# Enhancing Academic Performance and Instructional Design Compliance through LLM-Integrated Virtual Learning Environments

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# Enhancing Academic Performance and Instructional Design Compliance through LLM-Integrated Virtual Learning Environments.

**Abstract**

Integrating Large Language Models (LLMs) within Virtual Learning Environments (VLEs) presents an opportunity for enhancing academic compliance in higher education, particularly in matching learning outcomes and established educational standards and their compliance. Research indicates that online and hybrid instructional approaches have benefited student performance, particularly in programming courses where flipped and online modalities have shown improved outcomes compared to traditional methods. This is related to the effectiveness of adaptive learning technologies in personalizing educational experiences to meet diverse student needs. Current literature shows several gaps regarding the practical applications of LLMs in enhancing educational outcomes and ensuring adherence to instructional design principles. Then, the following research question emerges: How does an LLM-based deployment enable academic performance and instructional design compliance?

This work aims to answer this question, proposing an LLM-integrated VLE system using an ad-hoc learning representation formalism to represent and analyze student interactions and assess alignment and compliance between teaching and instructional design. A custom architecture has been developed to connect the LLM to the VLE. This system enables critical indicators such as flexibility, adaptability, and compliance, helping instructors adjust course content dynamically based on student needs. The implementation follows the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to progressively ensure an iterative process that improves the teaching and learning experience. A pilot experience was carried out in redesigning and implementing an online Introduction to Programming course. Automated verification and expert validation using ad-hoc tests were applied to evaluate the proper execution of the compliance analysis. Preliminary results show that this approach enhances the alignment of courses with regulatory standards, evidencing the corresponding teaching compliance.

**Keywords:** LLMs, Virtual Learning Environments, academic performance, Instructional Design Compliance, Adaptive Learning Technologies

## Introduction

The digital transformation of education, particularly in higher education, has been accelerated by the need to adapt to changing circumstances, such as the COVID-19 pandemic. This shift has led to the widespread adoption of Virtual Learning Environments (VLEs), essential for maintaining educational continuity and personalizing learning experiences. Integrating Large Language Models (LLMs) into these environments presents a promising opportunity to enhance educational outcomes and ensure compliance with instructional design principles. Research indicates that online and hybrid learning approaches have yielded significant benefits in student achievement, especially in technical fields like programming, where innovative methodologies have outperformed traditional teaching methods [1], [2]. Adaptive learning technologies are crucial for customizing educational experiences to meet diverse student needs, promoting flexibility and adaptability within VLEs. Implementing LLMs can enhance this adaptive learning by providing real-time feedback and support, fostering a more engaging educational environment. Studies have shown that generative artificial intelligence tools, such as ChatGPT, can motivate students, increase participation, and offer individualized assistance, thereby improving learning experiences[3], [4]. However, there are notable gaps in the practical application of LLMs within VLEs, as many institutions struggle to integrate these technologies into their instructional frameworks effectively [5].

The proposed research addresses these gaps by exploring how LLMs can enhance academic performance while ensuring adherence to established instructional design principles. By developing a VLE system that incorporates LLMs and employs a formalism of learning representation, the study will analyze student interactions and assess the alignment between teaching practices and instructional design. The research methodology follows the ADDIE model, which encompasses a systematic process of Analysis, Design, Development, Implementation, and Evaluation, ensuring that educational interventions remain relevant and effective [6]. A pilot study conducted within an online Introduction to Programming course will assess the effectiveness of the LLM-integrated VLE system, with preliminary results indicating improved alignment with regulatory standards and enhanced compliance in teaching practices [7]. In conclusion, integrating LLMs into VLEs offers a significant opportunity to enhance educational outcomes and ensure compliance with instructional design principles. By leveraging adaptive learning technologies and personalized approaches, educators can create more engaging and effective learning experiences that cater to diverse student needs. The research seeks to answer the following questions: How does an LLM-based deployment enable academic performance and instructional design compliance? This inquiry aims to contribute to the ongoing evolution of digital education and the pursuit of educational excellence in higher education[8], [9].

## Related work

The transition to Virtual Learning Environments (VLEs) has significantly transformed higher education in recent years, driven by the need to ensure continuity in education and personalized teaching experiences. Hybrid and online models have proven effective in improving academic performance, especially in technical areas such as programming courses [10],[11]. This positive impact is attributed to incorporating adaptive technologies that customize educational content to individual student needs, promoting flexibility, adaptability, and personalized learning [12], [13].

In this context, adherence to quality standards in online instructional design, such as those established by Quality Matters (QM), is essential for ensuring effective, accessible, and coherent learning experiences. These standards address not only course content but also pedagogy, interactivity, accessibility, and assessment, all aimed at enhancing student learning and satisfaction [14], [15], [16]. Implementing frameworks such as QM ensures that online courses meet essential criteria, including clear learning objectives and the alignment of assessments with these objectives, fostering an educational experience that benefits both students and instructors [17], [18].

Large Language Models (LLMs) offer transformative potential in education, particularly their ability to generate, analyze, and personalize content at scale. However, current research reveals critical gaps in the practical integration of these models into educational environments, especially in ensuring alignment with standards like QM and enhancing the alignment of learning outcomes with instructional design goals [19].

Instructional design, mainly through the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), has been widely used to structure effective teaching processes. This model ensures precise alignment between educational goals and learning activities while facilitating iterative improvements in virtual courses. Combined with standards such as QM, it emphasizes the importance of structuring courses that promote effective interaction, appropriate use of technology, and accessibility for all students, including those with disabilities [14], [20].

Recent studies have also highlighted how monitoring and requirements diagnosis, such as the approach proposed by Dounas, can optimize adaptive learning systems by enabling dynamic adjustments and ensuring alignment with specific competencies [21]. These technical capabilities are supported by innovative tools like Petri-Nets, a formalism that facilitates real-time modeling and reconfiguration of complex educational processes, ensuring workflows remain adaptive and robust [22].

Conceptual models like ACTIONS have proven effective in integrating principles of accessibility, cost, and usability during transitions to digital environments [23]. QM standards complement these approaches by emphasizing key areas such as the clarity of objectives, the alignment of materials and activities, and accessibility in course navigation [14].

These advancements also underline the importance of continuous evaluation and improvement in virtual course design. Examples include the redesign of learning modules in development economics [24] or task-based approaches in language teaching [25] underscore how advanced technologies and innovative strategies can significantly enhance student engagement and foster meaningful learning.

While significant progress has been made in digital education, critical gaps remain, particularly regarding the direct integration of LLMs into VLEs to assess and enhance compliance with educational standards. Current literature also does not fully address how these technologies can support the flexibility and adaptability needed to address rapid changes in educational environments. This work aims to bridge these gaps by proposing an LLM-integrated system that, leveraging the ADDIE model and aligning with standards such as Quality Matters, enables the analysis and optimization of student interactions while ensuring compliance with educational objectives.

## Methodology

### *Formal Specification*

In the first phase, an exhaustive review of academic guidelines and instructional design standards from educational institutions and evaluation guidelines was carried out. These guidelines and standards were used to construct a set of rules and parameters that the LLMs can interpret. Based on this analysis, the following key elements were structured:

- Instructional objectives: Classified according to learning levels (e.g., comprehension, application, analysis) to ensure a structured pedagogical approach.
- Assessment guidelines: Based on formats already established by teachers to maintain consistency and regulatory compliance.
- Alignment criteria: Designed to ensure that the guides and assessments generated met the required educational standards.

Design validation was carried out through successive iterations, using LLM queries to analyze the guidelines and provide feedback on their alignment with predefined standards. This unstructured but standards-driven approach ensured that the specification was amenable to analysis and effective use by language models.

### *System Development*

The development of the system was carried out iteratively, following a cyclical approach of design, implementation, and evaluation. This process ensured that each system component responded to the objectives and aligned with academic standards. During the planning stage, the conceptual architecture of the system was defined, which was structured into three main components:

- Frontend (React and Vite): Designed as a dynamic and accessible interface, facilitating user interaction with the system.
- Backend (FastAPI): Planned to manage system logic, process requests, and coordinate communication with the LLM.
- Integration with LLM (Ollama on AWS EC2): Developed as the processing core, in charge of the tasks of generation, evaluation, and verification in real-time.

During this phase, meetings were held with pedagogical experts to identify the functional requirements that the system had to meet. These queries made it possible to define the key parameters for the endpoints and establish how to integrate the system with the LMS Canvas, determining student segmentation and platform design. In addition, the integration with Canvas as an LMS facilitated two-way interaction, allowing students to access personalized content and centralizing the learning process.

*Implementation of Formalism*

The implementation of formalism focused on ensuring that the educational workflow was adaptable and free of blocks, using dynamic queries using LLMs. Although tools such as YAWL (Yet Another Workflow Language) or Ripple Down Rules (RDR) are not directly implemented, they served as conceptual inspiration to develop a more flexible and unstructured approach. Implementation follows these steps:

- Adaptive Workflow Modeling: Based on existing pedagogical guides, rules and parameters were defined to ensure alignment with academic standards and contextual needs.
- Dynamic Consultations and Flexibility: The LLMs analyzed and adjusted workflows in real-time, customizing educational activities according to the emerging conditions captured by the corresponding LMS.
- Validation of Critical Properties: e.g., no blockages, continuous reachability of each pedagogical state, and flexibility.

*Implementation of Instructional Design*

Each endpoint was deployed and tested in a controlled development environment. Functional and comprehensive testing included generating personalized guides and evaluations according to student profiles, automatically evaluating responses with specific feedback, and verifying consistency in academic compliance indicators. The results of these tests demonstrated that the platform aligned with pedagogical objectives and complied with normative standards, ensuring a coherent integration between technical functionalities and educational goals.

## Implementation and results

*Formal Specification*

The development of the formal specification began with a state-of-the-art study in which an extensive database of articles related to e-learning, compliance measurement, adaptability, and flexibility was compiled. This process resulted in a reduced set of key articles that defined the fundamental principles for constructing the formal specification. An iterative approach was chosen as a solution, validating the specification through queries to the LLM. This approach made it possible to verify that the guides generated complied with the defined academic standards.

*Platform design*

Figure 1 shows the overall system architecture, highlighting the interaction between the frontend, backend, the LLM model hosted on an AWS EC2 instance, and the Canvas LMS. This structure ensured interoperability, flexibility, and efficiency in generating, evaluating, and verifying guides and evaluations.

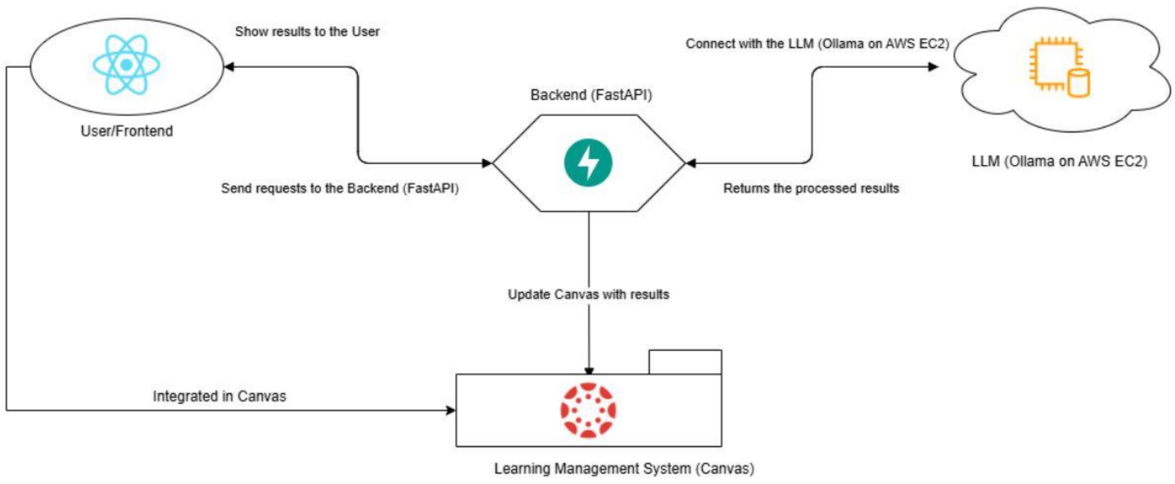


**Figure 1: General Architecture.**

The system's development was iterative, guided by technical decisions and challenges that arose at each stage.

*Selection of Technologies*

Python and FastAPI were chosen for their ability to efficiently integrate advanced AI libraries, such as LangChain, and their robust support for REST APIs. GPT was initially used for testing, but it was necessary to explore open-source alternatives due to confidentiality concerns with the data (guidelines and evaluation guidelines). After discarding options such as Amazon Bedrock due to its cost and model limitations, Ollama was chosen. This model allowed an instance to be deployed on AWS EC2 and listen to requests on port 11434, achieving simple and efficient integration.

Regarding the front end, React + Vite was used to create a simple front end, combining it with Tailwind CSS to stylize the interface. This design allowed for building a functional chat that replicated the system's intended end use, facilitating testing with users and adjusting the model's behavior in a visual environment.

*Model Comparison*

Several LLM models were evaluated, and response times and quality of results were analyzed. The average times obtained were:

- Llama3.1 7b: 48.55s
- Llama3.2 3b: 19.31s
- Mistral-Nemo 12b: 1 m 38.28s
- Mistral 7b: 23.28s

● GPT-4o: 24.37s

Finally, Llama3.2 was selected for its balance between quality and response time. The EC2 machine was configured with limited resources to optimize costs.

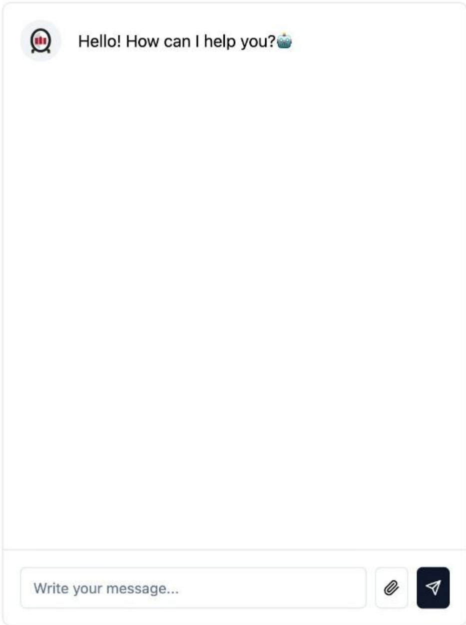


**Figure 2: Example of the graphical interface.**

Challenges at this stage include latency in model responses: The EC2 server configuration has been optimized, and prompts have been adjusted to reduce query times. Also, a simplified interface is needed to ensure that it is intuitive and functional for initial testing, such as choosing a classical chatbot. Activity proposals, deviations, or updates on the corresponding instructional design can be written, and the systems provide guidelines, evaluations, or compliance checking.

*Implementation of Formalism*

Although frameworks such as YAWL or Ripple Down Rules (RDR) were not directly implemented, they served as a conceptual reference for developing a flexible and adaptive system. YAWL inspired the idea of dynamic flows that adjust tasks according to the user's needs. On the other hand, RDR influenced the definition of specific rules to change the guidelines and evaluations in real-time.

Consequently, workflows that model the corresponding instructional design are designed to avoid blockages, adapt in real-time, and maintain reachability. The implemented LLMs processed these rules dynamically, allowing for effective personalization of activities.

*Implementation of Instructional Design*

Each of the system's endpoints was implemented, tested, and validated:

- /generate: Generated personalized guides for the three identified student profiles.
- /evaluate: Evaluated responses automatically, providing specific feedback based on predefined guidelines.
- /compliance: Verified compliance with academic standards.

Target tests were developed over an Introduction to Programming full-online twelve-week course instructional design for engineering students deployed in Canvas. This tool was deployed separately, but the corresponding instructional design was specified using our current formalism. Academic standards were validated for lectures according to Quality Matters specifications, and learning outcomes were expected for the distinct stages of the courses. Test cases corresponding to the generation of programming exercises using /generate endpoint, validation of responses over these exercises using /evaluate endpoint, and updates of instructional design regarding new activities using /compliance endpoint. Some challenges emerged, mainly regarding compliance testing, such as variability in model responses. Prompts were adjusted to ensure more consistent results.

**Discussion**

This work is a direct extension of the research described in [26]. While the previous approach used formal specifications to model educational workflows using Petri-Net, this research opted for a more unstructured approach, using large-scale Language Models (LLMs) to dynamically analyze and adapt learning activities. This change responds to the need for greater adaptability and flexibility in implementing real-time educational workflows.

Previous work established the theoretical basis for flexibility in virtual environments, highlighting the importance of managing exceptions and adapting pedagogical processes to changing contexts. This project takes these concepts to a more direct practical application, integrating advanced natural language processing technologies to personalize and evaluate educational guides while ensuring compliance with academic standards.

During the implementation of this research, several challenges and opportunities for improvement emerged that can guide future iterations of the system.

- Structuring using LLMs: Although the unstructured approach allowed for dynamic adaptations, a more formal framework could improve the system's replicability and efficiency. Incorporating elements inspired by frameworks such as YAWL or RDR, which were not implemented directly, could provide greater consistency in decision-making and facilitate exception handling.
- Infrastructure optimization: Using Ollama on AWS EC2, while functional, presented cost and performance constraints. A future option would be to explore hybrid architectures, where lighter processing requests are handled locally while more complex queries are delegated to more powerful services. In addition, evaluating new open-source models could offer cheaper and faster alternatives.
- Improved interaction between modules: The current integration between the backend (FastAPI), frontend (React + Vite), and LMS (Canvas) worked well in initial testing but

could benefit from a microservices-based architecture to increase scalability and component independence.

Concerning results, the results obtained demonstrate the feasibility of the approach adopted but also reveal critical areas for reflection:

- Architectural decisions: FastAPI was wisely chosen for the backend because of its flexibility and ability to integrate with AI tools such as LangChain. However, reliance on a single language model (Llama3.2) limited customization capabilities compared to GPT-4, although it significantly reduced costs.
- Comparison with previous work: In contrast to the use of Petri-Net in earlier research, the use of LLMs allowed a more dynamic and adaptable analysis, especially in educational settings with high variability. However, the unstructured approach also entails a more significant effort to ensure consistency and validation of workflows.
- Impact on adaptive teaching: One of the system's most outstanding achievements was personalizing educational activities according to student profiles. This validates LLMs' ability to address complex challenges in online teaching, such as personalization and dynamic assessment. However, the long-term impact on student achievement remains to be assessed.

Finally, based on the results and challenges observed, the following lines of research are suggested:

- Formalizing the use of LLMs: Develop a more structured framework for analyzing and generating educational content, integrating elements of YAWL or RDR into decision-making.
- Exploration of emerging models: Evaluate new open-source models with shorter response times and improved capabilities, especially to handle more complex workflows.
- Expanding the scope of the system: Implementing the system in broader and more diverse educational settings to assess its scalability and adaptability to different contexts.

## Conclusions

The results confirm the feasibility of using LLMs to personalize learning and meet academic standards. Among the main achievements are:

- Achievement of objectives: It was possible to build a formal specification based on existing guidelines, validated through consultations with the LLM, and develop a system capable of performing real-time compliance checks.
- Technological contribution: The implemented system provides an adaptable and efficient architecture, integrating open-source tools and learning platforms.
- Educational impact: According to student profiles, personalization optimizes virtual environments' learning experience.

However, there are still areas for improvement and future lines of research:

- Formalizing the use of LLMs: Develop a more structured framework for generating and analyzing educational content, integrating approaches such as YAWL and RDR.
- Infrastructure optimization: Evaluate hybrid architectures and new open-source models to improve performance and reduce costs.
- Scaling Up: Scaling the system for application in various educational contexts and more extensive courses.

In conclusion, this project advances the practical implementation of LLMs in education and opens the door to new opportunities for personalization and adaptability in virtual environments. Integrating advanced technologies with robust pedagogical approaches is essential to transform teaching and learning in the digital age.

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