Designing Multi-Tenant E-Learning Systems in the Cloud: A Process-Oriented Approach for Higher Education

Sameh Azouzi
Laboratory RIADI-GDL,
ENSI, Manouba, Tunisia

Sonia Ayachi Ghannouchi
Laboratory RIADI-GDL,
ENSI, Manouba, Tunisia

ABSTRACT
This study examines the shortcomings of conventional Learning Management Systems (LMSs) and introduces a cloud-based solution tailored to the varied requirements of higher education institutions. It proposes a configurable and reusable multi-tenant e-learning process, modeled using the Business Process Feature Model (BPFM). This model integrates principles from Software Product Line (SPL) engineering and Business Process Management (BPM), enabling dynamic scalability, flexible deployment, and efficient resource sharing. The approach is validated through a real-world case study, which highlights its practical benefits and its capacity to improve flexibility, collaboration, and cost-efficiency in modern e-learning environments.

Keywords
E-learning process, Cloud computing, Business process, Virtual laboratoires

1. INTRODUCTION
The importance of e-learning systems has significantly increased, particularly during the COVID-19 pandemic, which compelled educational institutions worldwide to shift toward remote learning. These systems provide continuous access to educational resources and support personalized learning experiences, enabling learners to progress at their own pace and according to their specific needs.

Despite the advancements of well-known platforms such as Moodle, Claroline, and WebCT, traditional Learning Management Systems (LMSs) continue to exhibit limitations regarding flexibility, scalability, and collaborative functionality.

To address these challenges, the present study proposes a cloud-based solution aimed at enhancing e-learning environments through a configurable multi-tenant learning process, modeled using the Business Process Feature Model (BPFM). This approach enables the creation of adaptive, scalable, and collaborative infrastructures tailored to the heterogeneous requirements of educational institutions.

Cloud computing is increasingly regarded as a transformative paradigm, offering infrastructure, software, and diverse services on demand via the Internet, with a billing model based on actual usage [2]. Building on these advantages, the proposed solution focuses on the design and management of an online collaborative learning process that overcomes key limitations of conventional LMSs.

The proposed system comprises two core components. The first is a reusable, configurable, and collaborative learning process, developed through the integration of principles from Business Process Management (BPM) and Software Product Line (SPL) engineering. The second component involves deploying this process in the cloud as a Business Process as a Service (BPaaS), enabling dynamic adaptation and cost-effective delivery.

To validate the feasibility and benefits of the model, a real-world case study is presented, demonstrating the impact of cloud infrastructure on the delivery of practical learning modules.

The remainder of this paper is structured as follows: Section 2 discusses the role and benefits of cloud computing in e-learning. Section 3 outlines the methodology, including the proposed architecture and the use of BPFM for process modeling. Section 4 reviews related work. Section 5 presents the conclusion and future research directions.

2. IMPACT OF CLOUD COMPUTING ON E-LEARNING
The adoption of cloud computing in higher education has expanded rapidly in recent years. According to a 2014 Campus Computing survey involving 470 higher education institutions [1], 68% of respondents utilized cloud services for conferencing and collaboration, 65% for storage, 65% for office and productivity tools, and 62% for messaging. These statistics reflect the increasing reliance on cloud-based technologies in educational contexts. Within this framework, e-learning delivered via the cloud can be interpreted as a form of Education-as-a-Service, and more specifically, as Software-as-a-Service (SaaS).

The integration of cloud computing into e-learning environments offers several key advantages:

Cost Reduction: Cloud-based solutions reduce the need for costly software licenses and frequent updates. Additionally, their inherent flexibility enables experimentation and iterative improvements at lower cost [2].

Flexibility: Institutions can easily test, modify, and compare various educational tools and environments using cloud infrastructure—capabilities that would be prohibitively expensive in traditional on-premise systems [3].

Elasticity: Conventional LMSs often encounter scalability issues when faced with a surge in concurrent users. Cloud infrastructure addresses this by allowing dynamic resource allocation at the Infrastructure-as-a-Service (IaaS) level, which enables institutions to scale capacity based on real-time demand. This eliminates the need for overprovisioned hardware and reduces operational costs.

Variability and Configuration: Institutional and learner needs differ significantly across contexts. Cloud platforms enable educational workflows to be tailored accordingly. This configurability aligns with the Business Process as a Service (BPaaS) paradigm, which allows institutions to customize learning processes while maintaining a shared infrastructure. This perspective builds on earlier work addressing variability in e-learning processes [4].

Reusability: Centralizing learning processes in the cloud facilitates their reuse across multiple institutions, courses, or user groups. A well-designed process model can be instantiated in various contexts, thereby enhancing efficiency and consistency.

Collaboration: Cloud-based environments promote two forms of collaboration. First, they provide reusable workflows accessible to educators and learners across different institutions. Second, by integrating Web 2.0 tools such as document sharing, discussion forums, and real-time communication, they foster active engagement among all participants in the learning ecosystem.

3. PROPOSED APPROACH FOR COLLABORATIVE E-LEARNING PROCESS IN THE CLOUD

As outlined in the previous section, cloud-based e-learning systems exhibit several critical characteristics that support scalable, flexible, and collaborative learning environments. Prior to presenting the proposed process model, this section introduces the foundational concepts that shape its design: multi-tenancy, variability, and Business Process as a Service (BPaaS).

3.1 TextMulti-tenancy

Multi-tenancy is a core attribute of cloud computing, allowing a single application instance to simultaneously serve multiple users, or tenants. A multi-tenant system offers each user a customized experience while maintaining efficient resource utilization and simplified system management.

From the perspective of the service provider, multi-tenancy reduces operational costs and enhances scalability through centralized development, maintenance, and updates. Each tenant may have distinct and evolving requirements, making customization an essential feature of any multi-tenant architecture. The extent of customization is typically determined and controlled by the provider [5].

Multi-tenancy involves balancing two often competing requirements: isolation and sharing [6]. Tenants usually require strict data and configuration isolation for security and autonomy, while also benefiting from shared services and infrastructure that enable efficient system operation.

Scalability within a multi-tenant environment is vital, as the system must be capable of accommodating increasing numbers of users, learning processes, and simultaneous requests. This adaptability is particularly relevant in academic settings, where usage may fluctuate significantly depending on institutional schedules, class sizes, or specific pedagogical activities.

3.2 Variability

The effective management of variability is critical to ensuring the reusability, flexibility, and scalability of multi-tenant applications. In cloud-based systems, variability arises across multiple dimensions, including application behavior, business processes, deployment strategies, platforms, and service providers [7].

This study focuses specifically on business process variability, whereby each educational institution (tenant) can select or configure subprocesses according to its unique pedagogical needs. Such configurability enables the creation of customized learning workflows within a shared technical infrastructure.

Abu-Matar et al. [8] distinguish two main forms of variability: customer-driven and realization-driven. Customer-driven variability refers to tenant-specific functional requirements, such as different learning activities, instructional sequences, or evaluation methods. In contrast, realization-driven variability encompasses the implementation strategies used to fulfill those functional needs.

The proposed model incorporates design decision variability as a mechanism to address realization-driven variability. This approach enables both high-level customization and streamlined deployment across tenants, thereby supporting the development of configurable, scalable, and maintainable e-learning processes [9][10].

3.3 Business Process as a Services (BaaS)

The proposed approach conceptualizes the e-learning process as a configurable, multi-tenant business process deployed in the cloud following the Business Process as a Service (BPaaS) paradigm. According to the National Institute of Standards and Technology (NIST) [11], cloud services are typically classified into three primary layers:

Infrastructure as a Service (IaaS): provides fundamental computing resources such as storage, networking, and virtual machines.

Platform as a Service (PaaS): offers environments and tools for developing, testing, and deploying applications.

Software as a Service (SaaS): delivers fully functional, web-accessible applications.

Positioned above these layers, BPaaS provides not only software functionalities but also the executable logic of complete business processes as services [12]. In the context of e-learning, BPaaS allows educational institutions to define, configure, and execute complex pedagogical workflows directly in the cloud, without the need to manage or maintain the underlying infrastructure or middleware.

Figure 1 presents the layered structure of cloud services, highlighting BPaaS as the highest level of abstraction in this model.

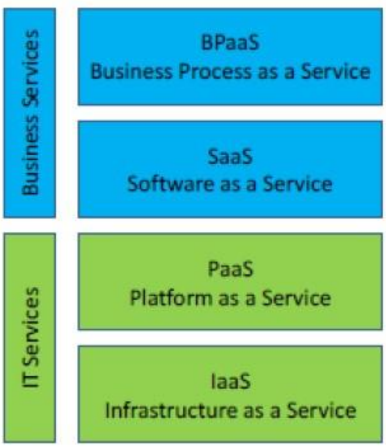

Fig 1: Classification of Cloud Services

Additional perspectives on the application of BPaaS and the challenges it entails are detailed in [13].

3.4 Proposed learning process model

Various modeling notations have been introduced to support multi-tenant configurable business processes, including BPMN, EPC, BPMT, vrBPMN, C-iEPC, and C-YAWL. However, as shown in [14], these notations often lack explicit mechanisms for modeling variability, which limits their applicability in scenarios requiring simple and scalable customization.

To address this limitation, the present approach adopts the Business Process Feature Model (BPFM) [15] to model variability in the proposed e-learning process. BPFM combines two established paradigms: Feature Models from Software Product Line (SPL) engineering, and Business Process Model and Notation (BPMN) from Business Process Management (BPM). The BPFM starts with a general process model, offered by the service provider, which includes all potential features or learning activities. From this comprehensive model, tenant-specific configurations are generated, resulting in customized BPMN instances tailored to institutional needs.

The SPL paradigm is particularly well suited for modeling process variability, as it focuses on building software systems from reusable core assets [16]. It distinguishes between commonalities and variabilities across different products or processes [17]. In this context, features can be categorized as:

Mandatory: always included,

Optional: selectable by the tenant,

Alternative: one selection among a set,

Or-group: one or more selections among a group [9].

SPL techniques enable efficient management of variability and support the development of adaptable, evolvable systems. In particular, Dynamic SPLs allow for runtime adaptation, which is critical in e-learning environments where user needs and contexts may frequently change [9].

Figure 2 illustrates a segment of the proposed BPFM-based learning process model. This model is inspired by pedagogical frameworks described in [18] and [19], and emphasizes learner–instructor interaction, process customization, and collaborative learning. The model is organized into four levels and includes five key subprocesses:

- Scripting
  This subprocess involves defining the course objectives. It is a mandatory activity and is present in all configurations.
- Inform
  This stage provides learners with access to pedagogically curated resources such as documents and web links. The delivery of materials is aligned with specific phases of the course and tailored to learners' tools and needs.
- Interact
  This subprocess fosters interaction through collaborative activities such as group work and thematic debates. These activities enhance scientific reasoning by exposing students to diverse perspectives and encouraging argumentation.
- Produce
  Students synthesize information from various documents, either individually or collaboratively. The emphasis is on the creation of knowledge, not simple summarization. Activities include:
  - Writing an individual synthesis,
  - Writing a group synthesis, both supported by Web 2.0 collaboration tools.
- Formative Evaluation
  This stage includes projects and assessments (e.g., multiple-choice questions, open-ended quizzes) to evaluate learners' understanding and guide further improvement.

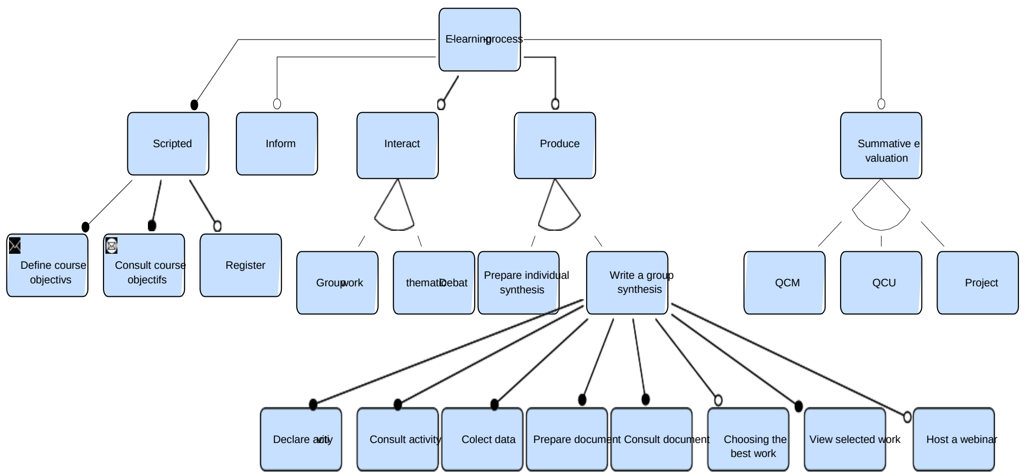

Fig 1: Figure 2. Configurable learning process

The proposed model emphasizes collaboration and communication among all stakeholders in the learning process. To support these interactions, various cloud-based tools are integrated within each subprocess, including Google Docs, Google Drive, discussion forums, and webinars.

As an illustrative example, the "Write a Group Synthesis" subprocess is examined in detail to demonstrate the collaborative dimension of the model. This subprocess consists of the following eight activities:

Declare Activity – The instructor defines and shares the objectives and expectations of the task (Mandatory).

Consult Activity – Learners review the task description and associated requirements (Mandatory).

Collect Data, Prepare Document, Share with Teacher – Students divide into subgroups, gather relevant content, and prepare a shared document collaboratively (Mandatory).

Consult Submissions – The instructor reviews the submitted documents and selects the most representative or complete work.

Host a Webinar – An optional live session is held by the instructor to present selected group outputs and encourage interactive discussion (Optional).

Once the general BPFM model is defined, educators and institutions can generate tailored process configurations that align with their specific pedagogical objectives and infrastructure capabilities.

The next section presents a real-world case study in which the proposed model is applied during a synchronous learning session. This example illustrates the operational benefits of cloud-based deployment compared to traditional institutional systems.

3.5 Use case

A case study was conducted to evaluate the integration of cloud computing in the delivery of a practical module entitled “Free Software-Based Development” at the ISIMM Institute, University of Monastir. This module aims to develop student competencies in web technologies, including HTML, CSS, JavaScript, and PHP. Two delivery modes were compared:

Traditional on-campus infrastructure, reposant sur les laboratoires informatiques locaux.

Virtual lab hébergé via des services cloud, offrant un accès à distance aux mêmes outils et environnements de développement.

L’analyse porte sur trois dimensions principales :

Workflow pédagogique, en examinant l’organisation des activités et la séquence d’apprentissage,

Outils logiciels, en comparant les technologies mises à disposition et leur ergonomie,

Implications financières, avec un focus particulier sur la consommation de ressources CPU et son impact sur le coût global.

3.5.1 Pedagogical Workflow and Software Requirements

The module is organized into a sequence of practical sessions that guide students through the essential phases of web development: requirements specification, design, implementation, testing, and final presentation. These stages are designed to support both individual and collaborative learning, culminating in the creation of personal websites and dynamic web applications developed in teams.

Table 1 outlines the main pedagogical tasks associated with each phase, along with the corresponding software tools required to complete them.

Table.1:Phases of website development

Phases	Tasks and software requirements
Specifications	Internal and external communication; task planning viashared agendas.
Design	UML modeling with Rational Rose.
Implementation	Database creation using MySQL; project developmentin NetBeans IDE; database connectivity.
Testing	Performance evaluation using tools like Google PageSpeed Insights.
Presentation	Final demonstration to a panel of instructors and experts.

3.5.2 Virtual Labs and Cloud Infrastructure

Cloud-based virtual laboratories provide educational institutions with scalable, on-demand access to computing, storage, and networking resources, typically provisioned through commercial providers such as Amazon Web Services (AWS). These resources are delivered over the internet and billed according to actual usage, which eliminates the need for significant upfront investments in physical infrastructure.

This model enables academic programs to expand dynamically in response to user demand, offering flexibility for both instructors and learners. Furthermore, existing literature indicates that cloud-based solutions can achieve cost reductions of up to 25 times compared to traditional institutional computing environments [20].

3.5.3 Cost Comparison: Institution vs Cloud Infrastructure

To evaluate the economic implications of cloud-based infrastructure in education, a comparative cost analysis was conducted. Assuming that each of the 30 students requires 21 hours of CPU time per semester (1.5 hours per week), Table 2 presents the average pricing of cloud services from major providers over a five-year period.

Table.2: Average pricing of cloud computing services [21]

Provider	CPU/hour	Bandwidth/month	Storage/month
Amazon	0.11$	0.12$	0.15$
Google	0.10$	0.11$	0.15$
Microsoft	0.12$	0.125$	0.15$

According to prior studies [20], CPU usage represents approximately 63% of the total cost of cloud computing resources, whereas storage and bandwidth contribute less significantly. As such, the cost analysis focuses primarily on CPU usage:

- Cloud CPU cost per student per semester: 0.11 × 21 = $2.31
- Cloud CPU cost per student over 5 years: 2.31 × 5 = $11.55
- Estimated cost of institutional infrastructure: approximately $500 per student over 5 years (excluding maintenance, electricity, and licensing costs)

This comparison clearly demonstrates that cloud-based infrastructure offers a substantial cost advantage for CPU-intensive educational activities. The difference is further amplified when factoring in hidden institutional costs such as hardware renewal, energy consumption, and proprietary software licensing.

The case study highlights the practical and economic benefits of adopting cloud-based virtual laboratories for web development training. Cloud infrastructure provides scalable, cost-effective, and flexible learning environments, offering access to professional-grade tools without the financial burden of traditional infrastructure. These advantages are particularly relevant for institutions with limited resources aiming to modernize their pedagogical approaches.

3.5.4 User Feedback and Practical Considerations

During the implementation of the cloud-based learning process, feedback from both students and instructors was generally positive. To capture user perceptions, a structured questionnaire was administered, focusing on four key criteria: ease of access, collaboration, system performance, and overall satisfaction.

Students particularly appreciated the ability to remotely access development environments without the need for local installations or high-performance hardware. This flexibility proved especially valuable for learners using personal or shared devices. From the instructors' perspective, the centralized management of resources facilitated student supervision and reduced the technical workload typically associated with traditional on-site setups.

Nevertheless, several practical challenges were identified. The effectiveness of the model depends heavily on reliable internet connectivity, which may be lacking in under-resourced or rural regions. Some students reported occasional latency during peak usage periods, and a minority expressed initial difficulty in adapting to the cloud-based interface. Additionally, the setup of the virtual lab required a degree of technical expertise that may not be readily available in all academic institutions. These observations underscore the importance of providing adequate training and support for both learners and educators when implementing cloud-based educational systems.

A summary of the simulated questionnaire results is presented in Table 3.

Table.3: Evaluation Results Based on Key Quality Criteria

Criterion	Average Rating (1–5)	Observation
Ease of Access	4.6	Most users found the platform intuitive and easy to navigate
Collaboration	4.2	Cloud tools supported effective teamwork among students
System Performance	3.9	Minor latency was observed during peak usage times
Overall Satisfaction	4.4	Participants expressed high overall satisfaction with the system

3.5.5 Detailed Analysis and Extended Evaluation

To provide a more comprehensive assessment of the proposed cloud-based e-learning system, this study extends the evaluation across multiple dimensions, emphasizing quantitative and qualitative metrics.

Cost Efficiency Analysis

Figure 3 illustrates a comparative cost analysis between traditional institutional infrastructure and cloud-based services over a 5-year period for a cohort of 30 students. The data highlights that cloud computing dramatically reduces costs, with an approximate 43-fold decrease in CPU-related expenses per student. This cost advantage is critical for resource-constrained educational institutions seeking to modernize their infrastructure without significant capital investment.

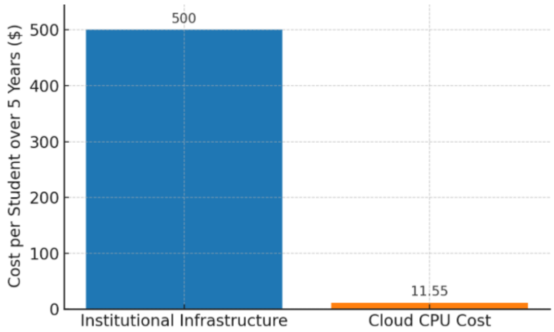

Fig3. User feedback radar chart based on questionnaire ratings across four criteria

Beyond cost considerations, the system's impact on pedagogical workflow was assessed by analyzing the sequence and management of learning activities. Cloud services enabled seamless scheduling, real-time resource sharing, and collaborative student engagement. These features contributed to increased flexibility in course delivery and improved student satisfaction, as reflected in the user feedback summarized in Table 3.

User Satisfaction and System Performance

Figure 4 presents a radar chart visualizing the average ratings from the user feedback questionnaire across four key criteria: Ease of Access, Collaboration, System Performance, and Overall Satisfaction. While the system performed well in accessibility and collaboration, minor latency issues slightly affected perceived system performance, suggesting opportunities for optimization.

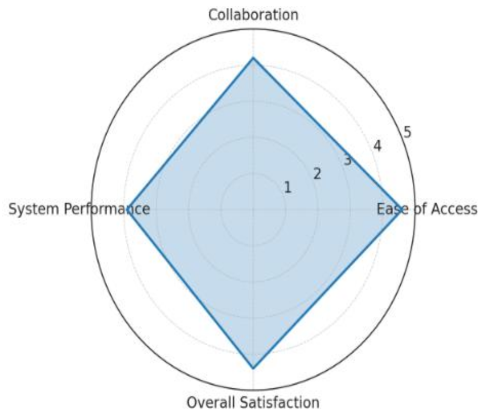

Figure 4. Radar Chart Representing Student Feedback on the Cloud-Based Learning System

Limitations and Future Work

This evaluation primarily focuses on a single course module and a limited user group. Future work will explore diverse course types, larger cohorts, and additional performance metrics such as network latency and system uptime. Furthermore, integrating AI-driven analytics could enhance real-time adaptation and personalized learning pathways.

4. RELATED WORK

In recent years, the use of cloud computing technologies has expanded significantly across various domains, including education and e-learning. The widespread adoption of Software as a Service (SaaS) is exemplified by platforms such as Gmail, Google Workspace, and Lotus Live, which have demonstrated the scalability and accessibility of cloud-based systems for general use. These same advantages are increasingly being leveraged in the context of educational delivery.

Multiple studies [22]–[25] have investigated the integration of cloud computing into e-learning to enhance flexibility, scalability, and system efficiency. For example, Ouf et al. [34] introduced a cloud-based e-learning model combining SaaS with Web 2.0 technologies to better address learners' expectations. Their model highlights benefits such as improved availability, cost-efficiency, risk management, and operational performance, with a particular emphasis on platforms like Google App Engine.

Aljenaa et al. [33] proposed a cloud-oriented e-learning architecture composed of two layers: (i) a cloud software platform that incorporates LMS functionalities along with collaborative and communication tools, and (ii) a management layer that ensures effective system operation and learner support throughout the educational process.

Another notable contribution is presented in [35], which introduces a centralized, shared "E-learning as a Service" model. This approach aims to unify multiple institutions under a common service-oriented infrastructure, promoting inter-institutional collaboration, resource sharing, and standardized content delivery.

In [32], an innovative architecture was proposed using mobile agents that act as intermediaries between learners and cloud resources. These agents personalize learning paths by adapting instructional content based on learner profiles and dynamically managing service selection and resource allocation.

Table 4 provides a comparative overview of the main contributions from these studies, focusing on key technical and pedagogical dimensions, including:

Cloud computing service model used (IaaS, PaaS, SaaS),

Application of Business Process Management (BPM) for learning workflow design,

Support for synchronous and asynchronous collaboration,

Personalization mechanisms,

Integration of multi-tenancy,

Cost optimization strategies.

Despite these contributions, most related studies provide predominantly high-level strategies for migrating traditional e-learning systems to cloud platforms. Additionally, they often lack concrete mechanisms to fully exploit cloud capabilities such as elasticity, scalability, and variability management.

The present approach seeks to address these limitations by proposing a comprehensive and configurable multi-tenant e-learning system. This system prioritizes process reusability, real-time adaptability to both institutional and learner-specific requirements, and explicit cost control enabled by cloud-native resource management techniques.

Table.4: Evaluation of previous approaches

	Cloud	BPM	Collaoration	Personalization	Multi-tenancy	Cost
Al-rouan et al., 2020, [25]	+	-	-	-	+	+
Kilanko et al., 2019, [28]	+-	+	+	-	+	+
Hendradi et al., 2019, [29]	+	-	+	-	+	-
Qwaider,2017, [26]	+	-	-	-	+	+
Naik et al., 2017, [27]	+	-	-	-	+	+
Kushwah et Bajpai, 2017, [24]	+	-	+	-	+	-
Arpaci, 2017, [30]	+	-	+	-	+	+
Bitar, 2017, [31]	+	-	+	-	+	-
Babu et al.,2014, [32]	+	-	-	-	-	-

Aljenaa& al., 2011, [33]	+	+	+	-	-	-
Ouf et al., 2010, [34]	+	+	+	-	-	-
Al Noor et al., 2010, [35]	+	-	-	-	-	-
ProposedApproach	+	+	+	+	+	+

5. FUTURE DIRECTIONS: INTEGRATING ARTIFICIAL INTELLIGENCE INTO CLOUD-BASED E-LEARNING

With the continuous evolution of educational technologies, the convergence of artificial intelligence (AI) and cloud computing represents a significant advancement in the development of adaptive and intelligent e-learning systems. The integration of AI within cloud-based e-learning platforms facilitates dynamic personalization of learning paths, real-time analytics, cognitive tutoring, and intelligent content recommendation.

Recent studies underscore the growing importance of AI in enhancing the adaptivity and responsiveness of e-learning environments. For example, Zhang and Li (2023) highlight the benefits of embedding AI algorithms into cloud-native learning platforms to deliver scalable and individualized educational services [36]. Similarly, Al-Rousan et al. (2023) demonstrate how machine learning techniques integrated within cloud infrastructures enable monitoring of learner behavior and dynamic content adjustment [37].

Furthermore, cloud-based AI supports advanced functionalities such as predictive modeling of student performance, semantic analysis of educational content, and automated generation of feedback. Chen and Patel (2024) argue that combining AI with cloud scalability introduces unprecedented flexibility for large-scale, multi-tenant e-learning systems [38]. This is particularly relevant for Business Process as a Service (BPaaS) models, where AI can optimize process flows and orchestrate learner interactions across multiple institutions.

From a data standpoint, the proliferation of sensor-generated and LMS-based educational data opens new avenues for AI applications in adaptive learning. Bitar (2023) demonstrates that integrating Internet of Things (IoT) data with cloud analytics enhances the contextualization of content, particularly in skills-based domains such as cybersecurity [39]. Additionally, Kilanko et al. (2023) propose intelligent learning environments that facilitate incremental knowledge construction through automated performance evaluations [40].

Looking forward, future research may focus on the application of generative AI models—such as large language models (LLMs)—to support personalized tutoring, conversational learning, and automated curriculum generation. The computational elasticity and scalability of cloud infrastructure provide a robust foundation for such AI-intensive services.

Moreover, emerging approaches like federated learning and explainable AI (XAI) offer promising solutions to privacy and transparency challenges, while preserving system performance.

In summary, the integration of AI and cloud computing holds transformative potential for creating the next generation of adaptive, intelligent, and equitable e-learning ecosystems.

6. CONCLUSION

This paper has examined the impact of cloud computing on e-learning systemsand reviewed various approaches that harness cloud technologies to enhance educational environments. Although numerous models have been proposed in the literature, most remain exploratory and constitute preliminary efforts toward fully leveraging cloud capabilities to develop adaptive and scalable e-learning platforms.

The proposed approach addresses key limitations inherent to traditional Learning Management Systems (LMSs) by introducing a collaborative, reconfigurable, and cost-effective e-learning process. This model integrates principles from Software Product Line (SPL) engineering and cloud computing, enabling educational institutions to dynamically customize learning workflows while optimizing resource utilization. A real-world case study was presented to validate the model, demonstrating the advantages of cloud infrastructure over conventional institutional setups.

Furthermore, the rapid evolution of educational technologies has fostered the emergence of adaptive e-learning, which empowers learners to progress at individualized paces and follow personalized learning trajectories based on their interests and behaviors. The widespread proliferation of devices and sensors globally generates vast amounts of educational data.

The analysis of such data through machine learning and data analytics is increasingly pivotal in uncovering insights and patterns that facilitate more effective and personalized learning strategies. Building upon the foundation established in this work, future research will focus on integrating data-driven methodologies to further enhance the adaptability and intelligence of cloud-based e-learning systems.

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