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Designing an Intelligent Adaptive Learning Environment

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ABSTRACT

Objective: The rapid advancement of artificial intelligence technologies, traditional learning environments have undergone a fundamental transformation. Concepts such as "intelligent adaptive learning" have emerged as innovative approaches to enhancing educational quality. An intelligent adaptive learning environment is a dynamic, data-driven system that personalizes educational content, difficulty levels, and learning pathways by analyzing learners' characteristics, needs, and performance. This study aims to identify and categorize the key components involved in designing intelligent adaptive learning environments through a systematic review of existing research.

Method: To achieve this goal, 342 scientific articles published between 2020 and 2025 were collected and analyzed from reputable databases such as Scopus, Web of Science, ERIC, Springer, IEEE Xplore, ScienceDirect, and Google Scholar. Following a rigorous screening process based on inclusion and exclusion criteria, 56 articles were selected for final analysis.

Results: Based on qualitative content analysis of the selected studies, the design of an intelligent adaptive learning environment requires consideration of eight key components: learner analysis and assessment, modeling and profiling, application of artificial intelligence technologies, content personalization, design of adaptive learning paths, intelligent feedback and interventions, specialized interactive tools, and continuous monitoring and improvement. Each of these components includes specific subcomponents that collectively enable personalised, data-driven learning.

Conclusions: The findings of this study present a structured conceptual framework for the design, implementation, and evaluation of intelligent learning environments, offering a scientific foundation for the development of adaptive educational systems and future research in AI-based learning.

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Introduction

In today's era, educational advancements in both theory and instructional methods advocate for personalised, student-centered approaches to teaching 21st-century skills; However, existing instructional practices,adhering to a "one-size-fits-all" model, often fall short in fostering optimal student engagement, raising a critical question: How can high-quality adaptive instruction be delivered at a personalised level? (Khazanchi & Khazanchi, 2021).

In response to this pedagogical challenge, the digital and smart learning age has witnessed the development of various platforms and tools aimed at enhancing learning effectiveness (Kem, 2022). The proliferation of online learning and diverse educational resources such as Massive Open Online Courses (MOOCs) and Intelligent Tutoring Systems has amplified the demand for personalised instruction within adaptive learning environments (Minn, 2022). Technological media now serve as essential tools for educators, enabling efficient lesson planning, creation of dynamic student work repositories, and facilitation of personalised learning experiences (Bezerra et al. 2022).

Despite these technological promises, a critical gap emerges when examining current Learning Management Systems (LMSs). These systems remain largely passive and generic, lacking the ability to adapt to learners in terms of learning skills, preferences, languages, cognitive abilities, learning patterns, and rhythms (Mona et al. 2023). While recent research demonstrates that Artificial Intelligence in Education (AIED) can facilitate personalised learning pathways through various technologies—including social networks, chatbots, expert systems, intelligent tutors and agents, machine learning, personalised learning systems, and virtual learning environments (Tapalova et al. 2022)—the literature reveals a fundamental problem: there is no comprehensive framework that systematically identifies and integrates the essential components required for designing truly intelligent adaptive learning environments.

This gap is particularly problematic because the design and implementation of intelligent adaptive learning systems involve multiple complex and interdependent challenges. Ethical issues related to privacy and effective teacher-student communication must be addressed (Rizvi, 2023). The mechanics and dynamics of gamification need alignment with individual learner traits such as personality, needs, values, and motivations (Benanni et al. 2021). Additionally, the underlying algorithms—including machine learning, natural language processing, and data mining—require careful integration to enable systems to adjust their interactions according to student needs (Rizvi, 2023); However, existing studies have examined these elements in isolation rather than as an integrated design framework, leaving researchers and practitioners without clear guidance on how to systematically conceptualize and develop comprehensive intelligent adaptive learning environments.

The absence of such a systematic framework represents a significant barrier to advancing the field. While the potential of AI to revolutionize education through personalised and adaptive guidance is widely acknowledged (Milani et al. 2022), the fragmented nature of current

knowledge prevents effective translation of AI capabilities into coherent educational solutions. Educators and system designers lack a comprehensive model that delineates the core components, their interrelationships, and implementation strategies necessary for creating effective intelligent adaptive learning environments.

Given the growing importance of AI in the digital transformation of education (Tapalova et al. 2022) and the urgent need to move beyond generic LMSs toward truly adaptive systems, a systematic synthesis of existing knowledge is essential. Only through a comprehensive review that identifies, categorizes, and integrates the dispersed components and subcomponents discussed in the literature can we develop a cohesive design model that addresses this gap. Therefore, this study aims to develop a design model for intelligent adaptive learning environments by identifying and categorizing the core components and subcomponents through a systematic review approach. Accordingly, the central research question is: What is the proposed design model for intelligent adaptive learning environments based on the components and subcomponents identified through systematic review?

Theoretical Framework

The design of intelligent adaptive learning environments in this study is grounded in a synthesis of established learning theories and contemporary technological paradigms that collectively inform personalised education. At the core of this framework lies constructivist learning theory, which posits that learners actively construct knowledge through interaction with their environment rather than passively receiving information. This theoretical foundation aligns with the shift from traditional "one-size-fits-all" instructional models toward student-centered approaches that emphasize individual needs and preferences (Khazanchi & Khazanchi, 2021). The technological media and platforms developed in the digital learning age serve as tools that facilitate this constructivist approach, enabling educators to create dynamic repositories and personalised learning experiences that respond to individual learner construction of meaning (Bezerra et al. 2022; Kem, 2022).

Complementing constructivism, self-regulated learning theory provides a critical lens for understanding how intelligent adaptive systems can support learner autonomy and metacognitive development. Self-regulated learning emphasizes learners' ability to set goals, monitor their progress, and adjust their strategies based on feedback—processes that are fundamentally dependent on accurate knowledge assessment and adaptive feedback mechanisms (Main, 2022). The student model, identified as a foundational structure for assessment in adaptive learning environments, directly supports self-regulated learning by tracking individual progress, identifying knowledge gaps, and providing targeted interventions. Furthermore, the integration of gamification elements in digital learning environments (Benanni et al. 2021) can be understood through self-regulated learning theory as mechanisms that enhance intrinsic motivation and engagement by aligning with individual learner traits such as personality, needs, values, and motivations—all of which are essential components of effective self-regulation.

The theoretical framework is further informed by personalization theory and adaptive learning theory, which together explain how AI-based educational systems can dynamically adjust to learner characteristics. Unlike traditional e-learning systems that deliver uniform content, personalised learning systems grounded in these theories provide tailored content and assessments by continuously analyzing individual comprehension levels, learning preferences, cognitive abilities, learning patterns, and rhythms (Mona et al. 2023). The theoretical underpinning here draws on the understanding that effective learning requires alignment between instructional methods and individual learner differences—a principle that AI technologies such as machine learning, natural language processing, and data mining can operationalize by enabling systems to adjust their interactions according to student needs (Rizvi, 2023). The various AIED technologies including intelligent tutors and agents, expert systems, and virtual learning environments (Tapalova et al. 2022) represent practical manifestations of personalization theory, offering pathways for both learners and educators to engage with content in ways that honor individual differences while supporting professional competency development.

Finally, this study acknowledges the socio-technical systems perspective, which recognizes that intelligent adaptive learning environments exist at the intersection of pedagogical theory, technological capability, and human interaction. This perspective is essential for addressing the complex challenges inherent in designing such systems, including ethical considerations related to privacy, the need for effective teacher-student communication, and the requirement to balance technological sophistication with pedagogical effectiveness. The growing importance of AI in the digital transformation of education (Tapalova et al. 2022) necessitates a framework that integrates constructivist and self-regulated learning principles with personalization theory while remaining attentive to the socio-technical realities of implementation. By synthesizing these theoretical foundations, this study establishes a comprehensive lens through which to systematically identify and categorize the core components and subcomponents of intelligent adaptive learning environment design.

Research Background

Akavova et al (2023), in their article *"Adaptive Learning and Artificial Intelligence in the Educational Space,"* found that educational technologies leveraging artificial intelligence and adaptive learning algorithms analyze learners' performance and provide personalised feedback and recommendations. This approach aids in identifying areas that require improvement and tailors learning experiences to individual needs. They also highlight that AI-based adaptive learning systems can assist teachers by automating administrative tasks, delivering real-time feedback, and generating comprehensive progress reports.

Rane (2023), in her article *"Education 4.0 and 5.0: Integrating Artificial Intelligence (AI) for Personalised and Adaptive Learning,"* states that education is shifting toward personalised and adaptive approaches. She explains that Education 4.0 represents a fundamental transformation wherein technology—especially AI—is used to enhance learning experiences.

Education 5.0 expands on this concept by emphasizing adaptive learning, where AI systems can adjust instructional strategies based on real-time feedback and learners' progress.

Tanashchuk et al. (2024), in their article *"Adaptive Educational Ecosystems Using Artificial Intelligence to Shape Students' Learning Pathways,"* emphasize the importance of developing effective methods for individualized learning in the era of digitalized education. They argue that adaptive educational technologies enable the determination of learning status, analysis of students' cognitive processes, identification of challenging topics, and content adaptation to deepen understanding. They consider the use of AI to be one of the most effective methods for developing adaptive learning systems.

Zhang (2024), in the article *"Leveraging AI for Personalised Learning Pathways: A Framework for Adaptive Learning Management Systems,"* explores the role of AI in constructing personalised learning pathways. He demonstrates how AI can facilitate student profiling, generation of adaptive learning paths, and continuous assessment through ongoing feedback loops essential for transformative personalised learning. Zhang also highlights key challenges related to AI-driven instruction, such as data privacy, scalability, and equity.

Joshi (2023), in his study *"Adaptive Learning through Artificial Intelligence,"* found that the integration of AI in adaptive learning systems can personalize education through machine learning and predictive analytics. He further notes that this integration has the potential to revolutionize education by offering customized and optimized learning experiences. These findings underscore the significance of AI in improving learning outcomes.

Sajja et al. (2023), in their research titled *"AI-Based Intelligent Assistant for Personalised and Adaptive Learning in Higher Education,"* discovered that using AI-based intelligent assistants can reduce learners' cognitive load and provide easy access to information, knowledge assessment, and personalised learning support. They also indicate that such systems can understand and respond to students' queries, generate quizzes and flashcards, and offer personalised learning pathways. These findings suggest significant potential for enhancing student learning outcomes, engagement, and satisfaction.

Mote (2024), in his study *"The Role of Artificial Intelligence in Personalised Education,"* found that personalised learning is driven by individual interests, learning styles, and self-paced progression. He also points out that AI-based adaptive learning systems facilitate personalised learning paths, enabling students to progress at their own pace while receiving targeted interventions and real-time feedback. These findings demonstrate the importance of AI in creating personalised and effective learning experiences.

Sun (2024), in her systematic review titled *"The Impact of Artificial Intelligence on Personalised Learning in Education: A Systematic Review,"* found that the application of AI in education positively enables more adaptive and personalised experiences for learners. She further notes that AI-driven adaptive learning systems tailor educational materials to the specific needs of learners and that intelligent educational systems increase engagement by

providing instant personalised feedback. These findings highlight AI's significant role in transforming education by enhancing the flexibility and effectiveness of personalised learning.

Despite growing research demonstrating AI's potential to transform education through personalised and adaptive learning, a critical gap persists in the literature. While existing studies have examined various aspects of intelligent adaptive learning systems—including personalised feedback and administrative automation (Akavova et al. 2023), real-time instructional adjustments (Rane, 2024), cognitive process analysis (Tanashchuk et al. 2024), student profiling and continuous assessment (Zhang, 2024), machine learning-based personalization (Joshi, 2023), cognitive load reduction (Sajja et al. 2023), self-paced progression (Mote, 2024), and instant feedback mechanisms (sun, 2024) these investigations have predominantly focused on specific AI applications or isolated features. What remains absent is a comprehensive, systematically derived design model that integrates the multifaceted components essential for holistic intelligent adaptive learning environments. Current research has not synthesized fragmented knowledge across pedagogical, technological, motivational, and ethical dimensions into a unified framework. The innovation of this study lies in addressing this gap through systematic review to construct an integrated design model that identifies and categorizes core components and their interrelationships. This provides researchers, educators, and system designers with a structured blueprint bridging theory and practice, enabling coherent development of intelligent adaptive learning environments and addressing the urgent need to transition from fragmented approaches to systematic, evidence-based design.

Research Objectives and Questions

Main Objective:

To design a model of an intelligent adaptive learning environment by identifying and categorizing its subcomponents into major components based on a systematic review of the scientific literature.

Sub-Objectives:

- To identify the subcomponents of an intelligent adaptive learning environment through a systematic review of scholarly texts.
- To categorize the identified subcomponents into core components of the intelligent adaptive learning environment.
- To design and propose a model for the intelligent adaptive learning environment based on the identified main components and subcomponents.

Main Research Question:

How can a model for designing an intelligent adaptive learning environment be developed based on the identification and categorization of its main components and subcomponents through a systematic literature review?

Sub-Questions:

1. What are the subcomponents of an intelligent adaptive learning environment according to a systematic review of the literature?
2. What are the main components into which these subcomponents can be categorized?
3. What is the proposed model for designing an intelligent adaptive learning environment based on the identified components and subcomponents?

Methodology

This study employed a systematic review following the PRISMA 2020 guidelines combined with qualitative content analysis using an inductive coding approach. The PRISMA framework guided the literature search, screening, and selection process, while qualitative content analysis facilitated the extraction and categorization of components from the selected studies. In order to address the research questions, this study aimed to present a coherent, analytical, and structured overview of the current state of research, theoretical frameworks, and design trends pertaining to adaptive learning environments. The ultimate objective was to extract evidence-based data and analyze it for the development of a localized and reliable design model grounded in robust empirical evidence.

Resource Search Strategy

To collect relevant literature, six reputable academic databases were selected as the primary sources: **Scopus, Web of Science, ERIC, Springer, IEEE Xplore**, and **ScienceDirect**. In order to enhance the comprehensiveness of the search process, a manual search was also conducted using **Google Scholar**.

The keywords used in the search process consisted of combinations of terms related to the research topic. The detailed keyword combinations are presented in **Table 1.**

Table 1. Keywords in systematic searches of English databases

Artificial-intelligence terms (within-group OR)		**Education/learning terms (within-group OR)**		**Adaptive/personalization terms (within-group OR)**
"artificial intelligence" **AI** **Smart**	**AND**	education Learn* Teach* Instruct* model "Instructional design"	**AND**	Adaptive Personalized Individualized Customized

Study Selection Criteria

The selection of sources for this study was limited to the period **2020 to 2025**. Only **peer-reviewed journal articles and papers published in reputable academic conferences** were included in the analysis. Sources such as **books, theses, reports, editorials**, and **non-scholarly articles** were excluded. The inclusion and exclusion criteria are summarized in **Table 2**.

Table 2. Inclusion and Exclusion Criteria for Study Selection

	Exclusion Criteria	Inclusion Criteria
Time	Articles published before 2020	**Articles published between 2020 and 2025**
Subject Area	Not related to intelligent adaptive learning environments	**Related to intelligent adaptive learning environments**
Source Type	Books, theses, grey literature, and non-peer-reviewed articles	**Published in reputable academic journals or conferences**
Language	Publications in languages other than English	**English-language publications**

Systematic Search Output

The systematic search process, using keywords related to *intelligent adaptive learning environments*, initially yielded **342 articles**. After removing **122 duplicate records** due to overlapping indexing across multiple databases, **220 articles** remained for preliminary screening. In the title and abstract screening phase, **71 articles** were excluded based on failure to meet the inclusion criteria. Ultimately, **56 articles** were selected for full-text content analysis.

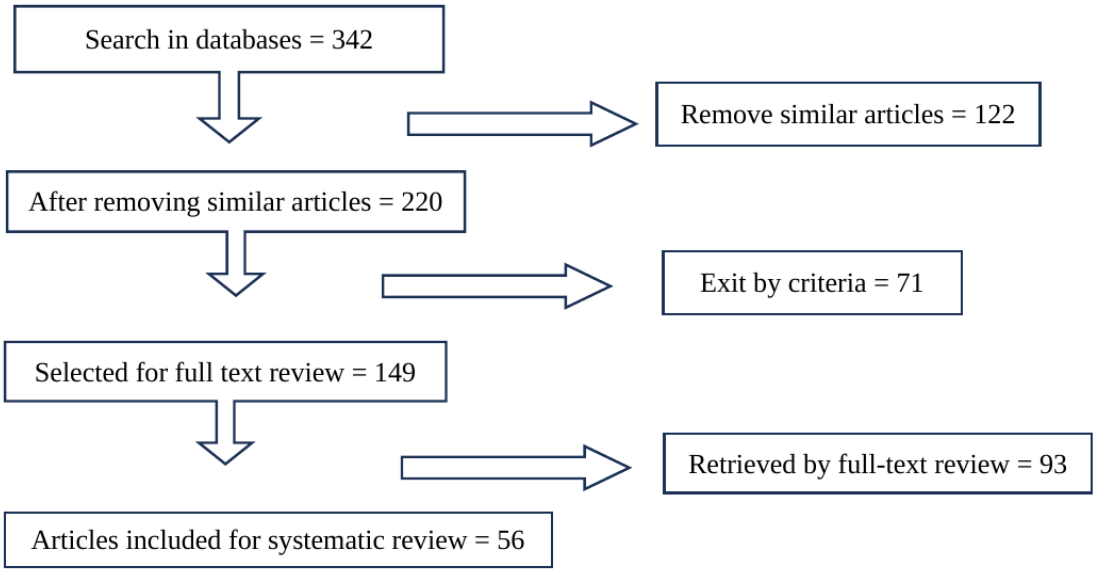

Figure 1. Article selection process chart

Final Article Analysis

In the final stage, the 56 eligible articles were reviewed and analyzed in full. Content analysis was conducted using an inductive approach and open coding method. Initially, key concepts and design-related elements of intelligent adaptive learning environments were extracted from the articles. These concepts were then organized into subcomponents, which were subsequently grouped into main components. Based on the analysis and synthesis of findings, a preliminary conceptual model for the design of intelligent adaptive learning environments was proposed.

Quality Appraisal of Included Studies

Because the included studies represented heterogeneous research designs, methodological quality was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools. The

checklist most appropriate for each study design was selected. The appraisal criteria addressed, as applicable, the clarity of the research objective, appropriateness of the study design, adequacy of the sample or data sources, validity and reliability of the measurements, appropriateness of the data analysis, and consistency between the reported findings and the conclusions.

Two reviewers independently appraised the methodological quality of all included studies. Any disagreements were resolved through discussion and consensus; unresolved disagreements were referred to a third reviewer. The results of the quality appraisal were reported descriptively and did not constitute an automatic exclusion criterion.

Screening and Data-Extraction Reliability

Two reviewers independently screened the titles and abstracts of all retrieved records and assessed the full texts of potentially eligible studies according to the predefined inclusion and exclusion criteria. Data were extracted independently using a standardized extraction form developed from the research questions. The form included publication characteristics, study objectives, study design, country, quality-appraisal results, and the components of intelligent adaptive learning environments.

The two reviewers compared their screening decisions and extraction matrices. Disagreements were resolved through discussion and consensus, with adjudication by a third reviewer when necessary. The final extraction matrix was checked against the original articles to minimize transcription and interpretation errors.

Calculation of Quality-Appraisal Percentages

For each study, the quality-appraisal percentage was calculated as follows: **Quality percentage = (number of "Yes" responses / number of applicable appraisal criteria) × 100.**

"No" and "Unclear" responses were not counted as fulfilled criteria, whereas "Not applicable" items were excluded from the denominator. The percentages were rounded to the nearest whole number and were used descriptively rather than as an official overall JBI score.

Table 3. Illustrative Example of a JBI-Based Methodological Quality Appraisal Summary for Selected Studies

Study	Study design	JBI tool	Yes	No	Unclear	N/A	Quality percentage
(Ejjami, 2024)	Qualitative	JBI Qualitative Checklist	8	1	1	0	80%
(Ezzaim et al. 2023)	Systematic review	JBI Systematic Review Checklist	9	2	0	0	82%
(okolo et al. 2024)	Quasi-experimental	JBI Quasi-experimental Checklist	7	1	1	0	78%

Findings

This section presents the findings derived from a systematic review of 56 scholarly articles focusing on the components of intelligent adaptive learning environments. Data from the final set of included studies were extracted using standardized tables. Table 3 provides a descriptive and qualitative overview of the reviewed articles. It includes key information such as the article title, authorship, year of publication, research objective, country of study, and the result of the quality assessment. This table facilitates a comprehensive understanding of the research orientations, geographical distribution, and methodological rigor of prior studies. Table 5 focuses specifically on the extraction of components of intelligent adaptive learning environments from each article. For every study, the table presents the article title, author(s), year of publication, along with the identified components and key conceptual themes. Finally, Table 6 is dedicated to the categorization of subcomponents into major components. By synthesizing findings across the reviewed articles, this table organizes subcomponents into conceptual groupings under overarching components, thus laying the foundation for the design of a conceptual model for intelligent adaptive learning environments.

To improve readability and avoid excessive table length, Table 4 presents selected examples of the included studies. These examples illustrate the information extracted from each study, including the article title, author and publication year, research objective, country of research, and quality-assessment result. The complete table containing the same information for all 56 included studies is provided in Supplementary Table S2.

Table 4. Descriptive Review and Quality Assessment of Articles Related to the Components of Intelligent Adaptive Learning Environments

No.	Study information	Quality
1	**Title:** Adaptive learning and artificial intelligence in the educational space **Author/Year:** Akavova et al., 2023 **Objective:** Examination of the integration of adaptive learning technologies with artificial intelligence algorithms to personalize and enhance students' learning experiences **Country:** Russia	78%
2	**Title:** Education 4.0 and 5.0: Integrating Artificial Intelligence (AI) for Personalised and Adaptive Learning **Author/Year:** Rane et al., 2023 **Objective:** Exploration of how artificial intelligence integration creates transformative changes in the education sector, particularly within Education 4.0 and 5.0 frameworks **Country:** India	81%
3	**Title:** ADAPTIVE EDUCATIONAL ECOSYSTEMS USING ARTIFICIAL INTELLIGENCE FOR FORMING STUDENTS' EDUCATIONAL TRAJECTORIES **Author/Year:** Tanashchuk et al., 2024 **Objective:** Investigation of customized artificial intelligence modules for creating personalised learning pathways **Country:** Ukraine	82%
4	**Title:** Harnessing Artificial Intelligence for Personalised Learning Pathways: A Framework for Adaptive Education Management Systems **Author/Year:** Zhang, 2024 **Objective:** Analysis of artificial intelligence's role in constructing personalised learning pathways and its applications in K-12 education, higher education, and lifelong learning **Country:** China	78%

5	**Title:** Adaptive Learning through Artificial Intelligence **Author/Year:** Joshi, 2023 **Objective:** Examination of artificial intelligence integration in adaptive learning systems for educational personalization **Country:** USA	73%

The data analysis revealed that among the countries represented in the reviewed studies, certain nations appeared with higher frequency, suggesting their leading or significant roles in the field under investigation. Based on frequency counts, **India** emerged as the most frequently represented country, appearing **13 times**, and thus ranked first. **The United States** followed in second place with **9 occurrences**. **China (5 occurrences)**, **Morocco (4 occurrences)**, and **Italy (3 occurrences)** were also among the top contributors. **Table 4** presents the distribution of the **top five countries** in terms of frequency of occurrence in studies related to intelligent adaptive learning environments.

Table 5. Leading Top Countries in Studies on Intelligent Adaptive Learning Environments

Rank	Country	Frequency
1	India	13
2	United States	10
3	China	6
4	Morocco	4
5	Italy	3
6	Saudi Arabia	3
7	France	2
8	Germany	2
9	Malaysia	2

Table 5 presents the nine most frequently represented countries among the included studies. The remaining countries not shown in the table were Indonesia, Kazakhstan, Pakistan, Portugal, Russia, Taiwan, Tunisia, Turkey, Uganda, Ukraine, and the United Arab Emirates, with one study representing each country.

Table 6. Extraction of Components and Key Concepts of Intelligent Adaptive Learning Environment from Selected Articles

N0.	Study information	Identified sub-components
1	**Title:** Adaptive learning and artificial intelligence in the educational space **Author/Year:** Akavova et al., 2023	• Learner performance analysis • Personalised feedback provision • Identification of areas needing improvement • Content adaptation and educational materials presentation • Continuous monitoring and assessment of student performance • Identification of weaknesses • Targeted interventions
2	**Title:** Education 4.0 and 5.0: Integrating Artificial Intelligence (AI) for Personalised and Adaptive Learning **Author/Year:** Rane et al., 2023	• Machine learning algorithms • Natural language processing • Dynamic adjustment of educational strategies • Adaptation of content, pace, and assessments

3	**Title:** ADAPTIVE EDUCATIONAL ECOSYSTEMS USING ARTIFICIAL INTELLIGENCE FOR FORMING STUDENTS' EDUCATIONAL TRAJECTORIES **Author/Year:** Tanashchuk et al., 2024	• Determination of learning process status • Analysis of student cognitive processes • Identification of challenging topics • Content adaptation

The findings indicate that intelligent adaptive learning environments (IALEs) first focus on the precise analysis of learner performance. These systems utilize advanced data mining techniques and machine learning algorithms to identify learning patterns (Akavova et al. 2023). *Learner modeling*, one of the core components of IALEs, enables the identification of students' strengths and weaknesses, learning styles, and progression rates (Joshi, 2023). This process involves the creation of detailed learner profiles that encompass all aspects related to learner performance (Hashim et al. 2022).

Once the learner's characteristics are identified, IALEs can adapt instructional content and deliver personalised learning pathways. This adaptation involves not only the educational content but also the pace of instruction and assessment methods (Rane et al. 2023). Advanced machine learning algorithms analyze students' cognitive processes and identify challenging topics to generate optimized learning paths (Tanashchuk et al. 2024). These learning paths are unique and tailored to the learners' needs, interests, and individual abilities (Mote, 2024).

Another key component of IALEs is the presence of continuous assessment systems and real-time feedback mechanisms. These systems employ automated assessment techniques to continuously monitor student performance and deliver personalised feedback (sun, 2024). The feedback loops in such systems allow for ongoing revision and improvement of the learning process (Zhang, 2024), helping learners become aware of their progress and identify areas for improvement (Akavova et al. 2023).

The implementation of IALEs requires the integration of advanced technologies such as artificial intelligence, machine learning, natural language processing (NLP), and big data analytics. Machine learning algorithms like **K-Means** are used for clustering learners (Riad et al. 2020). NLP enables the system to understand and respond to students' queries (Sajja et al. 2023), while deep learning techniques and artificial neural networks support more accurate modeling of learner behavior (Minn, 2022; Ezzaim et al. 2024).

By identifying learners' weaknesses, IALEs are capable of designing and executing targeted interventions. These include delivering suitable learning resources, interactive tools, and activities aligned with individual learner needs (Mote, 2024). Intelligent educational systems dynamically adjust instructional content based on collected data, tailoring it to individual abilities (Capuano & Caballé, 2020). This adaptation may involve changes in content difficulty, delivery methods, and activity types.

In IALEs, virtual tutors and intelligent agents play a significant role. Leveraging NLP, these agents can communicate with learners, answer questions, and provide personalised guidance

(Tapalova & Zhiyenbayeva, 2022). Virtual tutors offer immediate feedback and assist learners in overcoming learning challenges (Aggarwal et al. 2023a). Additionally, these agents can detect learners' emotional and motivational fluctuations and initiate suitable interventions (Tetzlaff et al. 2021).

Despite substantial advancements in AI, human–AI collaboration remains a critical component of IALEs. This partnership allows for leveraging the strengths of both humans and intelligent systems (Tong & Lee, 2023). Teachers can make more informed instructional decisions based on data-driven insights provided by intelligent systems (Lin et al. 2023). Moreover, such collaboration helps reduce teachers' workload through automation of tasks such as grading and feedback delivery (Aggarwal et al. 2023a).

Despite its many advantages, the design and implementation of IALEs face several challenges. One major challenge is the collection and analysis of sufficient data to enable accurate learner modeling (Murtaza et al. 2022). Several strategies have been proposed to address this issue, including the use of both historical and real-time data (Somasundaram et al. 2020), deploying Internet of Things (IoT) devices to collect classroom data (Zhou & Li, 2024), and applying Internet of Behavior (IoB) techniques for more precise behavioral analysis (Embarak, 2022).

Emerging trends in the IALE domain include the use of generative AI (Hardaker & Glenn, 2025), reinforcement learning (Riad et al. 2020), and explainable AI (XAI) (Embarak, 2022). These technologies promise to create highly advanced and personalised learning environments. Additionally, novel approaches such as the Adaptive Personalised Learning Theory (Ejjami, 2024) and predictive analytics for timely interventions (sun, 2024) are emerging to further enhance the effectiveness of these systems.

Table 6. Conceptual Categorization of Subcomponents within the Main Components of Intelligent Adaptive Learning Environments

No.	Main Component	Subcomponents	Description
1	Learner Analysis and Assessment	Performance, strengths, weaknesses, learning patterns	Identifies the learner's current learning status.
2	Learner Modeling and Profiling	Style, skill level, interests, motivation, preferences	Maintains a dynamic learner profile.
3	AI and Machine Learning Technologies	ML, NLP, neural networks, analytics	Supports data analysis and instructional decisions.
4	Adaptive Learning Pathways	Personalised sequencing and progress-based adjustment	Selects and updates the learning route.
5	Content Personalization and Adaptation	Content, difficulty, pace, strategy	Adjusts instruction to learner characteristics.
6	Specialized Tools and Modules	Chatbots, assessment generators, response systems	Provides interaction and learning support.
7	Intelligent Feedback and Interventions	Immediate feedback and targeted support	Responds to performance and learning barriers.
8	Management and Monitoring	Evaluation, monitoring, continuous improvement	Evaluates and improves the whole environment.

This section presents the findings related to the components and subcomponents of intelligent adaptive learning environments. Data analysis revealed that the design of such environments requires consideration of eight key components, each possessing specialized sub-components. These components are designed to collaboratively support the learning process for each individual in a personalised and data-driven manner.

First, learner analysis and assessment, as the most fundamental component, plays a pivotal role in identifying the actual learning status. This analysis encompasses continuous performance evaluation, diagnosis of strengths and weaknesses, and examination of individual learning patterns.

Based on these data, the second component, learner modeling and profiling, becomes feasible. At this stage, a comprehensive profile including learning styles, skill levels, interests, and learner motivations is constructed.

The third component, artificial intelligence and machine learning technologies, employs intelligent algorithms such as machine learning, natural language processing, and neural networks in service of data analysis and instructional decision-making. These technologies form the foundation of the fourth component, adaptive learning pathways, which are designed for each student in such a manner that the most optimal instructional pathway is provided based on individual progress and specific needs.

The fifth step involves content personalization and adaptation, during which content and instructional strategies are dynamically adjusted in accordance with individual characteristics. In parallel, specialized tools and modules, as the sixth component, come into operation, where the utilization of tools such as automated assessment generators, interactive chatbots, and intelligent response systems facilitates and deepens learner interaction with the system.

In the seventh component, intelligent feedback and interventions, through the provision of immediate and targeted feedback and personalised interventions, learning barriers are reduced. Finally, the eighth component, management and monitoring, with its focus on continuous performance monitoring, effectiveness evaluation, and continuous improvement, fulfills the quality assurance role throughout the adaptive learning process.

These eight components provide a comprehensive framework for the analysis, design, implementation, and evaluation of intelligent adaptive learning environments and can be considered a scientific foundation for the development of personalised, artificial intelligence-based educational systems.

Following the extraction of components and sub-components, the relationships among them were examined through thematic analysis and presented in the form of a model. The organization and linkage of these elements were conducted based on a specific theoretical framework, such that the significance of each element in interaction with other elements was

taken into account. These relationships are displayed in the conceptual model illustrated in Figure 2, demonstrating the overall structure of logical connections between elements.

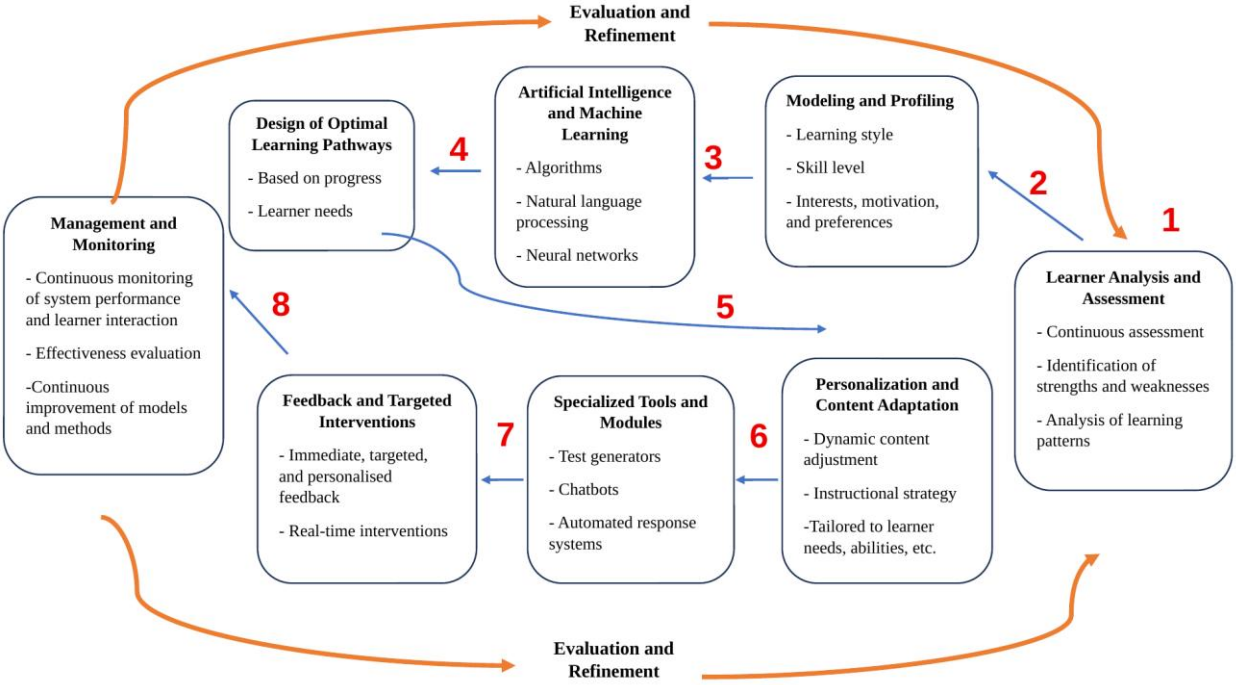

Figure 2. Conceptual model of an intelligent adaptive learning environment

Conceptual Explanation of the Intelligent Adaptive Learning Environment Model

An intelligent adaptive learning environment is a dynamic and integrated system that, through the utilization of advanced artificial intelligence technologies, machine learning, and data analytics, provides a fully personalised learning experience for each learner. This model comprises eight core components that, through coherent interaction with one another, form a continuous cycle of recognition, analysis, decision-making, delivery, and feedback.

Structure and Functionality of the Model

The learning process in this model begins when the learner enters the system. The system immediately commences collecting data pertaining to the learner. These data may include basic information such as age and educational background, as well as behavioral data derived from the learner's interaction with the system. The learner analysis and assessment component processes these data and identifies individual learning patterns. Based on these analyses, the learner modeling stage creates a comprehensive profile of the learner that encompasses their learning style, skill level, interests, motivations, and preferences. This profile is continuously updated with new data to reflect an accurate and current representation of the learner's status.

At the core of this system lies artificial intelligence and machine learning, which, through the employment of advanced algorithms, analyzes learner data and makes intelligent decisions to guide the learning process. The adaptive learning pathways stage designs an optimal learning path for each learner. This path is dynamically updated according to the learner's progress. The decisions made are transferred to the content personalization and adaptation stage, which

undertakes the responsibility of selecting and adjusting educational content in accordance with the learner's needs and capabilities.

To facilitate and enrich the learning experience, the specialized tools and modules stage provides a collection of interactive tools, support chatbots, assessments, and educational resources to the learner. These tools are designed to be compatible with the learner's needs and preferences. Throughout this pathway, the evaluation and feedback stage continuously assesses the learner's performance and delivers personalised feedback. Furthermore, upon identifying learning difficulties, it designs and implements targeted interventions.

Finally, the management and monitoring stage oversees the performance of the entire system and evaluates the effectiveness of instructional strategies. This stage contributes to the development and enhancement of the system through continuous improvement of patterns and instructional methods. Learning outcomes represent the end of one cycle and the beginning of a new one, and this process continues perpetually, such that the system is constantly learning, adapting, and improving.

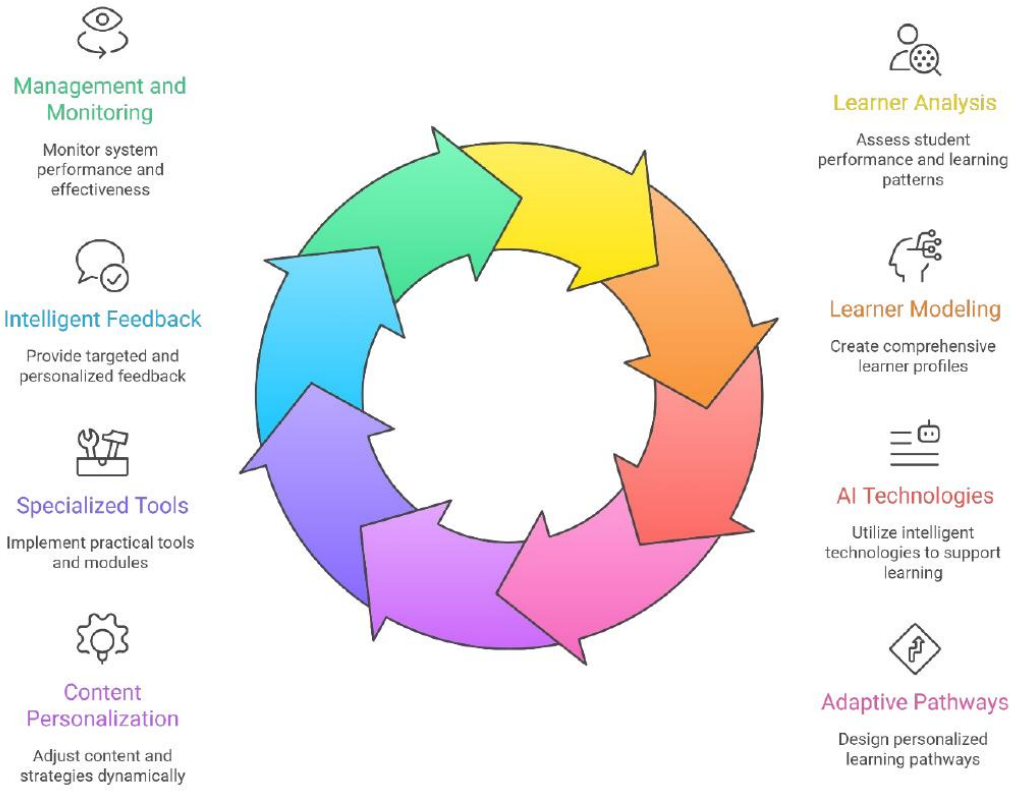

Figure 3. Cycle (process model) of the intelligent adaptive learning environment

Conclusion

The present study aimed to design a model for intelligent adaptive learning environments through the identification and categorization of its key components based on a systematic review of the scientific literature. The findings revealed that designing such environments requires simultaneous attention to eight core components that, through dynamic interaction with

one another, form an integrated cycle of recognition, analysis, decision-making, delivery, and feedback. These findings are not only aligned with constructivist and self-regulated learning theories articulated in the study's theoretical framework, but also go beyond them by elucidating how these theories become operationalized in digital, AI-based spaces. While constructivist theory emphasizes the active construction of knowledge by learners, the findings of this study demonstrate that intelligent adaptive environments, by providing tools for learner analysis, learner modeling, and personalised learning pathways, create a platform in which knowledge construction is not only realized but also guided and supported with greater speed and precision.

Comparison of the findings of this study with prior research reveals both alignment and increased depth in understanding the nature of adaptive learning environments. Previous studies such as those by Akavova et al. (2023), Rane et al. (2023), and Zhang (2024) have addressed discrete dimensions of these environments: personalised feedback provision, dynamic adjustment of instructional strategies, student profiling, and continuous assessment; However, these studies have been predominantly unidimensional, focusing on one or several specific aspects. The added value of the present research lies in its use of a systematic review approach and extensive qualitative content analysis to organize these scattered components into an integrated, multilayered, and interactive framework. In other words, while the existing literature has addressed "what" is needed, this study explicates "how" these elements systematically interconnect and the role each plays in the overall adaptive learning cycle.

From a theoretical perspective, the proposed model of this study adds greater depth to theories of educational personalization and adaptive learning. To date, self-regulated learning theory has emphasized learners' metacognitive capabilities in goal setting, progress monitoring, and strategy adjustment, but has largely overlooked the technological supports underlying these processes. The findings of this study demonstrate that AI and machine learning components—including deep learning algorithms, natural language processing, and neural networks—not only enable continuous monitoring but also, through identifying learning patterns, predicting knowledge gaps, and providing targeted interventions, fulfill the role of an "intelligent cognitive scaffold. This finding, in contrast to the traditional view of self-regulated learning which placed responsibility primarily on the learner, suggests a collaborative human-machine model in which intelligent systems act as active partners in the learning process.

Moreover, the proposed model addresses the conceptual gap between theory and practice in the field of adaptive learning. Many studies such as those by Murtaza et al. (2022), Tetzlaff et al. (2021), and Maghsudi et al. (2021) have pointed to practical challenges in these environments: collecting and analyzing sufficient data, algorithm calibration, privacy concerns, and scalability. The findings of this research demonstrate that these challenges emerge not in isolation but in interaction with one another, requiring a systemic approach. For instance, the "learner analysis and assessment" component is directly linked to "AI and machine learning technologies, and without a robust data infrastructure and accurate algorithms, learner modeling will not be possible. Similarly,"intelligent feedback and interventions" without adaptive

learning pathways and content personalization would lack context and effectiveness. This systemic understanding constitutes a key point of differentiation between this study and previous research.

From a practical standpoint, the results of this study have several direct implications for instructional designers, educators, and developers of digital learning systems. First, this model serves as an operational roadmap for designing and implementing adaptive learning systems. Instructional designers can use this framework to ensure that no critical component is overlooked and that all elements work harmoniously in service of personalised learning experiences. Second, the emphasis on the "specialized tools and modules" component demonstrates that successful adaptive environments require not only sophisticated algorithms but also intelligent user interfaces, chatbots, automated assessment systems, and interactive tools that enrich and make the learning experience more accessible. Third, the emphasis on "management and monitoring" points to the fact that intelligent adaptive learning environments cannot operate statically; they require continuous evaluation, ongoing improvement, and strategy adjustment based on feedback data. This finding aligns with agile approaches in software development and the emphasis on feedback loops in instructional design.

Nevertheless, the limitations of this research must also be considered. Although the analysis of 56 scientific articles provided a broad foundation for component extraction, this study is inherently theoretical and literature-based, requiring empirical validation in real educational contexts. Furthermore, while the focus on articles published between 2020 and 2025 ensures the currency of results, it may overlook certain historical and evolutionary perspectives. Additionally, most of the reviewed studies originated from countries such as India, the United States, and China, which may reflect more limited cultural and contextual diversity. Future research should address empirical testing of this model in diverse educational settings, examination of component effectiveness across different cultural and academic contexts, and optimization of human-machine interaction in these environments.

In conclusion, this research has made a valuable contribution to expanding the boundaries of knowledge in the field of intelligent adaptive learning environments by presenting a comprehensive and integrated conceptual model. This model not only provides a theoretical foundation for deeper understanding of personalised learning processes but also offers practical guidance for developers, teachers, and educational policymakers in the design, implementation, and evaluation of AI-based educational systems. Given the rapid evolution of artificial intelligence technologies and the growing need for personalised education in the digital age, the presented model can serve as a starting point for a new generation of learning systems that are not only more intelligent but also more human-centered and better aligned with learners' real needs.

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