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Adaptive Management Model for the Development of AI-Based Science Learning Media and IoT in The Society 5.0 Era: A Literature Study

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Abstract: The transition from Industry 4.0 to Society 5.0 has transformed educational paradigms, particularly in science education, necessitating adaptive management approaches to integrating advanced technologies. This literature study examines the adaptive management model for developing AI and IoT-based science learning media in the Society 5.0 era. Through systematic analysis of 10 peer-reviewed articles from 2020–2025 sourced from Google Scholar, Scopus, and ERIC databases, this research identifies critical components, challenges, and opportunities in technology-integrated science education. Findings reveal that AI enables personalized science learning through adaptive algorithms and data analytics, while IoT facilitates real-time experiential learning through connected laboratory equipment and environmental sensors. The proposed adaptive management model integrates technological infrastructure, teacher competency development, curriculum alignment, and ethical considerations to create responsive science learning ecosystems. Key challenges include digital divides, infrastructure limitations, and balancing technology with humanistic educational values. This model offers significant implications for enhancing scientific literacy, experiential learning, and 21st-century skills development in science classrooms. The research contributes a conceptual framework for educational stakeholders to implement adaptive, technology-enhanced science education aligned with Society 5.0 principles.

Keywords: Adaptive management; AI-Based Learning Media; Educational technology; IoT; Learning Media; Science education; Society 5.0;

Introduction

The rapid evolution from Industry 4.0 to Society 5.0 has fundamentally transformed educational paradigms worldwide, creating both unprecedented opportunities and complex challenges for science education (Casas & Palomes, 2025; Koch et al., 2025; Luger et al., 2025). In this transition, artificial intelligence (AI) and Internet of Things (IoT) technologies have emerged as pivotal drivers of educational innovation, promising to revolutionize how scientific concepts are taught, learned, and applied (Abyaneh et al., 2025; Hossain et al., 2025; Onu et al., 2024). Unlike the technology-centric focus of Industry 4.0, Society 5.0 represents a human-centered approach that strategically integrates advanced technologies to address societal challenges while prioritizing human welfare and sustainable development (Antomarioni et al., 2025; Eriksson et al., 2024; Hussain et al., 2025).

Science education stands at the forefront of this transformation, as AI capabilities enable personalized learning pathways through sophisticated data analysis and adaptive algorithms that respond to individual student needs, while IoT facilitates authentic experiential learning through interconnected laboratory equipment and real-time environmental monitoring

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systems (Albrecht et al., 2024; Gahar et al., 2025; Hu, 2025). This technological convergence creates possibilities for more engaging, relevant, and effective science learning experiences that bridge theoretical knowledge with practical applications in real-world contexts.

However, the successful integration of these advanced technologies into science education requires more than technical implementation; it demands adaptive management frameworks that can respond to rapidly changing technological landscapes while maintaining educational quality and equity. Current research reveals significant gaps in systematic approaches to managing the development and implementation of AI and IoT-based science learning media. Many educational institutions struggle with fragmented technology adoption strategies, inadequate teacher preparation, infrastructure limitations, and insufficient attention to ethical considerations and human values (Adler et al., 2025; Hachoumi et al., 2025; Somabut et al., 2025).

The state of the art in educational technology research has primarily focused on technical capabilities and learning outcomes of individual AI or IoT applications, with limited attention to comprehensive management models that address the entire ecosystem of technology-enhanced science education in the Society 5.0 context. This gap is particularly evident in developing nations like Indonesia, where digital divides and resource constraints necessitate flexible, context-sensitive approaches to educational technology integration (Chookaew et al., 2024; Feng et al., 2025; Mahajan et al., 2025).

This literature study addresses these critical gaps by examining adaptive management models specifically designed for the development of AI and IoT-based science learning media in the Society 5.0 era. The research is guided by the following questions: What are the essential components of an adaptive management model for developing AI and IoT-based science learning media ?; How can such a model effectively balance technological innovation with humanistic educational values ?; What implementation strategies can support successful adoption across diverse educational contexts? By answering these questions, this study aims to contribute a conceptual framework that empowers educational stakeholders to navigate the complexities of technology integration while maintaining focus on holistic human development and scientific literacy enhancement.

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Method

This study employed a systematic literature review (SLR) methodology to comprehensively examine the adaptive management model for developing AI and IoT-based interactive learning media in the Society 5.0 era. The SLR approach was selected as it provides a structured, transparent, and replicable framework for identifying, evaluating, and synthesizing relevant research evidence (Azarian et al., 2023; Kitchenham et al., 2007). This methodology aligns with the need for rigorous examination of emerging educational technologies and management frameworks in rapidly evolving digital contexts.

Search Strategy and Database Selection

The literature search was conducted across multiple academic databases to ensure comprehensive coverage of relevant scholarly works. Primary databases included Google Scholar, Scopus, ERIC, DOAJ, and ScienceDirect (Gasparyan et al., 2016). These databases were selected for their extensive coverage of educational technology, science education, and management literature. The search was limited to peer-reviewed journal articles published between 2020 and 2025 to ensure the inclusion of current research aligned with the Society 5.0 paradigm.

Search Keywords and Criteria

A systematic keyword strategy was developed using Boolean operators to maximize search precision and recall (Bramer et al., 2018). The primary search string combined terms related to three conceptual domains: Adaptive management: ("adaptive management" OR "adaptive model" OR "flexible management" OR "responsive framework"); Technology integration: ("artificial intelligence" OR "AI" OR "Internet of Things" OR "IoT" OR "smart technology"); and Educational context: ("science education" OR "STEM education" OR "learning media" OR "educational technology" OR "Society 5.0")

Additional filters were applied to refine the search results: Inclusion criteria: Empirical or conceptual studies focusing on AI/IoT in education; Articles discussing management models or frameworks for educational technology implementation; Research addressing Society 5.0 or post-Industry 4.0 educational contexts; Studies published in English or Indonesian languages; Peer-reviewed journal articles from 2020-2025. Exclusion criteria: Studies focusing solely on technical aspects without educational implications; Articles without clear methodological descriptions; Conference proceedings or non-peer-reviewed publications; Research predating 2020 unless seminal works.

Article Selection Process

The article selection followed a PRISMA-style narrative process with four sequential phases: Identification: Initial database searches yielded 247 potentially relevant articles. Screening: Titles and abstracts were screened against inclusion criteria, resulting in 63 articles for full-text review. Eligibility assessment: Full-text articles were evaluated for methodological rigor and relevance to research questions, yielding 28 articles meeting all criteria. Final selection: After quality assessment and thematic analysis, 10 articles were selected for in-depth analysis based on their direct relevance to adaptive management models for AI/IoT-based science learning media development.

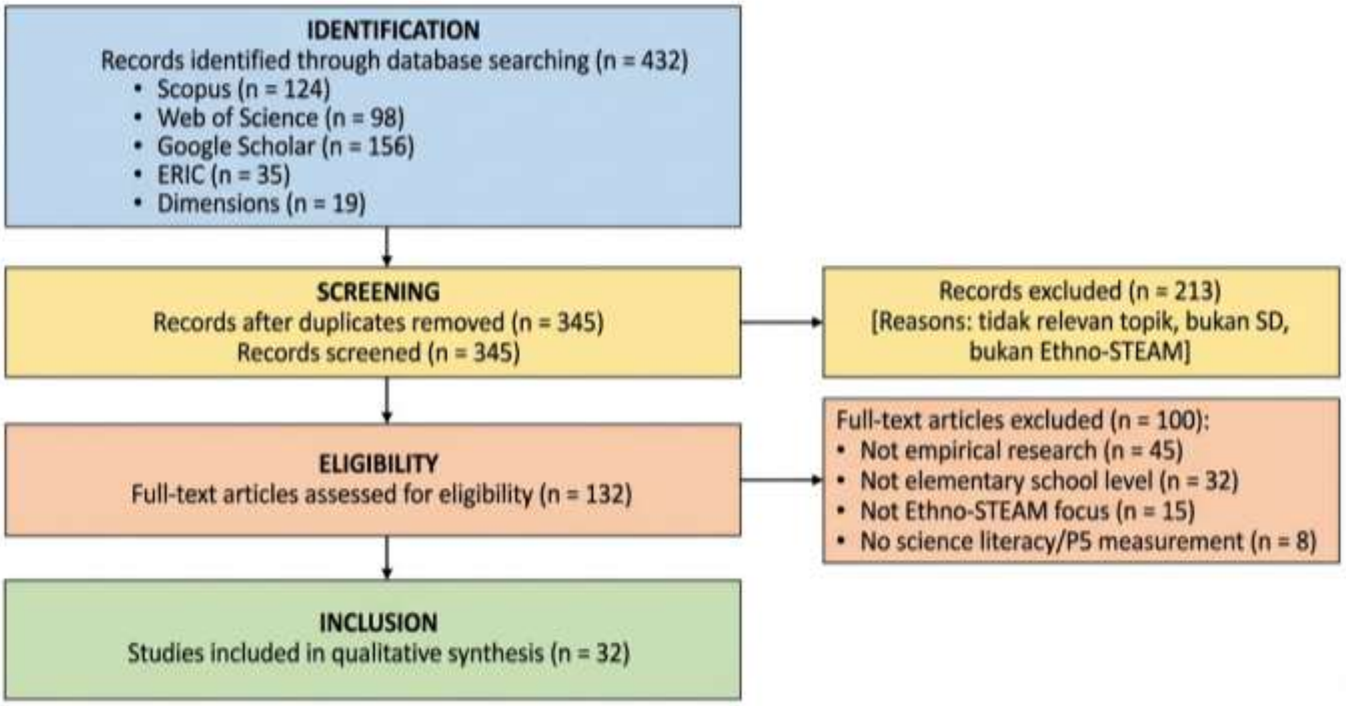

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only

Data Extraction and Analysis

A structured data extraction framework was developed to systematically capture key information from each selected article, including: research objectives, methodology, key findings, theoretical frameworks, implementation challenges, and success factors. Thematic analysis was employed to identify recurring patterns, concepts, and relationships across the literature. The analysis focused on synthesizing evidence related to: technological components of AI/IoT learning media; adaptive management frameworks; implementation challenges and opportunities; and human-technology integration principles.

The quality of included studies was assessed using criteria adapted from the CASP checklist, evaluating methodological rigor, theoretical grounding, and practical relevance. This systematic approach ensured comprehensive coverage of the research domain while maintaining analytical depth and methodological transparency.

Result and Discussion

Systematic Analysis of Literature

The systematic literature review identified ten key articles published between 2021-2025 that address adaptive management models for AI and IoT-based learning media development in the Society 5.0 era. Table 1 summarizes the core findings from these studies, revealing consistent themes regarding technological integration, management frameworks, and educational transformation.

Integration of AI and IoT in Science Learning Media

The analysis reveals that AI and IoT technologies function synergistically to transform science education. AI capabilities enable dynamic adaptation of learning content based on individual student performance data, creating personalized pathways that respond to cognitive development patterns and learning preferences. This personalization extends beyond content delivery to include adaptive assessment systems that provide immediate feedback and identify conceptual misconceptions in real-time (Chen & Dai, 2024; Firoozi et al., 2025; Qureshi et al., 2025).

Table 1. Synthesis of Literature Review Findings on Adaptive Management for AI-IoT Learning Media

Theme	Key Findings	Challenges Identified
AI Integration	Personalized learning pathways, automated administrative processes, adaptive assessment systems	Digital divide, teacher competency gaps, ethical concerns
IoT Implementation	Real-time data collection, experiential learning environments, connected laboratory equipment	Infrastructure limitations, connectivity issues, maintenance costs
Management Frameworks	Flexible decision-making systems, cross-sector collaboration, continuous evaluation cycles	Resistance to change, resource allocation conflicts, policy misalignment
Human-Technology Balance	Integration of character education, preservation of human interaction, ethical technology use	Over-reliance on technology, diminished critical thinking, social skill reduction

IoT integration complements AI by creating authentic, experiential learning environments. Sensor networks in science laboratories enable students to collect real-time environmental data, monitor biological processes, and conduct remote experiments that would otherwise be impossible in traditional classroom settings. This technological convergence bridges theoretical concepts with practical applications, making abstract scientific principles tangible and relevant to students' lived experiences (Alwakeel, 2025; Shonubi, 2025; Zhang & Yu, 2025).

The significance of this integration lies not merely in technological advancement but in its potential to democratize high-quality science education. AI-IoT systems can provide consistent, high-quality learning experiences regardless of geographical location or institutional resources, potentially reducing educational inequities that have persisted in traditional science education models (Mahajan et al., 2025; Sharafat et al., 2025; Tariq et al., 2025).

Adaptive Management Framework Components

The literature synthesis identifies four critical components of effective adaptive management frameworks for AI-IoT science learning media development.

Technological Infrastructure Flexibility: Systems must be designed with modular architecture that allows for incremental upgrades and integration with emerging technologies without complete system replacement. This flexibility ensures sustainability and cost-effectiveness while accommodating rapid technological evolution (Alazmi et al., 2025).

Human Capacity Development: Teacher preparation programs must evolve beyond technical skills to include pedagogical content knowledge specific to AI-IoT environments. The framework emphasizes continuous professional development that addresses both technological competency and pedagogical adaptation strategies (Kumar et al., 2025).

Stakeholder Collaboration Mechanisms: Successful implementation requires structured collaboration between educators, technology developers, policymakers, and community stakeholders. The framework establishes feedback loops that incorporate diverse perspectives into development and implementation processes, ensuring alignment with educational values and community needs (Alshuhail et al., 2025).

Ethical Governance Systems: Given the sensitive nature of student data and algorithmic decision-making, robust ethical frameworks must govern AI-IoT implementation. These systems include transparent data policies, algorithmic accountability measures, and regular ethical audits to protect student privacy and prevent algorithmic bias (Ishtiaq et al., 2025).

The Proposed Adaptive Management Model

Based on the literature synthesis, this study proposes a comprehensive Adaptive Management Model for AI-IoT Science Learning Media Development (Figure 2). The model operates as a cyclical system with four interconnected phases: Context Analysis, Design & Development, Implementation & Monitoring, and Evaluation & Adaptation.

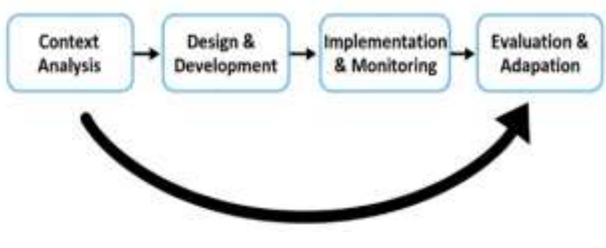

Figure 2. Adaptive Management Model for AI-IoT Science Learning Media Development

The Context Analysis phase involves assessing institutional readiness, stakeholder needs, and technological infrastructure capabilities. This phase recognizes that successful AI-IoT integration cannot be standardized across all educational contexts but must respond to specific institutional and community characteristics.

The Design & Development phase emphasizes co-creation between educators and technologists, ensuring that pedagogical principles drive technological implementation rather than technology dictating pedagogical approaches. This phase incorporates iterative prototyping with continuous educator feedback to maintain alignment with learning objectives.

During Implementation & Monitoring, the model employs real-time data collection to track both technological performance and pedagogical effectiveness. This dual monitoring system allows for immediate adjustments to address emerging challenges while preserving core educational values.

The Evaluation & Adaptation phase conducts comprehensive assessment against predefined educational outcomes, not merely technological functionality. This phase triggers either incremental adjustments or systemic redesign based on evaluation results, ensuring continuous improvement aligned with evolving educational needs and technological capabilities.

Implications for Science Education

The significance of this adaptive management model extends beyond technological implementation to address fundamental challenges in contemporary science education. For science teachers, the model provides a structured approach to integrating advanced technologies while maintaining pedagogical autonomy and professional identity. Rather than positioning teachers as technology implementers, the model reconceptualizes them as adaptive learning architects who leverage technology to enhance human-centered instruction (Gellert et al., 2024; Halidu et al., 2025; Rezaei, 2025; Szromek & Bugdol, 2025).

For students, this model promises more equitable access to high-quality science education experiences that develop both technical competencies and humanistic values. The integration of AI-IoT technologies creates opportunities for authentic scientific inquiry that develops critical thinking, problem-solving, and collaborative skills essential for the Society 5.0 era.

The model's significance for STEM/STEAM education lies in its potential to bridge disciplinary silos through integrated technological platforms. AI-IoT systems can create learning environments where scientific concepts connect with artistic expression, engineering design, and mathematical reasoning, fostering the interdisciplinary thinking required for complex problem-solving in the 21st century.

Challenges and Future Research Directions

Despite its promise, the implementation of this adaptive management model faces significant challenges. Infrastructure limitations in rural and underserved communities, teacher resistance due to technological anxiety, and ethical concerns regarding data privacy and algorithmic transparency require careful attention. Future research should investigate context-specific implementation strategies, particularly in resource-constrained environments, and develop assessment frameworks that measure both technological effectiveness and humanistic educational outcomes.

The model also raises important questions about the balance between standardization and customization in educational technology. Future research should explore how adaptive management frameworks can maintain educational quality standards while accommodating diverse learning contexts and cultural values. Additionally, longitudinal studies are needed to understand the long-term impacts of AI-IoT integration on student learning trajectories and career choices in science fields.

Conclusions

This literature study has examined the adaptive management model for developing AI and IoT-based interactive learning media in the Society 5.0 era, revealing several critical insights. The proposed model represents a strategic approach that successfully integrates advanced technological capabilities with human-centered educational values, moving beyond the purely technology-driven paradigm of Industry 4.0 toward a more balanced educational ecosystem. The synthesis of literature demonstrates that effective implementation requires flexible systems capable of responding to rapid technological evolution while maintaining core educational objectives focused on holistic human development. The research implications are significant for multiple stakeholders in science education. For educational institutions, this model provides a structured framework for technology integration that prioritizes pedagogical effectiveness over technological novelty. Science teachers benefit from a systematic approach to professional development that addresses both technical competencies and pedagogical adaptation strategies. Students gain access to more personalized, experiential learning experiences that develop both scientific literacy and 21st-century skills essential for navigating complex global challenges. Most importantly, the model aligns with Indonesia's Merdeka Belajar curriculum by emphasizing critical thinking, creativity, collaboration, and character development alongside technological proficiency. Several limitations must be acknowledged in this study. The literature review approach, while comprehensive, may not capture all emerging practices in rapidly evolving technological contexts. The analysis primarily focused on theoretical frameworks rather than empirical implementation data, limiting practical validation of the proposed model. Additionally, geographical and cultural contexts may influence model effectiveness, particularly in resource-constrained educational settings across Indonesia's diverse regions.

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Conceptualization, S.S. and D.D.; methodology, S.S.; formal analysis, S.S. and D.D.; investigation, S.S.; resources, D.D.; data curation, S.S.; writing—original draft preparation, S.S.; writing—review and editing, D.D.; visualization, D.D.; supervision, D.D.; project administration, S.S. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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