389/fpsyg.2026.1806913

Yau, K. W., Chai, C. S., Chiu, T. K., Meng, H., King, I., & Yam, Y. (2023). A phenomenographic approach on teacher conceptions of teaching Artificial Intelligence (AI) in K-12 schools. *Education and information technologies*, *28*(1), 1041-1064. https://doi.org/10.1007/s10639-022-11161-x

Yue, M., Jong, M. S.-Y., & Dai, Y. (2022). Pedagogical Design of K-12 Artificial Intelligence Education: A Systematic Review. *Sustainability*, *14*(23), 15620. https://doi.org/10.3390/su142315620

Yue, M., Jong, M. S. Y., & Ng, D. T. K. (2024). Understanding K–12 teachers' technological pedagogical content knowledge readiness and attitudes toward artificial intelligence education. *Education and information technologies*, *29*(15), 19505-19536. https://doi.org/10.1007/s10639-024-12621-2

Zhao,Y. (2025). The Innovation and Transformation of Education Models Driven by Artificial Intelligence—Taking Compulsory Education and Higher Education as Examples. *Applied and Computational Engineering*, 150 (1), 35-40. https://doi.org/10.54254/2755-2721/2025.22320

Zhou, Y., Zhan, Z., Liu, L., Wan, J., Liu, S., & Zou, X. (2022). International prospects and trends of artificial intelligence education: A content analysis of top-level AI curriculum across countries. In *Proceedings of the 6th international conference on digital technology in education* (pp. 337-343). https://doi.org/10.1145/3568739.3568796

Zhu, J., & Fu, L. (2025). The Latest Innovations and Dilemmas in AI Empowering Personalized Education. In *2025 5th International Conference on Artificial Intelligence and Education (ICAIE)* (pp. 245-249). IEEE. https://doi.org/10.1109/icaie64856.2025.11158694

About the Authors

Dr. Mehmet Akın BULUT
Ibn Haldun University | akin.bulut[at]ihu.edu.tr
ORCID: 0000-0002-7506-8750

Dr. Mehmet Akın Bulut is the founding director of Artificial Intelligence - Innovative Learning and Teaching Center at Ibn Haldun University. Having served as Head of the Department of Educational Sciences and Vice Dean at School of Education at Ibn Haldun University, he holds a BA in School of Education from Boğaziçi University, and a PhD in Educational Technology from Bahçeşehir University specializing in education technology, faculty development, artificial intelligence, micro-learning, MOOCs, and teacher training. Dr. Bulut has authored numerous SSCI and Scopus-indexed publications. His scholarly work is complemented by his role in managing high-impact projects funded by European Union, The Scientific and Technological Research Council of Türkiye (TÜBİTAK) and the John Templeton Foundation among many others as well as supervision of graduate students' thesis studies. His expertise spans through training across K-12, university, and corporate sectors. He is serving in the editorial board of respected journals: International Journal of Technology and Design Education (SSCI/SCIE, Q1), Interactive Learning Environments (SSCI, Q1), and the Associate Editor in SN-Social Sciences (Scopus). Dr. Bulut is among the members of renowned international technology education research centers.

Dr. Jeffrey BUCKLEY
University of the Shannon, Visiting Senior Lecturer at Linköping University
jeffrey.buckley[at]tus.ie | ORCID: 0000-0002-8292-5642

An accomplished scholar in the field of engineering education, Dr. Jeffrey Buckley serves as a Lecturer in Research Pedagogy at the Technological University of the Shannon and a Visiting Senior Lecturer at Linköping University. He earned his PhD from KTH Royal Institute of Technology in 2018, specializing in Education and Communication within the Technical Sciences. His extensive editorial leadership includes serving as Editor-in-Chief of the *International Journal of Technology and Design Education* (SSCI/SCIE Q1), and Series Editor for Springer Nature's *Emergent Directions in Engineering Education*. His research explores spatial ability in learning, adaptive comparative judgement, and gender inclusivity, alongside significant contributions to meta-research aimed at enhancing disciplinary practices. A dedicated educator, he instructs Doctoral and Master's students across diverse faculties in research methodology, academic writing, and ethics. He remains deeply committed to mentoring postgraduate students, guiding them through the complexities of their academic and research journeys with expertise and professional rigour. Dr. Buckley is the founding director of a technology education research center.