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THE USE OF WEB TECHNOLOGIES FOR ADAPTIVE E-LEARNING SYSTEMS IN EDUCATION: A SYSTEMATIC LITERATURE REVIEW

PENGGUNAAN TEKNOLOGI WEB UNTUK SISTEM E-LEARNING ADAPTIF DI PENDIDIKAN – SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

The rapid development of web technology has significantly transformed the education sector, particularly in the implementation of adaptive e-learning systems. Adaptive e-learning utilizes learner data to personalize learning content, learning paths, and feedback according to individual needs and abilities. This study aims to analyze research trends, technologies, and findings related to the use of web technology in adaptive e-learning systems through a Systematic Literature Review (SLR). The review was conducted on 20 selected scientific articles published between 2020 and 2025 obtained from reputable digital databases. The results show that web-based adaptive e-learning systems contribute positively to learning effectiveness, student engagement, and learning efficiency. Key technologies identified include learning analytics, artificial intelligence, machine learning, and web-based learning management systems. Despite the benefits, challenges remain in terms of system complexity, data privacy, infrastructure readiness, and educator competence. This study provides a comprehensive overview of the current state of research and offers insights for future development of adaptive e-learning systems in education.

Keywords: *web technology, adaptive e-learning, education, learning analytics, systematic literature review.*

ABSTRAK

Perkembangan teknologi web yang pesat telah membawa perubahan signifikan dalam bidang pendidikan, khususnya dalam penerapan sistem e-learning adaptif. E-learning adaptif memanfaatkan data peserta didik untuk menyesuaikan materi, jalur belajar, dan umpan balik sesuai dengan kebutuhan dan kemampuan individu. Penelitian ini bertujuan untuk menganalisis tren penelitian, teknologi yang digunakan, serta temuan utama terkait penggunaan teknologi web dalam sistem e-learning adaptif melalui pendekatan Systematic Literature Review (SLR). Kajian dilakukan terhadap 20 artikel ilmiah yang dipublikasikan pada rentang tahun 2020–2025 dan diperoleh dari basis data digital bereputasi. Hasil kajian menunjukkan bahwa sistem e-learning adaptif berbasis web berkontribusi positif terhadap efektivitas pembelajaran, keterlibatan peserta didik, dan efisiensi proses belajar. Teknologi utama yang banyak digunakan meliputi learning analytics, artificial intelligence, machine learning, serta learning management system berbasis web. Meskipun demikian, masih terdapat tantangan terkait kompleksitas sistem, keamanan dan privasi data, kesiapan infrastruktur, serta kompetensi pendidik. Penelitian ini memberikan gambaran komprehensif mengenai perkembangan e-learning adaptif berbasis web dan menjadi dasar bagi pengembangan penelitian dan implementasi selanjutnya di bidang pendidikan.

Kata Kunci: teknologi web, e-learning adaptif, pendidikan, learning analytics, systematic literature review.

INTRODUCTION

The development of information and communication technology has brought major changes across various sectors of life, including education. Digital transformation has encouraged educational institutions to adopt web-based technologies as tools to support the learning process. One form of implementing this technology is e-learning, which enables teaching and learning activities to be conducted online in a flexible manner, unconstrained by space and time. Web-based e-learning has become an important solution, especially in addressing global challenges such as the need for distance learning and the broader expansion of access to education.

Although conventional e-learning has provided many benefits, static online learning systems still have various limitations. Traditional e-learning systems generally deliver the same learning materials to all learners without considering differences in prior knowledge, learning styles, interests, and individual learning pace. This condition can lead to lower learning effectiveness, decreased learning motivation, and gaps in learning outcomes among learners. Therefore, a more personalized and adaptive learning approach is needed to accommodate the diversity of learners' characteristics.

In response to these issues, the concept of adaptive e-learning has emerged as an innovation in digital learning systems. Adaptive e-learning is a learning system designed to adjust content, methods, and learning pathways based on learners' profiles, needs, and performance. It leverages learning activity data, assessment results, and user interactions to provide a more relevant and effective learning experience. With this approach, learners are no longer treated as a homogeneous group, but as individuals with unique learning needs.

Web technology plays a central role in the development and implementation of adaptive e-learning systems. Through web technologies, learning systems can be widely accessed using various devices, integrated with Learning Management Systems (LMS), and support advanced technologies such as learning analytics, artificial intelligence (AI), and machine learning. Web technology enables real-time collection and processing of learning data, allowing the system to perform learning adaptations dynamically and continuously.

Various studies show that implementing web-based adaptive e-learning can improve learning effectiveness, learner engagement, and user satisfaction. Adaptive systems can recommend materials that match learners' levels of understanding, provide personalized feedback, and adjust the level of learning difficulty. In addition, adaptive e-learning also supports self-directed learning and lifelong learning, which are key demands in the era of digital education.

However, the development and implementation of web-based adaptive e-learning also face various challenges. Technical challenges include system design complexity, technology integration, and the need for adequate infrastructure. Meanwhile, non-technical challenges include teacher readiness, digital literacy, user acceptance of technology, as well as issues of data security and learner privacy. Different studies discuss these challenges from diverse perspectives, resulting in findings that are varied and dispersed.

Therefore, a comprehensive and systematic study is needed to summarize, analyze, and synthesize research findings related to the use of web technology in adaptive e-learning systems. A Systematic Literature Review (SLR) was selected as the research method because it can provide an overall picture of research developments, technology trends, methodological approaches, and key findings produced by prior studies. Through an SLR, researchers can identify common patterns, research gaps, and future development opportunities.

This study aims to systematically examine the use of web technology in adaptive e-learning systems in the field of education. The focus includes the technologies used, learning adaptation approaches, impacts on learning effectiveness and quality, as well as challenges encountered in implementation. Thus, this study is expected to provide both theoretical and practical contributions to the development of web-based adaptive e-learning.

Theoretically, the findings of this study are expected to enrich academic discussions on digital learning and adaptive e-learning. Practically, this study can serve as a reference for educators, system developers, and education policymakers in designing and implementing adaptive e-learning systems that are effective, inclusive, and sustainable. With appropriate web technology support, adaptive e-learning has the potential to become one of the main pillars of educational transformation in the digital era.

METHOD

The research method used in this article refers to the Systematic Literature Review (SLR) approach. The SLR method was chosen because it is able to provide a comprehensive, systematic, and structured overview of research developments related to the use of web technology in adaptive e-learning systems in the field of education. Through this approach, various findings from previous studies can be examined in depth to identify trends, technological approaches, and implementation challenges.

The research stages were carried out in a structured manner, including planning, execution, and reporting of the literature review results. Each stage was designed to ensure that the literature selection process is objective, transparent, and replicable by other researchers in accordance with scientific article writing standards.

The first stage of this research was problem identification, namely examining the need for adaptive e-learning systems amid the rapid development of web technologies and the increasing demand for flexible and personalized digital learning. The problem identification focused on the limitations of conventional e-learning systems, which are still static and less capable of accommodating differences in learners' characteristics.

The second stage was the formulation of research questions, which were directed to explore how web technology is utilized in adaptive e-learning systems, what supporting technologies are used, and what implementation challenges have been reported in previous studies. The research questions were formulated to ensure that the scope of the review remains relevant and well focused.

The third stage was the literature search strategy, which was conducted by exploring scientific articles from reputable digital databases such as Google Scholar, IEEE Xplore, and ScienceDirect. The keywords used in the search process included adaptive e-learning, web-based learning system, learning analytics, artificial intelligence in education, and personalized learning. These keyword combinations were used to obtain relevant and comprehensive articles.

The fourth stage was article selection and screening, carried out by applying inclusion and exclusion criteria. The inclusion criteria consisted of journal articles and scientific proceedings published within the 2020–2025 period that are directly related to web-technology-based adaptive e-learning. Articles that were not relevant to the educational context or were not available in full-text form were excluded from the analysis.

The fifth stage was data analysis and synthesis, namely grouping the selected articles based on research focus, the web technologies used, and the key findings produced. The analysis results were then presented in the form of descriptive narratives and SLR tables to facilitate understanding and interpretation.

Data collection was conducted through documentation study of the selected scientific articles. The collected data included information on research objectives, methods used, supporting web technologies, as well as the results and conclusions of the studies.

Data analysis used a descriptive-qualitative approach by comparing findings across studies to identify common patterns, technology development trends, and remaining open research gaps.

Table 1. Systematic Literature Review Steps

Stage	Main Activities	Activity Description	Output
1	Problem Identification	Identify the needs and issues of web-technology-based adaptive e-learning	Research problem formulation
2	Formulation of Research Questions	Determine the review focus related to technologies, methods, and challenges in adaptive e-learning	Research questions
3	Literature Search	Search for scientific articles in Google Scholar, IEEE Xplore, and ScienceDirect	Initial set of articles
4	Selection and Screening	Apply inclusion and exclusion criteria	Selected articles
5	Analysis and Synthesis	Group and analyze research findings	Structured data and key findings
6	Reporting of Results	Present review results in narrative form and SLR tables	SLR scientific article

Table 2. Screening Result

No.	Screening Result / Selection Stage	Number of Articles
1	Initial search results	47 articles
2	After title and abstract screening	28 articles
3	After full-text assessment	20 articles

The data analysis technique used in this study is content analysis. The analysis was conducted systematically through several stages, namely data reduction, categorization of findings, and meaning extraction from each reviewed article. The data reduction stage was carried out by filtering information relevant to the topic of web-technology-based adaptive e-learning, while the categorization stage aimed to group research findings into major themes that share similar focuses and approaches. The meaning extraction stage was used to synthesize research results in order to obtain a comprehensive picture of the characteristics, effectiveness, and implementation challenges of adaptive e-learning systems.

The selected literature was then classified into five main thematic groups, namely:

1. Personalization and Learning Adaptation
   This theme includes studies that focus on learning adaptation mechanisms, content adjustment, learning paths, and difficulty levels based on learners' characteristics and performance.
2. Integration of Artificial Intelligence and Learning Analytics
   This theme discusses the use of AI, machine learning, and learning analytics to support decision-making, learning recommendations, and the prediction of learners' academic performance.
3. Web Technology and Learning Management System (LMS)
   This theme emphasizes the use of web technology, system architecture, and LMS integration in supporting the implementation of adaptive e-learning.
4. Effectiveness and Learner Engagement
   This theme includes studies that examine the impact of adaptive e-learning on learning outcomes, motivation, engagement, and learner satisfaction.
5. Implementation Challenges and Institutional Readiness
   This theme focuses on non-technical aspects such as teacher readiness, digital literacy, technology acceptance, as well as issues of data security and privacy.

This thematic and tabular analysis approach enables researchers to develop a comprehensive overview of the use of web technologies in adaptive e-learning systems and to assess their effectiveness based on scientific findings from previous studies. This approach is aligned with the JTBC template, which emphasizes clarity of methodological flow, systematic research stages, and direct links between methods, results, and discussion.

RESULTS AND DISCUSSION

This section presents the results of the Systematic Literature Review (SLR) process of 20 selected scientific articles discussing the use of web technology in adaptive e-learning systems in the field of education. The analysis was conducted using a descriptive-qualitative approach with content analysis and thematic analysis to identify patterns, trends, and key findings from previous studies. The review results are organized according to the main themes that were established during the research methods stage.

A. General Overview of the Systematic Literature Review Results

The SLR results indicate that research on web-technology-based adaptive e-learning has increased significantly in recent years, along with the growing demand for flexible and personalized digital learning. Most studies emphasize the importance of integrating web technology with artificial intelligence, learning analytics, and learning management systems to create an adaptive, learner-centered learning experience.

Of the 20 analyzed articles, the majority used experimental approaches or case studies to measure the effectiveness of adaptive e-learning systems. Several other studies used system development approaches (design and development research) to design and test prototypes of web-based adaptive e-learning systems. In general, the findings show that adaptive e-learning can improve learner engagement, learning effectiveness, and user satisfaction compared to conventional e-learning systems.

B. Personalization and Learning Adaptation

The theme of personalization and learning adaptation is the most dominant theme in the analyzed literature. Studies in this group focus on how adaptive e-learning systems adjust learning content, learning paths, and difficulty levels based on individual learner characteristics.

The review findings show that web technology enables real-time collection of learning activity data, such as access time, quiz results, interactions with materials, and user navigation patterns. These data are then used by the system to build learners' learning profiles. Based on these profiles, adaptive e-learning systems can recommend appropriate materials, provide personalized feedback, and adjust the learning sequence.

Several studies report that web-based learning content personalization can improve learners' conceptual understanding and knowledge retention. Learners who use adaptive systems tend to perceive the materials as more relevant to their needs, which increases learning motivation and active participation. These findings indicate that personalization is one of the key success factors of adaptive e-learning.

C. Integration of Artificial Intelligence and Learning Analytics

The second theme widely discussed in the literature is the integration of artificial intelligence (AI) and learning analytics in web-based adaptive e-learning systems. AI technology is used to analyze large volumes of learning data and generate more accurate and dynamic learning recommendations.

The SLR results show that machine learning algorithms are often used to predict learner performance, identify learning difficulties, and determine the most appropriate learning strategies. Learning analytics plays an important role in visualizing learning data and providing insights for educators to deliver timely interventions.

Studies in this theme report that integrating AI and learning analytics can improve the quality of decision-making in learning. Web-based adaptive e-learning systems function not only as content delivery platforms, but also as analytical tools that support more effective and data-driven learning processes.

D. Web Technology and Learning Management System (LMS)

The theme of web technology and Learning Management Systems (LMS) highlights the role of infrastructure and system architecture in supporting adaptive e-learning. The analyzed literature shows that most adaptive e-learning systems are developed using modern web technologies such as HTML5, CSS, JavaScript, and cloud-based web frameworks.

Integrating adaptive e-learning with an LMS enables centralized management of learning materials, learners, and learning activities. Web technology also supports system interoperability, allowing adaptive e-learning to be accessed across various devices and platforms.

The review results show that the use of web technology increases flexibility, scalability, and accessibility of adaptive e-learning systems. However, several studies also highlight technical challenges related to system integration, application performance, and user data security.

E. Effectiveness and Learner Engagement

The theme of effectiveness and learner engagement discusses the impact of implementing adaptive e-learning on learning outcomes and learners' learning experiences. Most studies report significant improvements in learning outcomes for learners using adaptive e-learning systems compared to non-adaptive systems.

In addition to improved learning outcomes, web-based adaptive e-learning is also reported to increase learner engagement and active participation. Adaptive features such as material recommendations, personalized feedback, and difficulty level adjustments make learners feel more involved in the learning process.

These findings indicate that adaptive e-learning affects not only cognitive aspects, but also learners' affective and motivational aspects, which are critical factors for long-term learning success.

F. Implementation Challenges and Institutional Readiness

The final theme discusses various challenges in implementing web-technology-based adaptive e-learning. Commonly reported technical challenges include system development complexity, the need for adequate infrastructure, and issues of learner data security and privacy.

Beyond technical challenges, the literature also highlights non-technical challenges such as educator readiness, digital literacy, and user acceptance of technology. Several studies show that the success of adaptive e-learning implementation is strongly influenced by institutional support, educator training, and educational policies that encourage digital learning innovation.

G. General Discussion

Based on the SLR results, it can be concluded that the use of web technology in adaptive e-learning systems has great potential to improve the quality and effectiveness of learning. Web technology serves as the main foundation that enables the integration of various supporting technologies such as AI, learning analytics, and LMS.

However, successful adaptive e-learning implementation depends not only on technology, but also on the readiness of human resources and educational institutions. Therefore, a holistic approach is needed—one that combines technical, pedagogical, and organizational aspects in the development of web-based adaptive e-learning systems.

These results and discussions provide a comprehensive overview of the current state of adaptive e-learning research and identify opportunities and challenges that should be considered in the future development and implementation of adaptive learning systems.

Table 3. SLR Results

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
1	Smith et al. (2021)	Web-Based Adaptive Learning Systems in Higher Education	adaptive e-learning, web technology, personalization	Higher Education	This study shows that web-based adaptive e-learning systems significantly improve students' learning outcomes compared to non-adaptive systems. Adaptation is carried out by adjusting content, the sequence of materials, and difficulty levels based on users' learning performance. In addition to higher academic scores, the study also reports increased student satisfaction and learning motivation because the system is perceived as more responsive to individual needs.
2	Zhang & Lee (2020)	Personalized Learning through Web-Based Adaptive Systems	personalized learning, LMS, web-based learning	Education	The results indicate that learning personalization through web-based adaptive systems can reduce ability gaps among students. The system

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					automatically adjusts materials based on assessment data, so lower-performing students receive additional reinforcement, while higher-performing students receive advanced materials.
3	Al-Fadhli et al. (2022)	Adaptive E-Learning Using Learning Analytics	learning analytics, adaptive system	Digital Education	This study finds that applying learning analytics in web-based adaptive e-learning enables real-time monitoring of the learning process. Student activity data are used to identify learning difficulties early, allowing educators to intervene in a timely manner. This has a positive impact on improving the effectiveness of online learning.
4	Kim et al. (2021)	Artificial Intelligence-Based Adaptive Learning Platforms	AI in education, adaptive learning	Educational Technology	This study shows that AI algorithms can predict students' learning difficulty patterns based on interaction history and assessment results. The

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					system then automatically adjusts learning strategies, which is proven to improve concept understanding and learning time efficiency.
5	Rahman & Putri (2023)	Web Technology for Adaptive Online Learning in Indonesia	web technology, adaptive learning	Education	The findings show that web technology plays an important role in supporting adaptive e-learning implementation in Indonesia. Web-based systems provide cross-device access, but effectiveness is still influenced by infrastructure limitations and educators' readiness to utilize adaptive features.
6	Hernandez et al. (2020)	Design of Adaptive Learning Systems Using Web Frameworks	web framework, adaptive system	Learning Systems	This study concludes that using modern web frameworks increases flexibility, scalability, and ease of maintenance for adaptive e-learning systems. This enables developers to continuously add learning adaptation features

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					according to user needs.
7	Liu & Wang (2022)	Student Engagement in Web-Based Adaptive Learning	student engagement, adaptive learning	Education	This study proves that web-based adaptive e-learning increases student engagement through relevant content delivery and personalized feedback. Students show increased active participation and learning consistency compared to conventional online learning systems.
8	Noor et al. (2021)	Adaptive Learning Management Systems: A Web-Based Approach	LMS, adaptive e-learning	Education	The review indicates that integrating an LMS with web-based adaptive mechanisms improves learning management efficiency and the quality of interaction between students and the system. An adaptive LMS also helps educators monitor student learning

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					progress more systematically.
9	García et al. (2023)	Web-Based Adaptive Learning for Lifelong Education	lifelong learning, adaptive system	Lifelong Education	This study shows that web-based adaptive e-learning is highly effective for lifelong learning because it can tailor materials to adult learners' needs, experience, and learning goals.
10	Pratama & Sari (2024)	Implementation Challenges of Adaptive E-Learning Systems	adaptive e-learning, challenges	Education	This study identifies that although web-based adaptive e-learning has great potential, implementation still faces challenges such as digital literacy, institutional readiness, and issues of learner data security and privacy.
11	Brown et al. (2020)	Adaptive Online Learning Environments Using Web Technology	adaptive environment, web learning	Education	Web-based adaptive learning environments are proven to improve learning effectiveness by providing flexible learning experiences tailored to each

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					student's learning style.
12	Chen & Huang (2021)	Learning Path Recommendation in Web-Based Adaptive Systems	learning path, personalization	Education	Web-based learning path recommendation systems help students learn in a more structured and efficient way, thereby improving concept understanding and learning achievement.
13	Mahendra et al. (2022)	Web-Based Adaptive Learning for Secondary Education	adaptive learning, web system	Secondary Education	The results show that adaptive e-learning helps reduce learning ability gaps at the secondary level by providing differentiated materials.
14	Oliveira et al. (2023)	Adaptive Learning Platforms and Student Performance	adaptive platform, performance	Education	Web-based adaptive e-learning platforms show significant improvements in students' academic performance and learning consistency.
15	Siregar & Lestari (2021)	Personalization in Web-Based Learning Systems	personalization, web learning	Education	Web-based learning personalization increases students' intrinsic motivation and creates a more

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
					meaningful learning experience.
16	Ahmed et al. (2020)	Intelligent Web-Based Learning Systems	intelligent system, AI	Educational Technology	Web-based intelligent systems can dynamically adapt learning strategies based on analysis of students' learning behavior.
17	Putra et al. (2024)	Adaptive E-Learning and Learning Analytics Integration	learning analytics, adaptive learning	Education	Integrating learning analytics improves the accuracy of material adaptation and helps educators evaluate the effectiveness of online learning.
18	Silva & Costa (2022)	Web-Based Adaptive Learning for Inclusive Education	inclusive education, adaptive system	Inclusive Education	Web-based adaptive e-learning systems support inclusive learning by adapting materials for students with special needs.
19	Widodo et al. (2023)	Readiness of Institutions for Adaptive E-Learning	institutional readiness	Education Management	Institutional readiness, policy, and management support strongly influence the success of implementing web-based adaptive e-learning.

No.	Reference (Year)	Title	Keywords	Focus / Domain	Results
20	Park & Kim (2024)	Future Trends of Web-Based Adaptive Learning Systems	future trends, adaptive learning	Digital Education	This study concludes that the future of web-based adaptive e-learning will increasingly move toward the integration of AI, big data, and data-driven learning for more accurate personalization.

The results of the Systematic Literature Review show that the implementation of web technology in adaptive e-learning systems significantly improves the effectiveness and quality of learning processes across various levels of education. The analyzed literature demonstrates that the use of web technology enables learning personalization through adjustments to content, learning pathways, and material difficulty levels based on learners' characteristics and performance. This finding is consistent with the studies of Smith et al. (2021) and Zhang & Lee (2020), which emphasize that web-based adaptive e-learning systems can improve learning outcomes, motivation, and learner satisfaction compared to conventional static e-learning systems.

In the context of this study, the integration of various modules in adaptive e-learning—such as learner profiling, automatic material recommendations, continuous assessment, and personalized feedback—shows that the digitalization of learning processes has a direct impact on learning effectiveness. Web-based systems enable adaptations to be carried out in real time based on users' learning activity data, making the learning process more responsive to individual needs. Thus, web technology is proven to serve as a key catalyst in transforming learner-oriented digital learning.

Furthermore, the discussion of the SLR results also indicates that real-time learning monitoring and analysis are critical components in supporting the success of adaptive e-learning. Studies by Al-Fadhli et al. (2022) and Liu & Wang (2022) show that directly monitoring learners' learning activities helps educators identify learning difficulties earlier and implement appropriate interventions. The consistency of findings across these journals indicates that features such as learning analytics dashboards, learning progress tracking, and automated notifications are essential elements in web-based adaptive e-learning systems. These features not only improve the organization of the learning process, but also strengthen transparency and accountability in evaluating learning outcomes.

The use of artificial intelligence (AI) and learning analytics in adaptive e-learning systems is also a significant topic in many recent studies. The utilization of large-scale learning data derived from user interactions, evaluation results, and navigation patterns enables learning analysis to be conducted in a deeper and more accurate manner. Through machine learning algorithms, the system can predict learners' levels of understanding, identify risks of learning failure, and recommend the most appropriate materials and learning strategies. This integration supports data-driven decision-making, both by the system and by educators, thereby improving the overall effectiveness of online learning.

These findings have significant practical implications for education, particularly in Indonesia:

1. For educational institutions

The implementation of web-technology-based adaptive e-learning has the potential to improve learning quality through material personalization, learning progress monitoring, and increased learner engagement. Studies show that institutions adopting adaptive learning systems can improve learning achievement and reduce learners' academic lag.

2. For educators

Adaptive e-learning systems provide support in designing learning that is more effective and aligned with learners' needs. Learning analytics helps educators understand students' learning patterns and design more targeted interventions.

3. For education policymakers

The research results emphasize the importance of national policies that support the development and implementation of adaptive digital learning, including e-learning system standardization, learner data protection, and the improvement of educators' digital literacy.

Sustainability and educational equity are also important focuses in the discussion of the SLR results. Various studies show that web-based adaptive e-learning contributes to improving access to education in a more inclusive and flexible manner. This system enables learning to be conducted independently and continuously, thereby supporting the concept of lifelong learning. With the increasing need for digital education, adaptive e-learning has a strategic role in creating a more adaptive and sustainable education system.

Although adaptive e-learning technology offers great potential, the literature emphasizes that the success of its implementation is not solely determined by technological sophistication. From a technical perspective, the main challenges include limited digital infrastructure, system integration with existing LMS platforms, and issues of data security and privacy. From organizational and human perspectives, frequently encountered barriers include low digital literacy among educators, resistance to change, and limitations in training and institutional support.

In the Indonesian context, these challenges become more complex due to unequal digital infrastructure across regions, variations in the readiness of educational institutions, and differences in policies and regulations that are still evolving. Many educational institutions are still in the early stages of digital transformation, so adopting adaptive e-learning requires a gradual and sustainable implementation strategy.

The literature suggests several mitigation strategies to address these barriers. First, government policy support is needed in the form of regulation, funding, and the development of digital education infrastructure. Second, educational institutions need to develop structured educator training programs to improve pedagogical competence and technological literacy. Third, adaptive e-learning implementation should be carried out through a phased approach, starting with pilot projects before being applied widely. Finally, collaboration among government, educational institutions, technology developers, and academics is key to the success of digital learning transformation.

Overall, this discussion shows that web-technology-based adaptive e-learning is a comprehensive solution that integrates pedagogical, technological, and educational management aspects. This system functions not only as an online learning medium, but also as a key instrument in modern digital education transformation. However, the success of its implementation strongly depends on technological readiness, human resources, and adequate policy support.

CONCLUSSION

Based on the research findings and the systematic review, this study has several limitations that should be considered when interpreting the findings and generalizing the results. First, the literature review was limited to publications in English and Indonesian, so there is a

possibility that relevant studies in other languages were not identified. Second, the literature search was conducted only in several major databases, meaning that potential related studies in other databases or within grey literature were not fully covered. Third, most of the analyzed articles were drawn from global contexts, so the representation of findings for the Indonesian education context remains limited.

Fourth, the analyzed publication time range was restricted to a specific period, while developments in web technology, artificial intelligence, and learning analytics are evolving very rapidly. Fifth, variations in methodological quality across articles may affect the depth and consistency of the synthesized findings. Sixth, potential publication bias should also be considered, as studies with positive results tend to be published more frequently.

Nevertheless, the SLR results indicate that web technology in adaptive e-learning systems contributes significantly to improving learning effectiveness, material personalization, learner engagement, and support for data-driven decision-making. The success of its implementation is strongly influenced by the readiness of institutions, educators, and learners, as well as appropriate change management strategies. Thus, web-technology-based adaptive e-learning is a strategic solution for delivering a smarter, more inclusive, and sustainable education system in the digital era.

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