Integrating Augmented Reality Learning Objects in Intelligent Tutoring Systems: A Conceptual Model for Engaging Learning Experiences

Hind Tahir, Najoua Hrich, Salma El Boujnani, Mohamed Khaldi
Research team in Information Technology and Modeling System Research Unit-Faculty of Sciences,
Abdelmalek Essaadi University, Tetouan, Morocco

Abstract—**Despite the progress achieved by E-learning platforms, several limitations remain in sustaining learner engagement over time. With the rapid evolution of information and communication technologies, augmented reality has emerged as a powerful medium for designing pedagogical objects that are interactive, immersive, and adaptable to diverse learning contexts. The integration of augmented reality- based learning objects into intelligent tutoring systems enhances the educational process by providing learners with contextualized, multisensory experiences that align with their preferences and profiles. In this perspective, our objective is to propose a model for augmented reality-based learning objects within the context of an Intelligent Tutoring System. The proposed framework addresses a critical research gap: the absence of systematic architectural models that enable real-time, bidirectional adaptation between AR content representation and ITS decision-making mechanisms. Our model aims to strengthen learner motivation and reduce the risk of disengagement by dynamically adapting content to individual needs. It provides a structured foundation for the design and development of augmented reality-based learning objects within an intelligent tutoring system, ensuring that immersive resources are not only technologically innovative but also pedagogically aligned and personalized through the system's diagnostic and feedback capabilities.**

Keywords—Augmented reality; intelligent tutoring systems; E-learning; adaptation; engagement; personalized learning; learning objects

I. Introduction

The rapid evolution of educational technology has fundamentally transformed pedagogical approaches and learning environments across diverse contexts. Among emerging technologies, augmented reality (AR) has demonstrated significant potential to revolutionize learning experiences by creating immersive and interactive educational scenarios that bridge virtual and real environments [1].

Simultaneously, Intelligent Tutoring System (ITS) have established themselves as powerful adaptive learning platforms capable of personalizing instruction based on individual learner characteristics, knowledge states and cognitive profiles [2].

Recent empirical evidence suggests that augmented reality significantly improves learner engagement and understanding of complex concepts [3]. Learning using AR-based tools often outperform peers in traditional settings and report higher engagement levels and more positive attitudes toward learning [4]. However, this engagement frequently proves transient: without ongoing pedagogical adaptation, the novelty effect of AR fades, and learners become disengaged despite the initial immersive appeal.

Despite these promising results, the integration of AR learning objects into intelligent tutoring systems remain relatively underexplored. Previous work by the authors has explored the general integration of artificial intelligence and augmented reality in educational environments, highlighting opportunities regarding personalization and learner engagement [5]. Building on these findings, systematic frameworks that guide AR-ITS convergence are still limited.

Key challenges include aligning AR's representational and interactive affordances with ITS adaptive mechanisms, ensuring pedagogical coherence across integrated components and maintaining technical interoperability between heterogeneous systems platforms.

This gap is particularly critical when learner motivation and engagement are considered, as they are decisive in educational success. Conventional ITS, may not always provide the rich and multisensory experiences that AR environments can offer. Conversely, many standalone AR applications lack the personalized scaffolding and fine-grained learner modeling capabilities characteristic of ITS.

Bringing these two technologies together creates an opportunity to harness AR's motivational power within an ITS-driven adaptive framework, potentially generating synergistic effects that enhance both engagement and learning outcomes.

In response to this need, the present study propose a model for integrating AR learning objects into intelligent tutoring systems. The model is structured around two complementary phases: a pedagogical phase that defines instructional objectives and learning activities, and technical phase that specifies the internal composition of AR learning objects into interconnected components (contextualization, exploration, assessment) and their adaptive sequencing with the ITS.

The primary contribution of this work is to synthesize pedagogical and technical dimensions into a cohesive framework that simultaneously addresses "what to teach" through AR-based learning objects and "how to deliver" through intelligent tutoring system architectures.

This dual-phase perspective emphasizes that effective educational technology integration depends not only on advanced technical solutions but also on carefully designed instructional strategies aligned with learner needs and contextual constraints.

While the proposed model is grounded in established pedagogical and ITS design principles, empirical validation through prototype deployment and controlled studies remains critical future work.

The remainder of this study is organized as follows: Section II presents the theoretical basis and related work, Section III details the methodological framework, and Section IV outlines the results and discussion. Finally, Section V concludes the study and highlights future research.

II. Theoretical Basis and Related Work

A. Augmented Reality in Education

Augmented reality superimposes digital information (3D objects, text, animation, sounds) onto the real world as perceived by the user, creating an enriched mixed experience [6]. AR systems rely on three fundamental technical components:

- The tracking system: detects and tracks physical markers (marker-based AR) or the real environment itself (marker-less AR) to determine where to display virtual content.
- The rendering engine: generates 3D objects and superimposes them in real time onto the camera view, taking into account perspective and lighting.
- The interaction interface: captures the user's gestures, manipulations, and actions to enable interaction with virtual objects.

Empirical research has highlighted several pedagogical benefits of augmented reality, particularly regarding learner engagement and motivation [3]. Its immersive and interactive experiences effectively capture learners' attention and support their intrinsic motivation.

Studies also indicate that learners using AR spend more time interacting with learning materials and higher levels of satisfaction [2].

B. AR-Based Learning Object: Definition and Properties

The concept of learning objects was first introduced in the early 1990s to describe modular educational resources that could be reused across various instructional contexts [7]. Wiley (2002) defined them as any digital asset that supports learning and can be flexibly recombined to suit different pedagogical needs [8]. The IEEE standard later formalized this notion by describing learning objects as digital or non-digital entities created specifically to facilitate learning, often containing multimedia elements such as text, images, audio, or video [9].

AR-based Learning Objects build upon this foundation by integrating augmented reality (AR) components, such as holographic visualizations, interactive overlays, or geolocated information into the learning process. Unlike traditional learning objects, AR-based learning objects are not limited to static or multimedia resources; they situate knowledge in authentic contexts, allowing learners to interact with content in real- world environments enhanced by digital layers.

Recent studies have demonstrated the pedagogical potential of AR-enhanced learning objects. For instance, Akçayir and Akçayir (2017) identified increased engagement and contextualization as key benefits of AR-based educational environments [10]. Similarly, Ibáñez and Delgado-Kloos (2018) showed that AR-supported learning objects significantly improve conceptual understanding and motivation in STEM disciplines [11]. These findings support the integration of AR-based learning objects as immersive and adaptable components within a personalized learning system.

The effectiveness of learning Objects based on Augmented Reality depends on a set of pedagogical and structural characteristics that ensure both adaptability and experiential relevance:

- Pedagogical Intent: To be effective, an AR-based Learning Object must be guided by a pedagogical intent that gives meaning to its learning objectives enhancements [12]. This intent shapes how immersive features are integrated, ensuring they support long-term educational goals rather than serving as superficial [13].
- Granularity: AR-based learning objects are modular, ranging from small, discrete units (e.g., individual images, text blocks, short animations) to comprehensive instructional sequences (e.g., lessons, modules) or entire curricula. This granularity supports flexible reuse and customization, facilitating adaptive learning paths [14].
- Reusability: Following the logic of reusable learning architectures [15], a reusable AR-based learning object may include instructional materials, practical interactions, and embedded evaluation activities aligned with a clearly defined educational goal [16]. Moreover, the degree of granularity plays a decisive role in the reusability of AR-based learning objects. Fine-grained learning objects are generally context-free and highly reusable across various courses or systems.
- Technological durability: Technological durability is a critical characteristic of AR-based learning objects, as it ensures their long-term usability and relevance despite the rapid evolution of hardware and software ecosystems. Augmented reality learning objects designed with durability in mind are not tied to a single device or platform but rely on open standards, modular architectures, and optimized performance to remain functional across contexts. This durability is reinforced by the use of interoperability frameworks (e.g., xAPI) that facilitate integration into diverse learning management systems [17].

The integration of Augmented reality based learning objects in digital E-learning can be analyzed through three complementary pedagogical dimensions that enhance learner engagement. AR-based learning objects:

- Act as representational tools; transforming abstract knowledge into immersive and context-sensitive visualizations that enhance conceptual clarity.
- Support mastery and proactive learning, as learners actively manipulate augmented environments, experiment with variables and receive adaptive feedback, thereby fostering self-regulation and deeper understanding.
- Enable a socioconstructivist approach, functioning as mediators of collaboration in shared augmented spaces where learners co-construct knowledge through dialogue and interaction.

According to Deci and Ryan's self-determination Theory [18], motivation is shaped by the degree to which learning environments support autonomy, competence and relatedness. When educators implement strategies that foster these conditions, such as adaptive, interactive learning tools, learners are more likely to engage meaningfully in the learning process and achieve stronger outcomes.

In this regard, our pedagogical strategy, which leverages AR-based learning objects, aims to simulate learner engagement through immersive and context-aware experiences. Fig. 1 highlights the connections between our strategy-centered on the use of AR-based learning objects and the resulting effects on learner engagement and educational success.

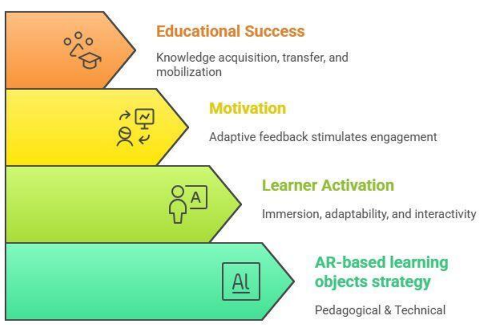

Fig. 1. From AR learning objects to educational success.

C. Intelligent Tutoring System

Intelligent Tutoring Systems (ITS) represent a specialized class of computer-based learning environments that employ artificial intelligence and cognitive science principles to deliver adaptive, personalized instruction tailored to individual learner characteristics and performance dynamics [19]. The foundational concept of intelligent tutoring systems emerged in the early 1970s and became formally established as a research field following seminal work by Sleeman and Brown [20], with subsequent development producing increasingly sophisticated architectures capable of replicating key aspects of expert human tutoring at scale.

The canonical architecture of ITS comprises four interdependent functional subsystems, as illustrated in Fig. 2:

- Domain Model: encodes disciplinary knowledge, conceptual relationships, procedural competencies and typical misconception patterns within a particular subject domain.
- Learner Model: maintains continuously updated representations of individual learner knowledge states, performance trajectories, cognitive abilities, learning preferences and metacognitive characteristics through systematic analysis of learner interactions and responses.
- Pedagogical Module (Tutor Model): employs instructional decision making algorithms to determine optimal activity sequencing, content selection, scaffolding strategies and feedback mechanisms by consulting both domain and learner representations.
- User Interface: facilitates bidirectional communication, presenting content through multiple modalities and capturing learner actions for subsequent analysis.

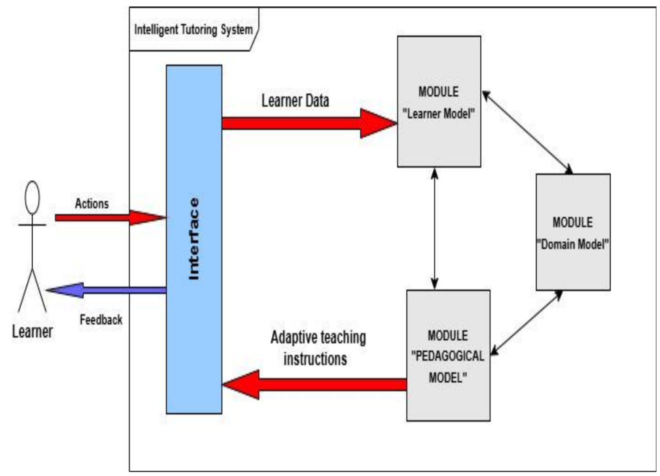

Fig. 2. A classical ITS architecture.

Contemporary ITS research increasingly incorporates emerging technologies and pedagogical frameworks [21]. Advanced ITS implementations now integrate immersive technologies such as augmented reality and virtual reality environments, expanding the representational affordances available for knowledge modeling and problem-solving activities beyond traditional textual and graphical interfaces.

D. State-of-the-Art: AR-ITS Integration and Current Limitations

Recent research has increasingly explored AR-ITS integration, with promising initial results. Uriarte-Portillo et al. conducted a comparative study with 106 middle school students evaluating an intelligent tutoring system with augmented reality (ARGeoITS) against a standalone AR system (ARGeo). Results demonstrated that combining AR with ITS-driven adaptation significantly outperformed standalone AR, suggesting that real-time adaptive tutoring integrated with AR analytics enhances student performance beyond mere visualization [22]. This foundational work established empirical evidence for the synergetic potential of AR-ITS integration.

Similarly, emerging work integrating Generative AI with AR environments demonstrates innovative approaches combining AI-powered conversational agents with AR visualization to support inquiry-based learning [23]. These systems show significant improvements in critical thinking, inquisitiveness, and learning motivation compared to traditional AR-only approaches. The integration of natural language processing further enables responsive, conversational tutoring interactions within immersive environments.

However, three critical limitations persist in current AR-ITS implementations, particularly concerning sustained engagement:

- Adaptation limited to sequencing and feedback; AR representation remains static: Existing systems adapt at the level of activity selection or textual feedback delivery, not at the level of AR content representation itself. The 3D objects, spatial complexity and interactive modalities remain unchanged during learner interaction, regardless of performance or comprehension. This represents a significant missed opportunity: the dynamic modification of the AR visualization based on real-time learner state maintains cognitive and emotional engagement, signals progress, provides adaptive scaffolding and maintains appropriate challenge.
- Lack of principles architectural frameworks for engagement-centered AR-ITS: While individual systems demonstrate effectiveness, no unified framework exists specifying how learner interactions with AR objects should inform domain model updates, which pedagogical rules should govern real-time content adaptation and how the learner model, pedagogical module, and AR engine achieve bidirectional coupling. Most implementations treat AR as a one-way presentation layer receiving instructions from an ITS backend, not as an adaptive component whose state continuously informs tutoring logic and engagement decisions.

These gaps highlight a clear research need: a systematic model and architecture that enables real-time, bidirectional adaptation between AR content representation and ITS decision-making, explicitly designed to foster sustained learner engagement, grounded in pedagogical frameworks and validated through implementation.

The present study addresses this need by proposing a dual-phase AR-ITS model that integrates pedagogical design (MARS, IMS-LD, SAMR) with technical architecture, enabling real-time, engagement-centered adaptation at the representation level. By situating our work at the intersection of pedagogical design, technical architecture and engagement science, we aim to move the field from isolated AR or ITS innovations toward coherent, replicable systems capable of sustaining engagement.

III. Methodological Framework

The design of our architecture is organized into two complementary phases: the pedagogical phase, which focuses on the design of the augmented reality (AR)-based learning object, and the technical phase that details the integration of this learning object within the Intelligent Tutoring System (ITS).

A. *Phase 1: Pedagogical Design and Scenario Development*

The pedagogical phase focuses on designing AR learning objects that effectively support learning objectives while maximizing learner motivation and engagement. This phase employs two complementary frameworks: the MARS model for motivation-centered design and IMS Learning Design for activity structuring and scenario orchestration.

1) MARS framework for simulation design: The MARS model (Model- Associations- Representation- Scenario) developed by Pernin (1996) [24], provides an operational structure for developing AR-based simulations and interactive learning objects through its four-component architecture, as illustrated in Fig. 3. Application to AR learning object design proceeds as follows:

- Model (M): Specify the functional model underlying the AR learning object, including 3D object behaviors, physical properties, interaction rules, and state transitions.
- Association (A): Define mappings between conceptual knowledge (domain model), visual representations (3D assets, animations), and learning activities. Associations ensure that when learners interact with AR elements, these interactions correspond meaningfully to underlying concepts and produce pedagogically appropriate feedback. This component supports alignment between learning objectives and AR affordances.
- Representation (R): Create the visual and interactive interface through which learners engage with the AR content. This includes designing 3D models, selecting appropriate mechanisms (marker-based, marker-less, and location-based), defining interaction modalities (touch, gesture, voice) and ensuring usability across target devices. Effective representation balances visual fidelity with cognitive load management, avoiding overwhelming learners with excessive detail.
- Scenario (S): Structure learners' use of AR simulation toward specific educational objectives.

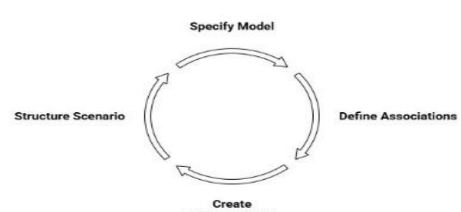

Fig. 3. AR learning object development cycle.

2) IMS learning design for activity orchestration: This design process is grounded in the IMS Learning Design (IMS-LD) framework, an internationally recognized pedagogical specification developed by the IMS Global Learning Consortium [25]. IMS learning Design provides the structural framework for organizing AR learning objects within coherent learning scenarios that orchestrate learner activities, resources and support mechanisms. The specification's three-level architecture enables increasing sophistication in scenario design:

- Level A: Activity Sequencing: At the foundational level, IMS-LD structures AR learning experiences through time-ordered activities assigned to specific roles. For AR-enhanced ITS, this involves defining learner and tutor roles, specifying AR-based learning activities (e.g., exploring 3D molecular structures, practicing assembly procedures in augmented space) and sequencing these activities within coherent learning flows. The activity structure specifies which AR learning objects are available to learners at different points in the learning trajectory.
- Level B: Adaptive Conditions: The intermediate level introduces properties and conditions that enable dynamic adaption based on learner actions and states. This proves particularly valuable for AR experiences based on learner model data. For example, if a learner demonstrates misconceptions about spatial relationships, the system might present AR activities emphasizing 3D manipulation; conversely, learners showing confidence might access more complex augmented scenarios. Properties store learner interaction data from AR activities, informing subsequent adaptive decisions.
- Level C: Notifications and Triggers: The advanced level supports notifications that dynamically trigger activities based on events. In AR-ITS contexts, this enables responsive scenarios where AR content adapts in real time to learner behaviors. For instance, if a learner spends excessive time on a particular AR interaction without progress, the system might trigger supportive interventions such as simplified AR demonstrations or hints overlaid in the augmented environment.

3) SAMR model as a framework for technology integration: The SAMR model, proposed by Puentedura [26], is designed to analyze the degree of pedagogical transformation brought by educational technologies. It distinguishes four levels, as shown in Fig. 4:

- Substitution: where technology replaces a traditional tool without changing the task.
- Augmentation: where technology enriches the existing activity.
- Modification: where technology enables a substantial redesign of the activity.
- Redefinition: where new tasks, previously impossible, become attainable.

This framework is used to evaluate the ability of our AR-ITS system to go beyond simple improvements to traditional approaches. Several components of our AR-ITS model move past mere replacement or enhancement, reaching the modification or redefinition levels by offering immersive, adaptive and collaborative learning experiences that are only possible through augmented reality and intelligent tutoring.

Fig. 4. SAMR model.

B. Phase 2: Technical Integration into ITS Architecture

The technical phase addresses the integration of AR learning objects into ITS architectures. To operationalize this integration, AR learning objects follow a structured three-component design, as shown in Fig. 5: Contextualization component, the exploration component, and the assessment component. This three-component architecture ensures that learner interactions with AR objects inform real-time adaptations and pedagogical decision-making.

- Contextualization component: communicates learning objectives, prerequisite knowledge requirements and establishes the pedagogical scenario. This component adapts based on the learner's profile within the ITS, presenting comprehensive information to novice learners and an abbreviated context to advanced learners.
- Exploration component: presents the core AR content and interactive activities. It structures information to promote active learning through multimodal representations. The ITS provides real-time scaffolding and adaptive feedback during learner exploration of AR objects.
- Assessment component: enables learners to demonstrate comprehension of key concepts. It provides formative feedback and assesses readiness for progression. If gaps are identified, targeted feedback is provided to specific learning elements, enabling iterative refinement until mastery is achieved.

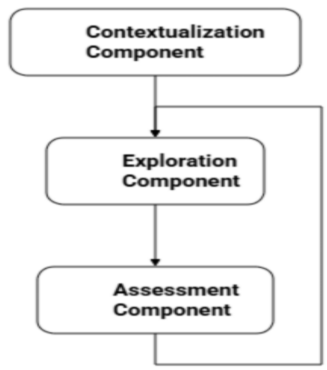

Fig. 5. AR learning object structure.

IV. Results and Discussion

The use of learning objects within adaptive instructional systems to foster learner engagement has become an active and multifaceted research topic, attracting sustained interest in the technology-enhanced learning community.

In this work, engagement is understood as a combination of cognitive and emotional involvement that leads the learner to willingly invest effort and attention in the learning task and to persist in order to reach predefined learning objectives. It is shaped by a set of internal and external factors that influence how and why a learner initiates, maintains, or abandons an activity.

Fig. 6 presents the overall architecture of the proposed AR-ITS model, in which augmented learning objects are integrated as a central mechanism for increasing learner engagement. The model is organized into two main phases, as previously described: a pedagogical design phase and a technical adaptation phase.

In total, the model comprises twelve classes, each representing a key component of the system and encapsulating the data and behaviors necessary to support adaptive AR-based learning experiences.

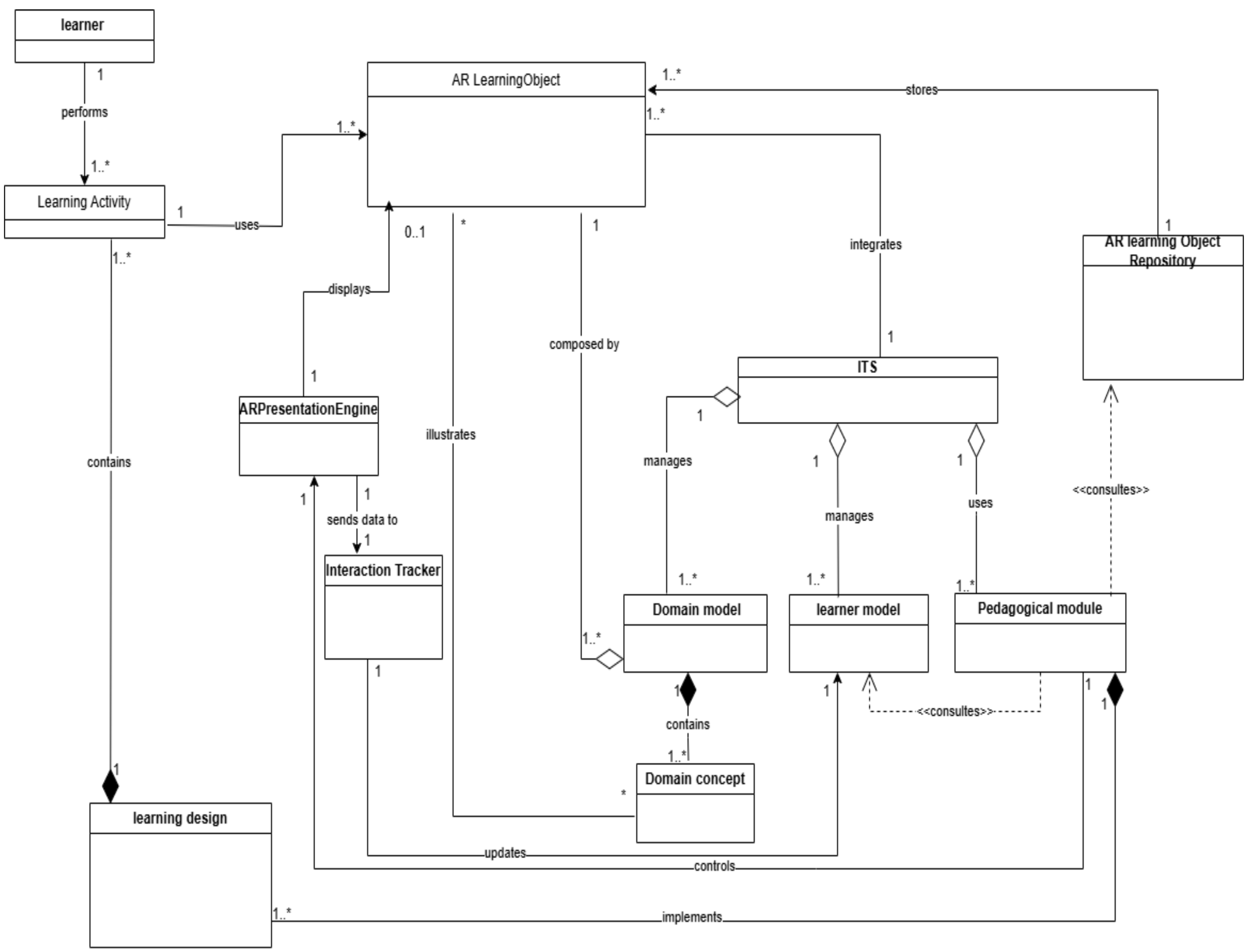

Fig. 6. Class diagram of the AR-ITS model.

1) Pedagogical phase: In this phase, we structure the learning experiences by specifying what should be learned, how it should be orchestrated, and within what scenario. This phase comprises:

- "Learning Design": defines the overall instructional sequence and organizes the learning activities and their pedagogical scenarios.
- "Learning Activity": Represents specific tasks and exercises the learner will perform. Each activity can use one or more AR Learning Objects as resources.
- "AR Learning Object": Provides the core augmented reality content for exploration, designed according to MARS principles and integrated within the learning scenario.

The pedagogical layer ensures that AR is not merely a technical add-on but is integrated within a robust pedagogical scenario. This layer aligns content, activities, and learner roles to support meaningful engagement and learning progression.

2) Technical phase: In this phase, we implement and execute the AR learning experience as specified by the pedagogical phase. It comprises:

- "AR Presentation Engine" and "Interaction Tracker": together, these manage the AR display, capture learner interactions in real-time, and provide event data to the ITS.
- "ITS" (Intelligent Tutoring System): acts as the central coordinator, integrating three core models:

a) "Learner model": Maintains a dynamic record of learner states, competencies and progress.

b) "Domain model": Holds the domain knowledge and conceptual structure that the learning content relies on.

c) "Pedagogical module": Implements the instructional logic for adaptation, feedback selection and activity progression.

- "AR Learning Object Repository": Stores reusable AR objects that can be retrieved and dynamically assigned to activities based on learner needs and activity requirements.

The technical phase enables real-time adaptation: it collects learner data, updates learner models, and collaboratively with the pedagogical Module, dynamically selects, adapts, and sequences AR learning objects and feedback.

The pedagogical and technical phases work in close coordination. The pedagogical phase defines what should be taught and how AR should enhance the experience; the technical phase delivers tracks and adapts the learning experience in line with the pedagogical plan.

This architectural separation supports methodological rigor, scalability, and the ability to evolve pedagogical approaches independently from technical implementations, thereby ensuring both pedagogical coherence and technical robustness.

The pedagogical layer specifies what should be taught and how it should be orchestrated. The technical layer delivers, tracks, and adapts the learning experience in alignment with the pedagogical plan. Bidirectional communication (represented in the diagram) enables learner data collected by the Interaction Tracker to inform ITS decisions, which then modify the AR learning Object representation.

3) The AR-ITS adaptive learning cycle: The dynamic behavior of the proposed AR-ITS is structured as a continuous adaptive learning cycle, as illustrated in Fig. 7. This cycle is repeatedly executed while the learner engages with AR-based activities. The following scenario summarizes the main steps of this cycle, from activity selection to learner mode update.

a) Step 1: Activity Initialization

At the beginning of a session, a "learning Activity" is instantiated from a "learning Design", which specifies the pedagogical scenario (sequence of activities, prerequisites, conditions for progression).

b) Step 2: Instructional Decision-Making

When an activity becomes active, the "ARPresentationEngine" requests guidance from the "PedagogicalModule" to determine which content and level of support should be provided. The "PedagogicalModule":

- Consults the "learner Model" to retrieve the current learner state.
- Then queries the "Domain Model" to identify relevant concepts.
- Identifies candidate "ARLearningObject" from the repository.
- Applies predefined adaptation rules to select the most appropriate "ARLearningObject" and support level.
- Sends selected AR content to the "ARPresentationEngine" with rendering specifications.

c) Step 3: Learner Interaction and Tracking

The learner interacts with the AR content (manipulations, exploration, task completion) as specified in the "learning Activity", while the "Interaction Tracker" records all relevant actions

- What the learner did (interaction Type).
- When it happened (timestamp).
- How long it took (duration).
- Quality of interaction (accuracy, correctness).

d) Step 4: Learner Model Update and Cycle Iteration

Interaction data collected by "InteractionTracker" is used to update the "Learner Model":

- Refining estimates of knowledge states.
- Identifying misconceptions.
- Assessing engagement levels.

- The updated "Learner Model" informs subsequent decisions of the "Pedagogical Module".
- The Module may adapt the current activity (extra scaffolding, hints, alternative AR object) or trigger the next activity according to the "Learning Design".
- This loop continues until the scenario is completed.

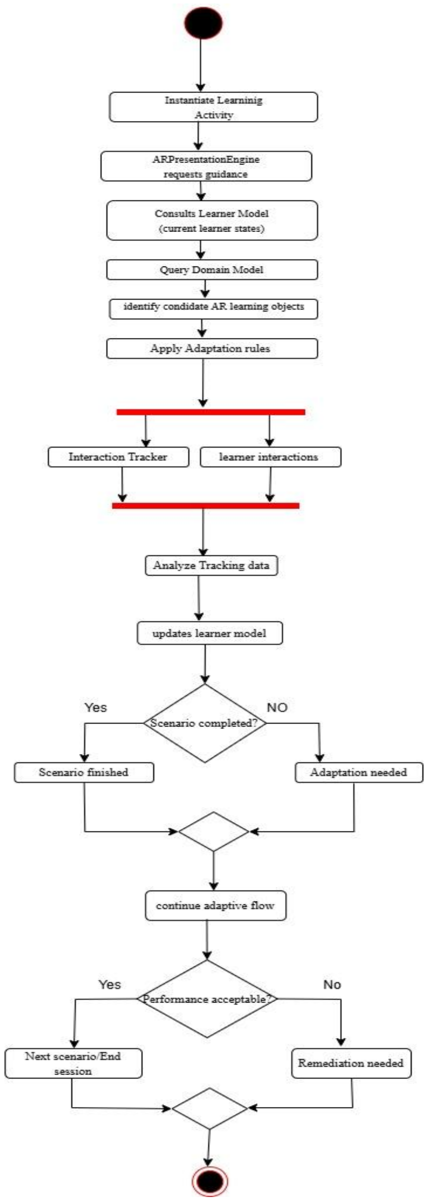

Fig. 7. Adaptive activity diagram flow of an AR-based intelligent tutoring system.

This adaptive cycle demonstrates how the model achieves real-time, bidirectional coupling between AR interaction and ITS decision-making, addressing the research gap identified.

The previous diagram presented the structural organization of the AR-ITS and the overall adaptive activity flow. The following sequence diagram, illustrated in Fig. 8, details the runtime interactions between the "ARPresentationEngine", the Pedagogical Module, and the Learner-related models during a single AR learning activity.

Upon initiation by the learner, the "ActivityManager" instantiates the learning activity based on the predefined design. The ARPresentationEngine then solicits pedagogical guidance, triggering a cascade of interactions within the Pedagogical Module.

This module consults the "LearnerModel" to retrieve the learner's current cognitive and affective state, queries the "DomainModel" for relevant conceptual targets, and accesses the "ARLearningObjectRepository" to identify suitable AR content.

Adaptation rules are applied to select the optimal support level and AR objects, which are then rendered by the ARPresentationEngine. As the learner engages with the AR content, the InteractionTracker captures detailed behavioral data—action type, timestamp, duration, and accuracy—updating the learner's profile with inferred knowledge states, misconceptions, and engagement metrics.

This updated profile informs the Pedagogical Module's decision-making for subsequent adaptations or activity transitions, which are executed by the "ActivityManager", ensuring a responsive and personalized learning loop.

The three diagrams jointly provide a coherent and complementary description of the proposed AR-ITS. The class diagram first specifies the static structure of the system by defining the main classes and associations, thereby grounding the architecture in concrete software entities.

The activity diagram then captures the global adaptive learning cycle, emphasizing how interaction tracking, learner-model updates, and the selection of AR learning objects are orchestrated within a continuous feedback loop.

Finally, the sequence diagram refines this behavioral view by detailing the ordered message exchanges between the learner, the activity manager, the AR presentation engine, the pedagogical module, and the learner model during a session.

Together, these models clarify the overall architecture and demonstrate the system's ability to dynamically personalize AR experiences in response to the learner's evolving profile.

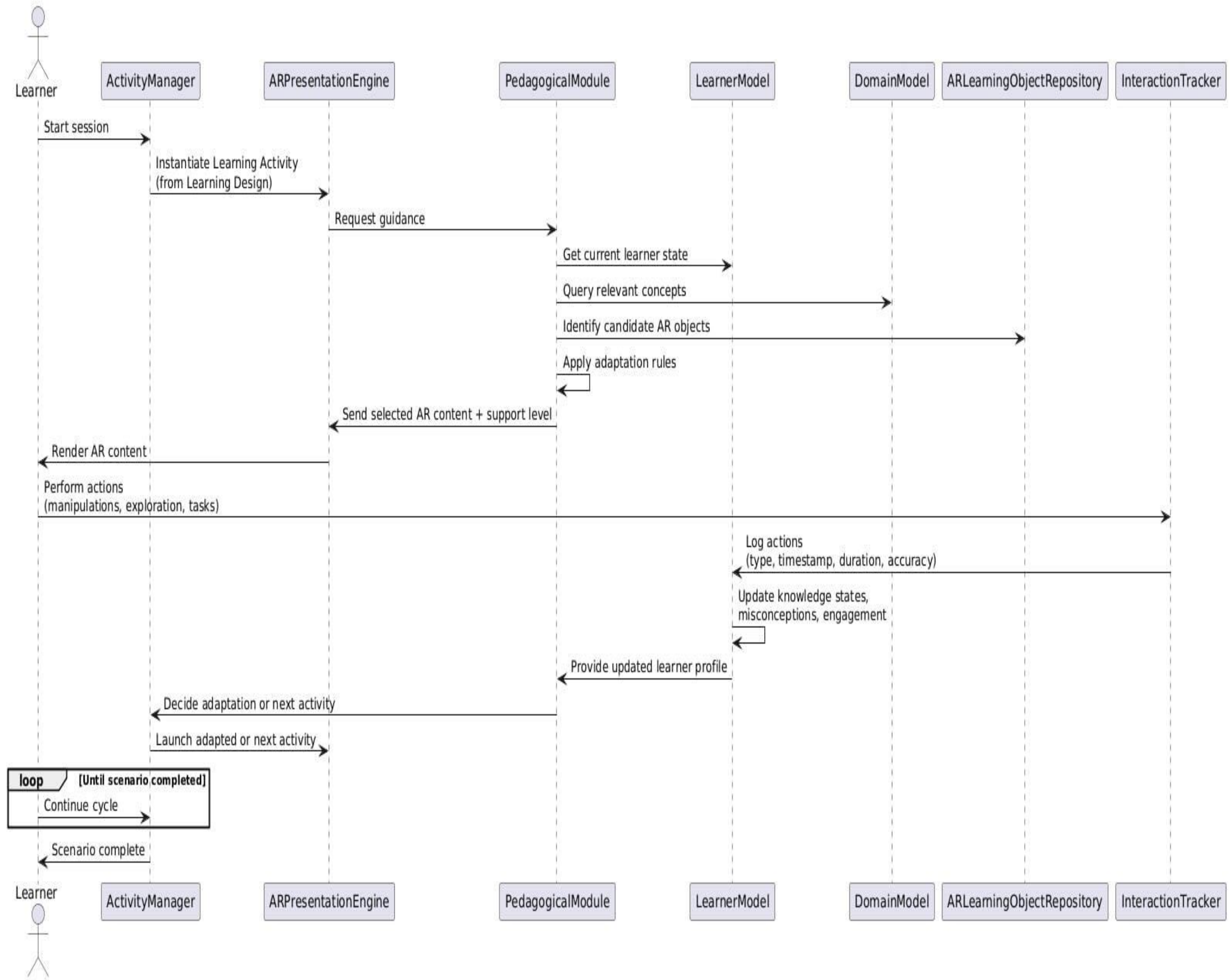

Fig. 8. Sequence diagram of the AR-ITS session flow.

V. Conclusion and Future Work

This research addresses the challenge of designing augmented reality-based intelligent learning environments that enhance learner engagement. The proposed AR-ITS model integrates AR learning objects with adaptive tutoring to create personalized learning experiences that respond to individual learner needs and preferences.

This study makes both theoretical and architectural contributions to the design of AR-based Intelligent Tutoring Systems, which can be summarized as follows: First, at the theoretical level, we establish that effective AR-ITS design requires an explicit integration of pedagogical frameworks with technical architecture, ensuring that AR learning objects are not only immersively designed but also pedagogically coherent and adaptively responsive to individual learner states. Second, in the architectural contribution, we provide a concrete UML model that operationalizes the coupling between AR content representation and ITS decision-making. This model is grounded in educational technology standards and demonstrates how data flows between layers, enabling real-time adaptation.

This study, therefore, offers a strong theoretical and architectural foundation; however, the critical next phase is empirical validation. The current work does not yet include user studies, learning outcome measurement, or comparative effectiveness analysis, and these are acknowledged as important limitations.

Looking forward, our next work will focus on implementing a fully functional AR-ITS that instantiates the proposed model for a concrete use case: teaching network topologies as part of the national computer science curriculum in Moroccan secondary education. This system will be empirically tested with learners in this context in order to evaluate its impact on learner engagement, personalization, and learning outcomes, thereby providing concrete validation of the proposed approach.

Such an evaluation will enable assessment of the model's effectiveness with its intended target audience and within an authentic educational setting.

Collectively, these efforts would help move from a theoretically grounded AR-ITS architecture to robust, field-tested systems. By demonstrating how AR-based learning objects enhance engagement within adaptive tutoring frameworks, this line of research contributes to advancing the design of next-generation intelligent learning environments.

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