Bol. Soc. Paran. Mat.
©SPM – E-ISSN-2175-1188
SPM: www.spm.uem.br/bspm

(3s.) **v. 2026 (44) 3** : 1–18.
ISSN-0037-8712
doi:10.5269/bspm.79692

A UML-Driven Framework for Intelligent Collaborative E-Learning

Soufiane Ouariach[1] *, Ziyad Cherradi[2], and Fatima Zahra Ouariach[1]

ABSTRACT: The growth of e-learning has introduced significant challenges related to maintaining learner engagement, facilitating effective collaboration, and offering personalized learning paths. Exciting opportunities are presented by artificial intelligence (AI), but its implementation is frequently not based on any solid foundations of pedagogy. This paper addresses this issue by formally describing a pedagogical scenario using the Unified Modeling Language (UML). The UML model not only describes what happened but also suggests a scenario in blueprint format. This framework synergizes human teamwork with a multi-layered substructure of AI-based support, including conversational agents and intelligent tutors. Using class, use, activity, and sequence diagrams, we specify the system's architecture, actors, and their dynamic interactions. The paper proposes that developing a scenario through formal modeling is an important approach that can bridge the gap between pedagogical intentions and technical realization in developing learning environments that are technologically sophisticated and fundamentally based on solid educational principles.

Key Words: E-learning, pedagogical scenario, unified modeling language, collaborative learning, artificial intelligence in education, personalized learning, instructional design, intelligent tutoring systems.

Contents

1. Introduction

The advent and democratization of digital technologies have catalyzed a substantial transformation of educational paradigms, positioning online learning as an unavoidable and constantly expanding pedagogical modality within the world's educational systems. This modality offers undeniable advantages in terms of wider accessibility, spatio-temporal flexibility and the potential to personalize learning paths [1]. The potential of educational technologies to enhance student engagement has long been recognized [2], however it's not simply a matter of adding technology and students to achieve engagement. Without careful planning and sound pedagogy, technology can promote disengagement and hinder rather than

* Corresponding author.
2020 *Mathematics Subject Classification:* 35K15, 35R30, 65D12, 90C53.
Submitted October 22, 2025. Published January 22, 2026

help learning [3,4]. Nevertheless, the transition to predominantly or exclusively digital learning environments is not without significant challenges. These include the difficulty of maintaining sustained learner engagement [5], the complexity of implementing truly adaptive personalization that responds to the diversity of cognitive styles, prerequisites and learning rhythms [6,7], as well as the need to structure and support distance collaboration that is both productive and socially enriching [8,9]. Collaborative learning is widely recognized for its significant benefits on the cognitive, social and motivational development of learners [10; 11]. In particular, it fosters critical thinking, complex problem-solving and the acquisition of essential interpersonal skills [12]. At the same time, the rise of e-learning and hybrid models has transformed pedagogical practices, offering greater flexibility and accessibility [13]. However, these digital and blended environments present specific challenges, such as maintaining learner engagement, managing cognitive load and facilitating quality social interactions at a distance [14]. Faced with this set of challenges, the reasoned and ethical integration of artificial intelligence (AI) and its various applications, including intelligent agents and tutoring systems, is increasingly being explored as a promising avenue for augmenting the capabilities of e-learning platforms [15;16;17]. From adaptive systems to conversational agents and intelligent tutors, these technologies offer new perspectives for personalizing pathways, providing immediate feedback and orchestrating mediated collaborative activities [18]. Despite this technological potential, one of the major challenges lies in the need for clear, well-structured pedagogical scenarios to guide the effective integration of these digital tools and AI at the service of e-learning. Without rigorous pedagogical design upstream, the risk is that the technology will be used superficially or, worse, unnecessarily complicate the learning experience. The challenge lies in creating a learning ecosystem where learner autonomy is guided, where social interactions are sources of co-construction of knowledge, and where individualized support, mediated by AI, optimizes each individual's learning path [19]. The main contribution of this work is twofold: on the one hand, it highlights the added value of an explicit modeling approach (via UML) for the design and communication of complex pedagogical scenarios integrating advanced technologies. We argue that this approach enables a better understanding of pedagogical needs and associated technical requirements. On the other hand, we offer the proposal of a specific pedagogical scenario, potentially reusable and adaptable, which seeks to articulate human collaboration and intelligent support in an innovative way. The use of the Unified Modeling Language (UML) for e-learning scenario design is justified by its ability to provide a clear visualization and structured conceptualization of complex pedagogical systems, thus facilitating communication and the application of software engineering rigor to instructional design [20;21]. In this work, we have employed the Unified Modeling Language (UML) to meticulously elaborate a pedagogical scenario. This modeling effort is not an end in itself, but rather the foundational step that opens the way for the development of an e-learning system. The primary role of UML here is to serve as a bridge between educational design and technical implementation, ensuring the resulting system is built upon a solid and explicit pedagogical approach. By formalizing the scenario, its actors, and their interactions, we create a robust blueprint that guarantees the system's architecture is intrinsically guided by sound learning principles, which is the central contribution of our methodology.

2. Theoretical Framework

2.1. Collaborative e-learning: foundations and challenges

Collaborative learning, defined as a situation where two or more individuals learn or attempt to learn something together, is firmly established in educational literature as an approach that promotes significant gains on multiple levels. Cognitively, it stimulates critical thinking, complex problem-solving and a deeper understanding of concepts, as learners are led to verbalize their ideas, confront their points of view and co-construct new knowledge [22]. The social interactions inherent in collaboration contribute to the development of essential interpersonal skills, such as communication, negotiation, leadership and the ability to work in a team - crucial assets in today's world [11]. On a motivational level, collaborative learning can increase engagement, perseverance in the face of difficulties and a sense of belonging to a learning community, thereby reducing isolation and fostering a positive attitude towards learning [10]. However, transposing these benefits into Computer-Supported Collaborative Learning (CSCL) is not automatic, and raises specific challenges. One of the main obstacles lies in group cohesion: physical distance, the absence of non-verbal communications and often asynchronous communication can hinder the development of strong interpersonal relationships and a sense of mutual trust, all of which are necessary for successful collaboration [8]. The issue of equitable participation is also of concern: online environments can exacerbate inequalities in participation, where some members dominate exchanges while others remain passive (the "free rider" or social loafing phenomenon), or where learners less at ease with the written word or technology struggle to contribute effectively, which can lead to frustration [9]. Finally, the cognitive load associated with online collaboration can be higher. In addition to the intrinsic load linked to the learning task itself, learners must manage the complexity of technological tools, coordinate their actions at a distance, and process information from multiple communication channels, which can overload their working memory and impair learning effectiveness if the environment is not carefully designed to minimize the extrinsic load linked to these aspects [12]. Addressing these challenges is therefore paramount to harnessing the full potential of collaborative learning in a digital context.

2.2. Personalized learning and e-learning engagement

The transition to digital learning environments has highlighted the crucial need to personalize learning paths in response to learner heterogeneity. Indeed, the implementation of truly adaptive personalization, which considers the diversity of cognitive styles, prerequisites, learning rhythms and individual goals, remains a complex but essential challenge for optimizing pedagogical effectiveness [6;23]. Such adaptation is not limited to simply offering varied content, but aims to create a tailored learning experience that is likely to increase the learner's perceived relevance and, consequently, foster engagement. This engagement, defined as the student's active and invested participation in his or her learning process, is a determining factor in e-learning success, but soliciting and maintaining it represents one of the most significant challenges of distance learning devices [5]. Several factors influence this engagement: the perceived value and usefulness of content, the clarity of objectives, the quality of feedback received, the sense of competence and autonomy, as well as the quality of interactions with peers and teachers [2]. Without careful planning and sound pedagogy, technology, far from promoting engagement, can instead foster disengagement and hinder learning [3;4]. With this in mind, strategies to support engagement rely heavily on personalized approaches. Tailoring resources and activities to the learner's profile, as suggested by recent studies showing improved satisfaction and performance when recommender systems take learning styles into account [24;25;26], can reduce cognitive load and increase intrinsic motivation. Artificial intelligence offers promising avenues here, making it possible to automate some of this personalization by providing adaptive feedback, dynamically adjusting learning paths or recommending specific resources based on learner interactions and performance [15;17;19]. Moreover, individualized and responsive support from the teacher, even mediated by technology, remains a powerful lever for engagement and academic success [27;28]. Thus, personalization, supported by thoughtful instructional design and, potentially, AI tools, appears to be a sine qua non for cultivating lasting and meaningful engagement in e-learning.

2.3. Artificial Intelligence for collaborative and personalized learning

The intersection of artificial intelligence (AI) and education has emerged as a transformative force, reshaping conventional pedagogical paradigms and redefining the possibilities of personalized learning [29;30;31]. It offers tools capable of finely analyzing learners' needs and orchestrating enriched pedagogical interactions. At the forefront of these innovations, intelligent tutors (ITS) stand out for their ability to offer advanced individualized support. These systems can diagnose conceptual gaps with increasing accuracy, model the learner's progress and provide adaptive feedback that guides the student through dynamically adjusted learning paths [32]. The effectiveness of ITS in improving knowledge mastery and reducing learning time has been documented in several studies, particularly in structured fields such as mathematics or science [33]. Technical Intelligence Systems have been used in computer science education to detect and correct misconceptions [34], provide automated assistance when students tackle particularly difficult aspects of programming [35], use peer agents to act as partners in pair work [36], and discuss topics such as program planning [37]. When designing Intelligent Tutoring Systems (ITS), it is essential to observe students' solving processes progressively, in order to spot errors and intervene in good time. The pattern tracing technique achieves this by comparing students' steps with a rule-based expert system. When students make mistakes or incorrect assumptions, the system offers explanatory feedback, hints or recommendations to help them identify and rectify their mistakes. If students advance correctly, the system continues to monitor silently without interruption [38]. In parallel, conversational agents (chatbots) enable human-computer interaction via natural language, applying natural language processing (NLP) technology [39]. Their main role is to provide first-level assistance, instantly answering factual questions [40], guiding users through resources [41], or providing reminders and clarifications about tasks [42]. Although less sophisticated in their pedagogical reasoning than ITS, chatbots contribute to learner autonomy and lighten the load on teachers by managing frequent requests. One of the major advantages of these agents lies in their ability to provide immediate responses, 24/7 [43], which is particularly valuable in distance learning contexts where direct access to a teacher is not always possible. Although chatbots are generally less sophisticated in their pedagogical reasoning than intelligent tutors, which aim for in-depth analysis of the learning process and complex adaptation to individual needs, they make a significant contribution to learner autonomy [44]. By enabling students to quickly find answers to their basic questions, they make them more independent in their learning process and can even encourage self-regulation of their learning [45]. As a result, chatbots considerably lighten the workload of teachers and support staff by filtering and managing a large volume of frequent and repetitive queries [46]. This frees up time for educators, who can then concentrate on higher value-added pedagogical interactions, such as personalized feedback on complex assignments, facilitating in-depth discussions or individualized support for learners in difficulty. Today's challenge is to develop these technologies ethically and integrate them harmoniously into teaching scenarios that maximize their potential while preserving the human dimension of learning.

2.4. Pedagogical scenario on the basis of the unified modeling language

The effectiveness of e-learning, and particularly the successful integration of advanced technologies, is intrinsically linked to the quality of pedagogical scripting. Effective teaching begins with rigorous planning [47], the absence of such planning and sound instructional design can lead to superficial use of technology, or even impede learning [48]. The design of scripting tools for learning activities is a complex process that requires a coherent, well-thought-out plan to ensure successful learning [20]. Pedagogical scenarios are therefore crucial, as they act as a roadmap, defining objectives, the sequence of activities, resources, learner and teacher roles, as well as interaction and assessment modalities. They are all the more important as traditional instructional engineering models have often been criticized for their lack of flexibility and inability to effectively guide the design of complex, interactive digital learning environments [49; 50]. Indeed, the failure of many initiatives is often attributed to poor pedagogical design, which neglects planning for reusability or risk management, for example [51; 52]. Faced with this need for structuring and to overcome the limitations of traditional approaches, the contribution of modeling, particularly derived from the principles of software engineering, is proving fundamental. Instructional designers can greatly benefit from software engineering ideas and techniques to improve their solutions [48]. A study provided a concrete illustration of this approach, highlighting the importance of adopting a systematic and methodical software engineering approach to the development of e-learning projects, with particular emphasis on the conceptualization of pedagogical scenarios [20]. The use of standardized modeling languages such as the Unified Modeling Language (UML) is central to this approach. UML provides a visual representation of the system architecture and informs instructional design decisions [20]. It facilitates communication between different stakeholders (instructional designers, developers, content experts) and collaboration, offering a common language for understanding requirements, specifying solutions and conveying ideas [20; 48]. Whether through class, use case, activity or sequence diagrams (Ouariach et al., 2023), UML modeling helps to break down complexity, analyze interactions, ensure consistency and establish conceptual rigor. This approach helps avoid costly design errors and create more robust, adaptive and meaningful learning environments [53; 54].

3. Modeling Pedagogical Scenarios with UML: A Methodological Approach

With the theoretical command of a coherent pedagogical design defined, we shift our gears to mastering a formalization on a more concrete level. The important next thing is not to design an implementation of a software system, rather it is to carefully design the pedagogical scenario itself. This activity will be a basic methodological decision: to exercise the rigor of a formal modeling language as an instructional design tool. It has as its goal the formulation of a comprehensive unified design plan of the planned learning. With this blueprint, our pedagogical intent becomes clear, none of the roles of the learners, neither the flow of activities, nor the incorporation of support tools can be done without the underpinning of solid educational theory, prior to any technical implementation. By doing so, we aim to bridge the often-cited gap between pedagogical intent and technical execution, creating a common language that educators, designers, and developers can share to ensure the final product is a true reflection of the educational vision. To capture the multifaceted nature of this scenario, our model is organized into two complementary perspectives that provide unique lenses through which to understand the learning process: a static view and a dynamic view. The static view will be the grammar basis of the learning environment. It will determine the minimum actors (Learner, Teacher), the participating structures that enable them (Learner-Group, Wiki-Group), and the intelligent support mechanic that helps them (IntelligentTutor, ConversationalAgent). This perception explains the nature of elements and inherent characteristics of each element and basic relationship that entail linkage of the elements. Basically, the static view determines the who and the what of the situation which details all that is possible to be engaged in and the resources that are at disposition in the learning ecosystem through class and use case diagram. On the contrary, the dynamic view gives the script of learning process narration. It will define the how and when by coordinating the activities through time. This view will plan the planned pedagogical routes, through activity and sequence diagrams, with the starting engagement and group formation, continuing with problem-solving and concluding the process with the final knowledge consolidation. More importantly, it will provide a picture of these decisional nodes, which include a group deciding on its state in need of assistance, and the exact patterns of interaction that ensue, with the role of peer support, AI agents, and human teachers complementing each other in real-time scenarios. We will begin our formalization with the static view, as it provides the essential structural framework upon which the dynamic, interactive elements of our pedagogical scenario are constructed and understood.

3.1. Static view

3.1.1. Class diagram.
The static view of our pedagogical scenario is formally represented by a comprehensive class diagram, which delineates a total of fifteen distinct classes. These classes are not arbitrary; they have been meticulously defined to encapsulate the core actors, structural entities, learning components, AI-driven support mechanisms, and collaborative tools that constitute the learning ecosystem. For clarity, these classes can be organized into five logical groups that reflect their function within the scenario. The verbs between classes indicate the types of relationships and cardinality. For example, a learner may consult one or more information resources, and vice versa. The various explanations of the classes are as follows:
TutorIntelligent

- Rationale and Contribution: This class is designed to embody personalized, adaptive pedagogical support within the platform. Its rationale lies in the need to offer learners more than just access to resources: intelligent support capable of explaining concepts (explainConcept), generating tailored exercises (generateExercise), providing adaptive feedback (provideAdaptiveFeedback), and even adjusting the learning path (adaptLearningPath). The escalateToHuman method is crucial, recognizing the limits of AI and providing a relay to the teacher.

- Indispensability: It is the driving force behind individualized pedagogical differentiation. Without it, the system's ability to respond dynamically to each learner's specific needs in terms of understanding and practice would be greatly reduced, limiting the "intelligent" aspect of the environment.

LearningPath

- Rationale and Contribution: Introduced to structure and sequence the learning experience. Its rationale is to provide a clear roadmap (steps, objective) for the learner to follow. It enables the teacher to design learning progressions and the system (via TutorIntelligent or recommendations) to propose or adjust these paths. The addStep and getSteps methods are fundamental to its construction and consultation.

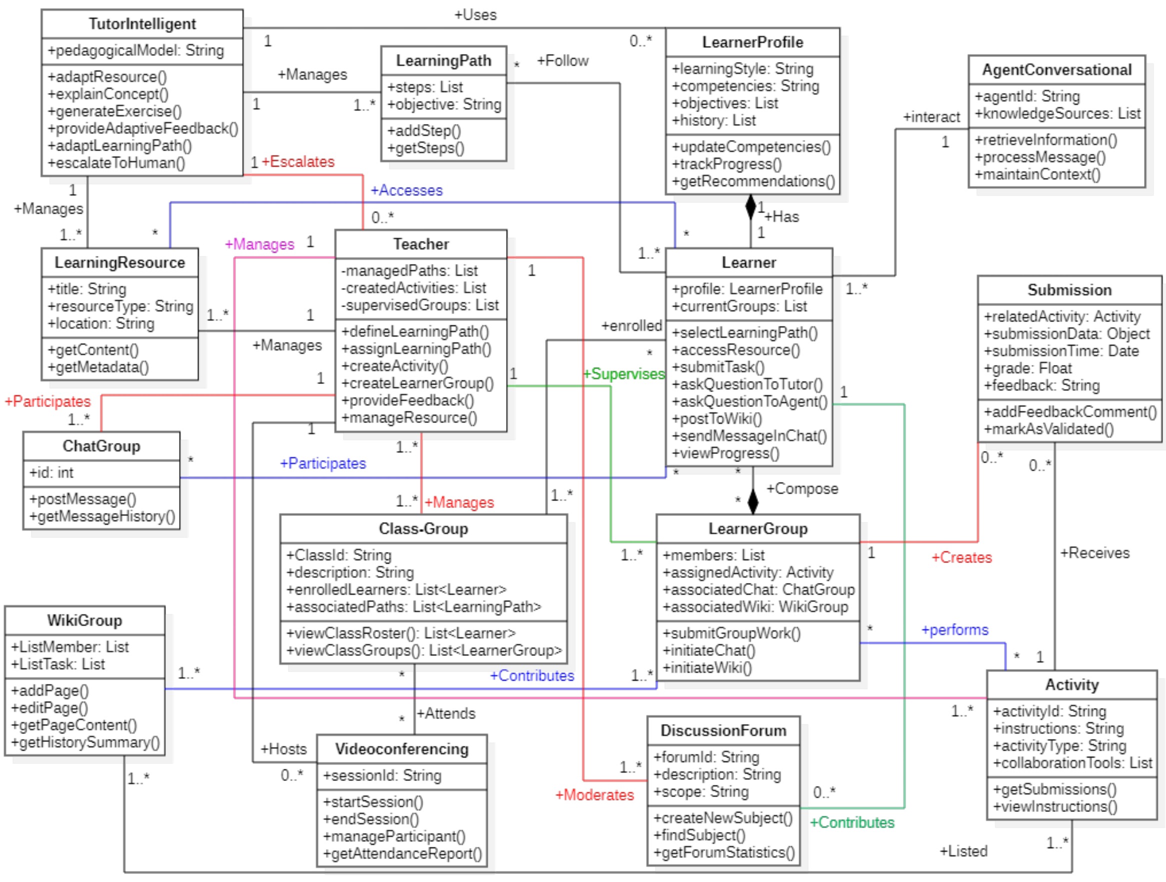

Figure 1: Class Diagram

- Indispensability: Essential for guiding learners, especially in resource-rich environments. It prevents the learner from feeling lost and enables logical progression towards defined objectives. It is the backbone on which activities and resources are articulated.

LearnerProfile

- Rationale and Contribution: This class is the heart of personalization, capturing the learner's characteristics and evolution. It is justified by the need to store dynamic information (learningStyle, competencies, objectives, history) that feeds TutorIntelligent's adaptation mechanisms and recommendations (getRecommendations). trackProgress and updateCompetencies reflect its evolutionary nature.

- Indispensability: Without a detailed, up-to-date learner profile, any attempt at advanced personalization would be in vain. This is the factual database that enables the system to "know" the learner and act accordingly.

AgentConversational

- Rationale & Contribution: Designed to provide first-level informational support and contextual assistance. Its rationale is to answer learners' immediate questions (retrieveInformation, processMessage) and maintain the thread of discussion (maintainContext), lightening the load on the IntelligentTutor and the teacher for simple queries. knowledgeSources indicates its basis of operation.

- Indispensability: It improves the learner's autonomy and the system's responsiveness to common requests. It acts as a guide and facilitator, particularly useful for navigation or understanding instructions.

LearningResource

- Rationale & Contribution: This class is introduced to represent and manage units of learning content. Its rationale is to provide a structured means (title, resourceType, location) of accessing learning material (getContent) and its descriptive information (getMetadata). It is the basic building block that the system manipulates and offers to learners.
- Indispensability: Fundamental, because without resources, there can be no formal learning. It catalogs and makes accessible the knowledge that the platform aims to transmit.

Teacher

- Rationale & Contribution: The Teacher is the system's human educational architect and supervisor. His rationale is to enable path design (defineLearningPath, assignLearningPath), activity creation (createActivity), group formation (createLearnerGroup), feedback provision (provideFeedback), and resource management (manageResource). It also supervises groups (supervisedGroups).
- Indispensability: It ensures the coherence and pedagogical quality of the whole. Even with AI tools, his expertise is crucial for initial design, overall monitoring and complex interventions.

Learner

- Rationale & Contribution: Represents the main actor in the learning process. Its rationale is to be the entity that interacts with the system: selects a path (selectLearningPath), accesses resources (accessResource), submits assignments (submitTask), queries support agents (askQuestionToTutor, askQuestionToAgent), collaborates (postToWiki, sendMessageInChat) and tracks its progress (viewProgress). It has a LearnerProfile and can belong to currentGroups.
- Indispensability: The system is designed with the learner in mind. All functionalities are designed to support the learner's learning and collaboration activities.

Submission

- Rationale and Contribution: Introduced to formalize and trace the work done by learners. Its purpose is to manage the details of a submission (relatedActivity, submissionData, submissionTime), its grade (grade), the associated feedback (feedback), and its status (markAsValidated).
- Indispensability: Essential to the evaluation process. It enables rigorous monitoring of learner production and formalization of pedagogical feedback.

ChatGroup

- Rationale and Contribution: Designed to provide a synchronous and informal communication space for groups. Its purpose is to facilitate rapid exchanges and coordination within a LearnerGroup. postMessage and getMessageHistory are its key functions.
- Indispensability: A direct and instantaneous communication tool, crucial for the dynamics and cohesion of working groups, particularly for resolving specific problems or making quick decisions.

Class-Group

- Rationale and Contribution: Represents the administrative and organizational entity that brings together a group of learners (enrolledLearners) for a given course or subject (description). It is justified by the need to manage associated paths (associatedPaths) and to have an overview of the class composition (viewClassRoster) and the groups that emerge from it (viewClassGroups).

- Indispensability: Provides the overall framework for organizing educational activities on a larger scale, allowing the teacher to manage multiple learners and groups under one banner.

LearnerGroup

- Rationale and Contribution: Formalizes the collaborative work unit. Its purpose is to enable the assignment of a specific activity (assignedActivity) to a group of learners (members) and to associate them with dedicated collaboration tools (associatedChat, associatedWiki). The submitGroupWork, initiateChat, and initiateWiki methods demonstrate its active role in collaboration.

- Indispensability: At the heart of collaborative activities. Without this class, structured teamwork management, collective task assignment, and group production monitoring would be difficult.

Activity

- • Rationale and contribution: Define a specific educational task to be performed. Its purpose is to provide a clear framework for the work requested (instructions, activityType) and to list the necessary collaboration tools (collaborationTools). It allows you to retrieve associated submissions (getSubmissions) and view instructions (viewInstructions).

- • Indispensability: This is the element that gives purpose and structure to learners' work, whether individual or in groups. It is the starting point for many interactions and outputs.

WikiGroup

- • Rationale and contribution: Provide a space for co-creation and asynchronous documentation for groups. Its purpose is to allow members of a LearnerGroup to collectively build content (addPage, editPage), view this content (getPageContent), and track the history of contributions (getHistorySummary). ListMember and ListTask suggest an internal organization.

- • Indispensability: Essential tool for collaborative work requiring the production of written documents, reports, or the capitalization of knowledge in a structured manner.

Videoconferencing

- • Rationale and contribution: Enable the organization of live, synchronous remote interaction sessions. Its purpose is to facilitate oral exchanges, presentations, or real-time discussions that are not possible via chat or forum. It manages sessions (sessionId, startSession, endSession), participants (manageParticipant), and can track attendance (getAttendanceReport).

- • Indispensability: Offers a rich mode of interaction, similar to face-to-face interaction, useful for debriefings, interactive lectures, or group presentations.

Discussion Forum

- Rationale and contribution: Provide a space for asynchronous, thematic exchange. Its purpose is to enable in-depth discussions on specific topics (createNewSubject, findSubject), which can be initiated by learners or the teacher and which persist over time. scope can define whether the forum is for the whole class or a group. getForumStatistics enables monitoring.

- Indispensability: Crucial for peer learning, clarifying doubts, debate, and collective reflection that do not require an immediate response. It allows questions and answers to be capitalized on for the entire community.

Having established the static architecture of the system through the class diagram—defining the 'who' (actors like Learner, Teacher) and the 'what' (entities like LearningPath, WikiGroup)—our model has a solid foundation. However, this static view does not yet illustrate how these components are utilized in practice. To bridge this gap, we now turn to the use case diagram. This diagram will shift our perspective from the internal structure to the external behavior, illustrating the specific functionalities offers to each actor to fulfill their pedagogical and learning objectives.

Figure 2: Use case diagram

3.1.2. Use case diagram.

Figure 2 illustrates the use case diagram, which shows the functionalities from the perspective of four main actors: the teacher, learner, group of learners, and class group.

For the Teacher, the system offers a comprehensive set of tools for design, management, and educational monitoring. This includes Creating learning materials, Adaptive tutoring management to personalize AI support, Create and manage learner groups, and View learning analyses and reports. The teacher also plays a central role in facilitating exchanges (Managing the discussion forum, Work Presentation call) and Remediation.

Learners, as individuals, interact with the system to access educational resources and receive personalized content recommendations. Their main use case, Request Help-Clarification, illustrates the extension relationship well: it can be extended by Escalate to human teacher if automated or peer-to-peer help levels prove insufficient. This extension provides an essential avenue of recourse. The Learner Group is the central actor in collaborative dynamics. The use case Collaborate on the task is a good example where specific features are included. Thus, using a group wiki includes fundamental operations such as Adding

a Wiki page, importing a file into the Wiki, and Deleting a Wiki page, all of which are necessary actions for effective use of the wiki. Similarly, use group chat is a component included for instant communication. The group is collectively responsible for Submitting group work and the Presentation of the work.
Finally, the Class-Group acts as the overall collective entity. Although most actions are initiated by the Teacher (who manages the class) or the Learners (who are part of it), the system offers features for which the Class Group is the context or the main beneficiary. For example, Managing the discussion forum can have a scope defined for the entire class, and Progress tracking can offer an aggregated view at the class level. The system therefore supports the structure and cohesion of the entire class, serving as a framework for the activities of the other actors.
This structuring of features by actor ensures that each entity individual or collective—has the necessary means to interact effectively within the learning environment, in accordance with the objectives of our collaborative and personalized scenario. The use case diagram has effectively outlined the functional capabilities of the system, clarifying what each actor—be it a Teacher, a Learner, a class, or a Group can do. It provides a high-level map of interactions and available tools. However, to understand how these functionalities are orchestrated over time to create a coherent learning experience, we must move from a functional view to a process-oriented one. The dynamic view, beginning with the activity diagram, will provide this crucial perspective. It will illustrate the step-by-step flow of the pedagogical scenario, showing the sequence of actions, decision points, and parallel processes from the initial engagement to the final consolidation of learning.

3.2. Dynamic view

3.2.1. Activity diagram.
The activity diagram illustrated in figure 3 provides a dynamic view of the flow of our educational sce-

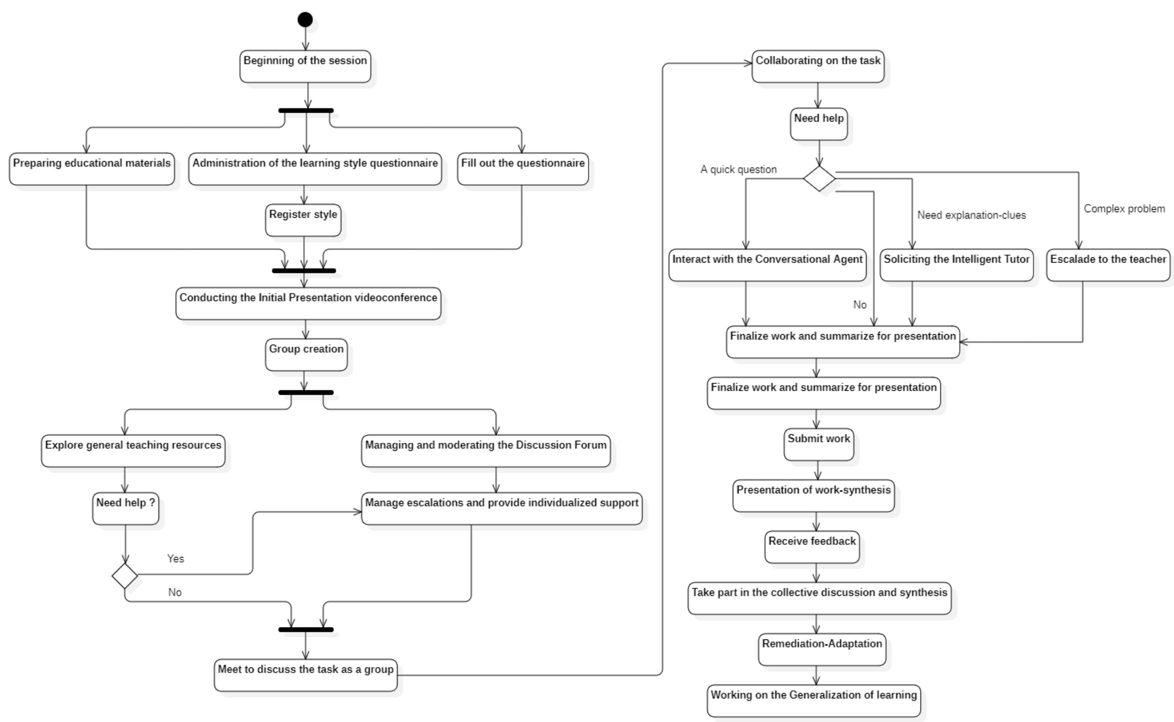

Figure 3: Activity diagram

nario, illustrating the sequence of actions and control flows from the beginning to the end of a learning session. It complements the previous diagrams by showing how features are orchestrated over time.
After the style has been recorded, the sequential process continues with the "Conducting the Initial

Presentation videoconference," involving teachers and learners. This step, far from being redundant, is crucial. It serves to establish a learning community, clarify the overall objectives, process, and expectations in an interactive manner, motivate students, and answer their initial questions [55]. It humanizes the journey before learner's dive into resource exploration and collaboration. This session is followed by "Group creation" by the teacher, potentially informed by the initial interactions.

On the one hand, learners are invited to "Explore general teaching resources." It is essential to understand here that, thanks to the initial personalization step, the resources recommended by the system can be filtered or highlighted according to the learner's learning style. This approach is consistent with recent research that highlights the importance of adapting learning paths and content to individual profiles in order to improve engagement and learning effectiveness. For example, two studies have shown that recommendation systems based on learning styles can significantly improve student satisfaction and performance in a university context [24;25]. Indeed, allowing learners to explore resources that better match their cognitive preferences can reduce cognitive load and increase perceived relevance, making this exploration more relevant and effective [26]. A recent systematic review on AI in higher education also confirmed that AI technologies, by tailoring content and feedback to individual needs, optimize educational outcomes [56].

On the other hand, the teacher focuses on "Managing and moderating the Discussion Forum." This ongoing activity is crucial, as the discussion forum, when actively moderated, becomes a powerful lever for collaborative learning and co-construction of knowledge. Research over the past five years confirms that teacher moderation in online forums is not limited to simple monitoring, but involves stimulating reflection, asking questions that deepen the discussion, and creating a supportive learning environment. For example, A study highlights how different teacher moderation strategies influence the quality of interactions and the depth of collaborative learning in online forums [57]. Furthermore, in a systematic review, found that interactive elements such as discussion forums, accompanied by adequate instructor-student interactions, are essential for improving both engagement and performance in online learning [58].

This moderation also includes "managing escalations and providing individualized support" to learners experiencing difficulties. The forum serves as a first filter where problems can be resolved collectively. However, when more complex or personal issues arise, or if a learner expresses a specific need for help that cannot be resolved by the community, individualized intervention by the teacher becomes essential. This personalized support is recognized as a key factor in student success and perseverance, particularly in online or hybrid learning environments. A study on the impact of online teacher support showed a significant positive correlation between the quality of individualized support and student academic success [59]. Furthermore, explicit teaching strategies and teacher behaviors, including individualized feedback, are crucial for student learning outcomes and holistic development.

It is important to highlight a deliberate choice in this phase of exploration and initial help-seeking: not to immediately integrate the conversational agent or intelligent tutor as a first resort. This decision is based on the desire to preserve and maximize opportunities for collaborative learning and peer interaction. Their feeling of being disconnected from their peers and institutions is one of the main obstacles to their academic success [60]. Indeed, in this specific activity, where learners are encouraged to explore resources and ask questions when needed, immediate use of AI tools could inadvertently short-circuit human interaction.

If learners systematically turn to an intelligent agent for answers, there is a risk that they will remain isolated in their individual learning, thus limiting opportunities to communicate and co-construct meaning with their peers. However, the development of communication, meaning negotiation, and collaborative problem-solving skills is fundamental to their future preparation, both academically and professionally. This approach is in line with social learning theories, which postulate that learning is fundamentally a social process in which interactions with others play a key role [61].

- **Collaborative Phase and Aid Management**

The main phase of the scenario is "Collaborating on the task." This step is central because it engages learners in co-constructing knowledge and solving problems as a group. Collaborative learning is widely recognized for its benefits in terms of engagement, critical thinking, and social skills. Research has established the advantages of collaborative learning, with findings that continue to be validated and refined [10]. More recently, studies on productive failure in collaborative contexts highlight how collaboration, even in the face of initial difficulties, can lead to deeper learning [62]. However, it can also create challenges, such as coordination problems, cognitive conflicts, or passivity on the part of certain members. This highlights the importance of adequate support mechanisms to promote computer-supported collaborative learning (CSCL).

This is where a fundamental decision point comes in: "Need help?" This diamond recognizes the importance of self-regulation of learning and help-seeking behavior. As a study points out on help-seeking, learners should be equipped with effective strategies for asking for help in order to achieve their learning goals [27]. This diamond is placed here, at the heart of the collaborative phase, because it is when learners are working together on a complex task that they are most likely to encounter obstacles requiring support. Enabling learners to actively identify their need for help and choose the most appropriate source of support is a key skill that promotes their autonomy and success.

When help is needed, we offer three types of assistance:
Interact with the Conversational Agent (Chatbot): This tool is chosen to provide immediate support, available 24/7. It is particularly effective for answering factual questions, clarifying instructions, or resolving low-level technical issues. Contemporary research demonstrates the ability of chatbots to promote engagement and offer immediate assistance [63]. Its advantage lies in its ability to provide instant answers, reducing learner anxiety and allowing teachers to focus on more complex interactions [46], a benefit also noted by another study [43]. In a collaborative context, it can serve as a quick source of information accessible to all, facilitating the resolution of minor issues without interrupting the main flow of collaboration.

Soliciting the Intelligent Tutor (Intelligent Tutor/Intelligent Tutoring System - ITS): ITS goes beyond a simple chatbot by offering more personalized and adaptive support. It is designed to analyze the group's progress, diagnose deeper misunderstandings, and provide targeted explanations, exercises, or formative feedback. Research on ITS [19], which reviews the effectiveness of intelligent tutors, continues to demonstrate their ability to significantly improve learning. The choice of this tool is justified by its ability to provide individualized "scaffolding" that adapts to the specific needs of the group, promoting deeper understanding and the resolution of more complex problems than a chatbot could handle.

Escalation to the teacher: This option recognizes that, despite the effectiveness of automated tools, the human expertise of the teacher remains irreplaceable. Escalation is intended for highly complex problems, open-ended questions, social-emotional support, or managing delicate group dynamics. The notion of "teacher presence" in online environments emphasizes the importance of this human interaction [55]. It ensures that learners do not get stuck on challenges that automated systems cannot solve and provides the teacher with valuable indicators of the difficulties encountered by learners, enabling targeted pedagogical intervention [64]

- **Finalization and Consolidation of Learning**

After potentially seeking help and continuing their collaboration, the groups proceed to "Finalize work and summarize for presentation." The flow continues sequentially with "Submit work," followed by "Presentation of work - summary" via a videoconference call, then "Receive feedback."

The last part of the process focuses on consolidating and adapting learning. It includes "Take part in the collective discussion and synthesis," a "Remediation-Adaptation" phase (which can be guided by the teacher or smart tutor depending on the difficulties identified), and concludes with the activity "Working on the Generalization of learning" by the learner, aimed at transferring the knowledge and skills acquired to new contexts.

In summary, this activity diagram provides a comprehensive and dynamic view of the learning process. It highlights the sequence of steps, key moments of parallelization (indicated by branch/synchronization bars where actions may overlap), the integration of personalization via the initial questionnaire, strategic decision points for seeking help, and the articulation of different support tools (Chatbot, STI, Teacher) specifically chosen for their complementary roles in supporting learners. It thus illustrates the collaborative, adaptive, and interactive nature of the learning experience offered.

The activity diagram successfully maps out the overarching workflow of our pedagogical scenario by detailing the sequence of activities and critical decision points. It offers a high-level, process-oriented perspective of the learning process. However, to fully understand the intricate dynamics of communication, we must zoom in on the specific interactions between actors and system components. The sequence diagram is the ideal tool for this purpose. It will complement the activity diagram by illustrating the chronological flow of messages, including who initiates a request, which system object responds, and the order in which they do so. This will offer a more granular understanding of how collaboration and support are realized moment by moment.

3.2.2. Sequence diagram.

The sequence diagram illustrated in figure 4 details the chronological interactions between the actors (Teacher, Learner, Learner Group, Class Group) and the components of the System (including specific objects such as Discussion Forum and Wiki) during key phases of the educational scenario.

For a more detailed representation of interactions, combined fragments are essential. Unlike a general activity diagram, they allow different possible sequences to be explored without redundancy. The major advantage of the sequence diagram lies in its ability to explicitly illustrate the flow of messages: who sends what, to whom, and in what order ("Who talks to Whom and When"). Another strong point is the visibility they provide on the call and use of specific system objects, such as a Discussion Forum or a Wiki, making their role in the process much clearer.

In our sequence diagram, we have used two types of combined fragments, the first, par (Parallel): This fragment is used to indicate that several sequences of interactions (several "operands" of the fragment) occur in parallel. The relative order of messages in the different parallel operands is not defined; they can interleave. The second, opt (Optional): This fragment represents a sequence of interactions that may or may not occur, depending on a condition ("Need help?"). If the condition is true, the sequence inside the opt fragment is executed. Otherwise, it is skipped.

By Beginning of the session, this section illustrates the initial interactions. We see that the Teacher interacts with the System (for example, to prepare materials or configure the session). At the same time, the Learner also interacts with the System (potentially to register, view initial information, or, as seen previously, fill out a questionnaire). These interactions initialize the learning environment for upcoming activities.

By knowledge construction. This phase overlaps with the videoconferencing phase and the creation of groups, focusing on learning and collaboration activities. An optional fragment (opt Need help?) shows that if a Learner needs help, they can interact with the Discussion Forum (for example, by posting a question). The Discussion Forum (as an object of the System) handles this interaction. A note specifies that "The teacher or other learners can respond," indicating the collaborative nature of this tool. The fact that this fragment is in the same "by" fragment shows that these different forms of help and collaboration can take place simultaneously.

On the other hand, the Wiki (System object) manages collaborative contributions. It is crucial to note that, in parallel and independently of these interactions with the Wiki, the system offers direct support mechanisms when the learner needs more targeted help. A second optional fragment, opt Need help?, is present in this parallel phase. This fragment is crucial because it represents the direct and adaptive support channels discussed earlier in the activity diagram (Interact with the Conversational Agent, Soliciting the Intelligent Tutor, Escalation to the teacher). Its presence and lifelines suggest that if the learner needs help, they can initiate a synchronous interaction with the Conversational Agent, the Intelligent Tutor, or the teacher. The use of opt here reinforces the idea that these interactions are conditional on the learner or group's need for help.

In this diagram, we see a series of interactions between the learner group, the Class-Group, the Teacher, and the Learner with the System. These represent the submission of work, participation in synthesis activities, or the receipt of feedback, as detailed in the activity diagram.

This sequence diagram highlights the dynamics of exchanges: who initiates communication, which system component is called upon, and how options (such as requesting help) fit into the overall flow of interactions. It thus offers a finer granularity on how actors and the system collaborate to accomplish the tasks of the scenario.

3.2.3. Synthesis.
To fully understand our learning system, we relied on four pillars of UML modeling: class diagrams, use

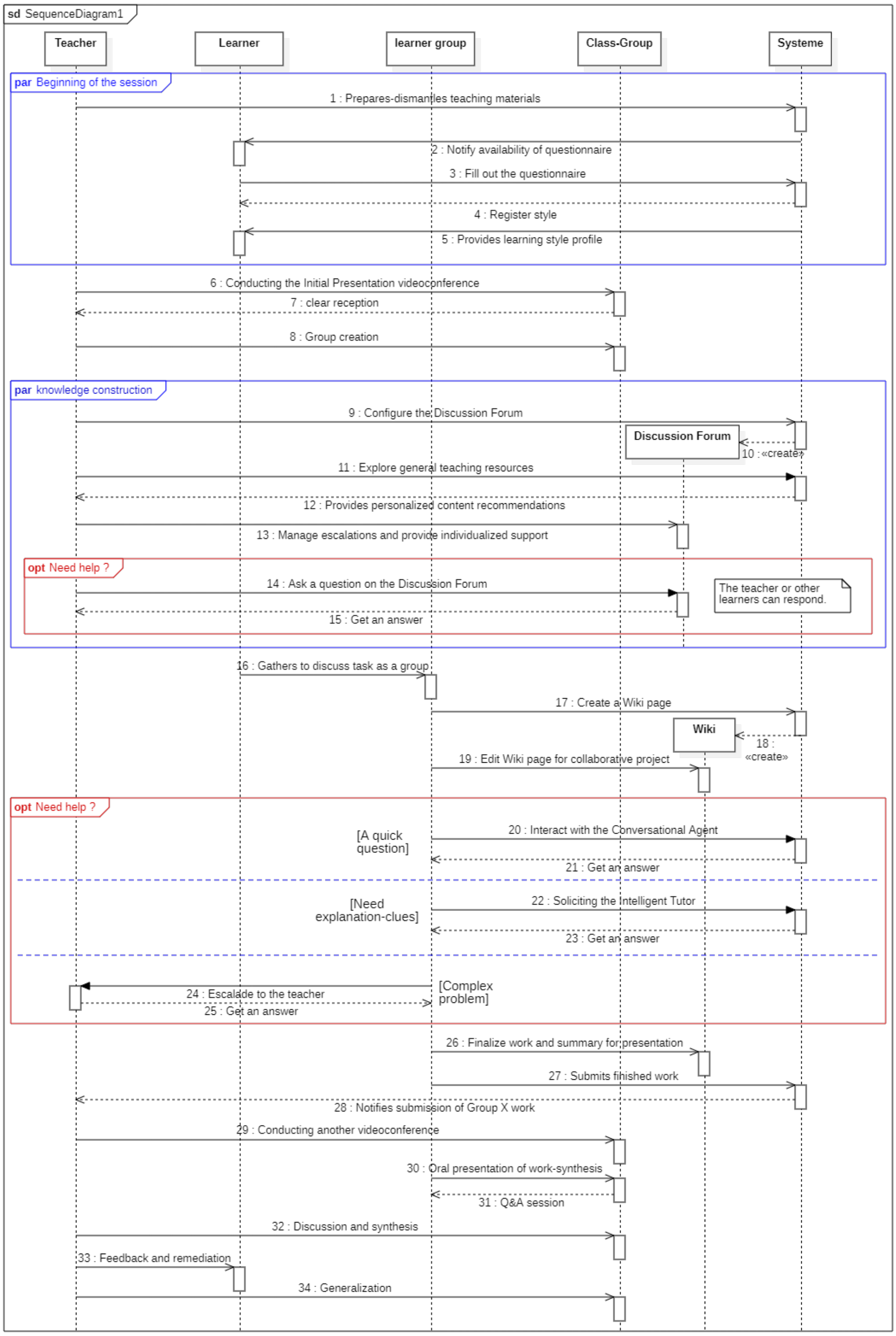

Figure 4: Sequence diagram

case diagrams, activity diagrams, and sequence diagrams. Far from being mere technical illustrations, these diagrams were powerful analytical tools. They enabled us to dissect the complexity of the system, identify the real needs, clarify who does what (roles), how things work (processes), and how all the information is organized (data structure). Thanks to this modeling work, we now have a solid foundation on which to move forward with the actual design of the system. And even though we haven't written a long descriptive narrative of every possible situation, the idea of a "scenario" is already very much present. Each use case is a bit like a scenario of what the user can do. Each path traced in our activity diagram is a way in which things can happen. And each element of the sequence diagram is a story of specific interactions. Ultimately, UML has really equipped us to understand in depth the nature of our system and how its various components interact with each other. This approach has proven to be very relevant to our project.

4. Discussion and limitation

The primary contribution of this paper is the detailed elaboration of a pedagogical scenario for a collaborative and personalized e-learning environment, using the Unified Modeling Language (UML) as a foundational design methodology. This approach directly addresses the critical need for rigorous, structured planning in the creation of complex digital learning systems, a challenge [20;48]. Our work demonstrates that UML is not merely a technical tool for software engineers, but a powerful bridge for translating abstract pedagogical principles into a concrete, implementable, and communicable system architecture.

Our proposed scenario is designed to tackle the core challenges identified in the theoretical framework. Firstly, it confronts the issue of waning learner engagement in digital environments [5] by weaving together multiple threads of interaction. The model provides clear learning paths (LearningPath class) to prevent disorientation, while the integration of an IntelligentTutor and personalized recommendations derived from the LearnerProfile aims to tailor the experience to individual needs, a key factor for maintaining motivation [24;25]. The deliberate, phased introduction of support tools—starting with peer interaction in forums before offering AI assistance—is a strategic choice designed to foster a sense of community and encourage the social co-construction of knowledge, directly addressing the risk of learner isolation [60].

Secondly, the model provides a structured solution to the complexities of Computer-Supported Collaborative Learning (CSCL). The challenges of group cohesion, equitable participation, and cognitive load [8;12] are explicitly addressed through the design. The LearnerGroup class, equipped with dedicated tools like ChatGroup and WikiGroup, provides a formal structure for collaboration. The activity diagram orchestrates the collaborative phase by embedding a multi-layered help-seeking mechanism. This tiered support system—from the ConversationalAgent for immediate, factual queries [46], to the IntelligentTutor for deeper conceptual scaffolding [19], and finally escalation to the human Teacher for complex issues—is designed to manage cognitive load by providing the right level of support at the right time. This structure ensures that learners are supported without short-circuiting the productive struggle that is essential to deep learning [62].

Finally, our work operationalizes the potential of Artificial Intelligence in education as envisioned by these studies [15;17]. The TutorIntelligent and AgentConversational classes are not presented as standalone gadgets, but as integral components of a larger pedagogical ecosystem. The UML diagrams, particularly the sequence diagram, clarify their exact roles and points of intervention within the learning flow. This formal modeling makes their function unambiguous, ensuring that technology serves a clear pedagogical purpose rather than becoming a distraction [3]. By defining the system in this way, we provide a clear blueprint that aligns technical development with the pedagogical goals of personalization and effective collaboration.

Despite the robustness of the proposed model, it is essential to acknowledge its limitations, which in turn open avenues for future research. While the UML diagrams provide a clear architectural overview, they abstract away the immense technical complexity required for implementation. Developing a truly adaptive TutorIntelligent capable of nuanced pedagogical diagnosis and feedback, or a ConversationalAgent with a rich, context-aware knowledge base, represents a substantial challenge in the fields of AI and software engineering. Our model specifies what these components should do, but not the intricate details of how they would be built and trained. The proposed scenario, while adaptable, is based on a specific pedagogical philosophy that prioritizes social interaction before AI intervention. The effectiveness of this approach may be highly dependent on the subject matter, the learners' age and digital literacy, and the specific learning objectives. It may not be universally optimal for all learning contexts. Future work could explore variations of this scenario tailored to different disciplines (e.g., STEM vs. humanities) or educational levels.

5. Conclusion

The aim of this paper was to answer the question of how the ongoing problems of engagement, collaboration and personalization in e-learning can be solved by developing a framework to structure and pedagogically-informed approach to system design. We have discussed how the successful use of such advanced technologies as AI cannot be a simple question of implementation, but one of the thoughtful and careful instruction designs. Our main idea is described in using the Unified Modeling Language (UML) to develop a pedagogical scenario carefully detailed, and it has thus developed an effective and consistent framework of the system that balances interaction between human and intelligent assistance.

Through the systematic application of class, use case, activity, and sequence diagrams, we have translated abstract educational goals into a concrete and formalized model. This process has allowed us to define the precise roles of learners, teachers, and AI agents, orchestrate the flow of learning activities, and structure a multi-tiered support mechanism that prioritizes peer collaboration before escalating to automated or human expert help. The UML models serve as a critical bridge, ensuring that the foundational pedagogical principles—such as fostering a learning community and managing cognitive load—are woven into the very architecture of the system.

Essentially, this work promotes a paradigm in which the rigor of software engineering is applied to instructional design. By formalizing pedagogical scenarios, we can express, share, and evaluate our educational goals. Although the presented model is conceptual and requires empirical validation, it establishes a robust basis for future development. The next logical steps are to implement a functional prototype based on these specifications and to conduct empirical studies with learners to assess the model's real-world impact. These steps will allow for iterative refinement of the model, bringing us closer to creating adaptive, collaborative, and engaging e-learning environments.

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[1] *Higher Normal School of Tetouan, Abdelmalek Essaadi University, Tétouan, Morocco*

[2] *Laboratoire d'informatique et de physique interdisciplinaire*

Ecole Normale Supérieure de Fès, Université Sidi Mohamed Ben Abdellah Fes, MAROC

E-mail address: soufian.ouariach@etu.uae.ac.ma