A Framework for Designing Serious Games with Extended Reality to Enhance Learning

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Abstract— **This paper introduces a comprehensive framework for designing Serious Games (SG) that integrate eXtended Reality (XR)—including virtual, mixed, and augmented reality systems, to create immersive and interactive learning experiences. Key features include a model to define game mechanics and learning content, a specification approach to ensure effective XR integration, alignment with educational goals, and iterative evaluation by designers, educators, and students to ensure continuous improvement. Our design approach empowers educators to define the purpose, mechanics, and XR features of the game while keeping them closely aligned with the pedagogical objectives. The proposed framework provides a step-by-step guide for participants in SG with XR (XR-SG) design, covering all stages from preparation to testing. This work contributes to the workshop's mission by advancing the use of XR applications in education and fostering multidisciplinary collaboration for the creation of impactful, immersive learning solutions.**

I. INTRODUCTION

Serious Games (SG) leverage video game and simulation technologies to engage and motivate players to achieve meaningful objectives. By incorporating advanced innovations such as eXtended Reality (XR), including virtual, augmented, and mixed reality, and Artificial Intelligence (AI), SG provides immersive and interactive experiences that position them as powerful educational tools. These games have the potential to create dynamic and engaging learning scenarios. Integrating XR in an educational setting presents significant opportunities and challenges. [10], [9], [2]. XR technologies provide a transformative way to engage with both virtual and physical environments. Virtual Reality (VR) immerses learners in entirely virtual worlds, while Augmented Reality (AR) enhances real-world experiences by overlaying digital information onto the physical environment [8]. Mixed Reality (MR) creates an immersive experience by allowing real and digital objects to coexist, replacing natural sensory perceptions with computer-generated ones, and blurring the lines between virtual and real environments. Embracing these technologies can revolutionize the learning experience. Many studies have focused on designing and developing serious games that combine game mechanics with educational content. Due to the complexity of game features, researchers have aimed to identify the key characteristics of SG as learning mechanics and to align these with game elements [1], [19], [16]. Although these models assist designers, educators, students, and researchers in understanding how learning components can be integrated into educational games, they often do not effectively demonstrate how to merge game elements with learning components in XR environments. While numerous systematic reviews have been published, there remains an absence of a well-defined framework that identifies and organizes the various design dimensions of XR systems within an educational SG design [6]. Prior research has emphasized that instructional design holds greater significance than other engaging features of XR technologies and should be prioritized as the core of the design process for educational XR applications. Existing SG design frameworks often struggle to balance educational and entertainment aspects effectively [11]. Many are overly tailored to specific learning environments, game genres, or target audiences, limiting creativity and disrupting the harmony between fun and education [15], [13]. As XR technology becomes increasingly integrated into education, incorporating it into SG design remains a challenge, requiring a participatory approach, specialized technical expertise, and a well-structured design methodology. This paper introduces a framework built upon a previous generic serious game design approach, proposed in [1], aiming to support designers, educators, and researchers in developing serious games that provide effective learning experiences enriched by XR technologies, we named XR-SG. The framework application begins with a non-iterative preparation phase, involving project initiation, where the designers and educators pinpoint the learning experiences with XR, the desired level of immersion, and technical constraints within the XR-SG education objective and learners' accessibilities. For example, they define the XR that allows scenarios and learning experiences that are often inaccessible to learners or difficult to perceive with the human eye. This is achieved using 3D modeling, simulation, and visualization. The design process follows an iterative process, starting with a design phase and moving through specification, conceptualization, and design prototyping to create initial prototypes. These prototypes are then refined into software versions that accurately replicate XR environments for testing with appropriately connected devices. Then the XR-SG is shaped as a complete game in the development phase. The progression between phases is validated based on the XR-SG specification output. If the artifacts meet the established quality principles set by the design participants, they will define the inputs for the next

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phase. If not, the designer identifies the iteration level to restart the design improvements. The inter-phase evaluation round is significant for such games. It allows designers, educators, researchers, and students to assess the technologies and hardware devices within specific prototypes before integrating them into the complete XR-SG and performing final playtesting. The process concludes with the testing phase validation, resulting in an XR-SG beta version.

II. RELATED WORK

SGs are an innovative approach that can be integrated with XR technologies to enhance and optimize teaching and learning activities [9]. XR-SG shows great potential in education by motivating students to engage in learning while enjoying the process. However, several challenges persist, such as the educational system struggling to keep up with XR advancements and the lack of teacher proficiency in XR technologies [5].

A. Serious Game Design

SG are differentiated from traditional entertainment games by their additional objectives, including educational purposes and learning content, in addition to providing fun and amusement [18], [17]. Many methods, models, and frameworks have been proposed for SG design, but few effectively address how to specify game characteristics or their interrelationships. Most e-learning standards—such as LOM, SCORM, and IMS-LD—do not adequately represent serious game characteristics (SGCs) [14], [1]. Although there have been attempts to refine these standards and adapt them to the gaming context, they still fall short. Previous research has identified specific generic characteristics that are essential across different domains. These include twelve Common Serious Game Characteristics (CSGCs) such as Adaptability, Assessment, Gameplay, Interactivity, and Technical Features, along with four Specific Serious Game Characteristics (SSGCs) that relate to the application area, target audience, game purpose, and theoretical content [1]. Building on this foundation, a three-level model categorizes SGCs into generic characteristics (CSGCs and SSGCs), intermediate game mechanics, and concrete game elements that implement these game features [12]. The specification stage in game design provides a detailed overview that enables stakeholders to visualize and monitor the game [14]. Effective specifications for SG depend on collaboration between educators and design teams, which is essential for defining the game characteristics and learning objectives [1]. Effective game development practices include managing roles, utilizing agile methodologies (such as Scrum, Extreme Programming, Lean, and Kanban), creating prototypes, and integrating feedback from playtesting. The game development process typically consists of four main phases: initiation, pre-production, production, and testing. Iterative approaches like Scrum are among the most widely used methodologies. Techniques such as concept brainstorming, early prototyping, and iterative design have proven to be valuable in both video game and serious game development.

B. Exploring XR Technologies

Virtual reality, augmented reality, and mixed reality are key technologies within the immersive reality spectrum. VR refers to a fully simulated environment created using computer systems and digital formats, offering users an all-encompassing sensory illusion of being present in a different reality [3]. In contrast, AR overlays synthetic elements, such as 3D objects, multimedia content, or text, onto real-world images, blending the physical and virtual worlds to deliver immersive, context-sensitive experiences [4]. AR systems are characterized by three key features: the combination of real and virtual worlds, real-time interaction, and accurate 3D alignment of virtual and real objects. MR, a more recent development, combines elements of both AR and VR by integrating real-world and virtual objects. Situated on the Reality-Virtuality continuum, MR encompasses both augmented reality and augmented virtuality, providing an environment where real and virtual components coexist seamlessly [7], [6].

C. XR challenges in education

Adopting XR technologies in education presents several challenges that complicate its implementation. Accessibility remains a critical issue, as not all students have access to the necessary hardware and software outside of school, limiting opportunities for practice and revision. Scalability is another concern, as the rapid evolution of XR technology requires schools to update content to remain relevant continuously. Ensuring content validity is also essential, as the immersive nature of XR can sometimes distract students from the educational objectives, making it crucial to balance technical engagement with learning goals. Additionally, the high cost of XR systems—including development, equipment, maintenance, and updates—poses a significant barrier to widespread adoption. Robust infrastructure, such as high-performance computers, XR headsets, and stable internet connectivity, is essential but can be difficult to establish. Motion sickness caused by the immersive nature of XR also presents a barrier for some users, potentially excluding them from fully engaging in XR-assisted activities. Furthermore, effective implementation demands interdisciplinary collaboration among experts in education, design, and research, as well as extensive training for educators and IT support staff to effectively integrate XR into curricula and assessments. These challenges underline the complexities of leveraging XR technologies in educational settings. Additionally, the high costs associated with XR systems, including development, equipment, maintenance, and updates, pose a significant barrier to widespread adoption.

III. FRAMEWORK FOR DESIGNING XR SERIOUS GAMES

Designing educational serious games that integrate XR technologies (XR-SG) is a collaborative and multidisciplinary process that involves game designers, instructional designers, educators, artists, developers, and learners. The main challenge is to find a balance between entertainment and educational objectives. Especially, with XR environment challenges, creating immersive and engaging learning experiences. We propose a design framework adapted to agile practices and effective role management to address this issue. This framework breaks down the production phase into two clear stages: prototyping and development, while emphasizing a dedicated evaluation phase significantly. It includes a preparation phase and five iterative phases: design, prototyping, development, testing, and evaluation. We adapt the SG characteristics taxonomy model (see Figure 1) and the specification approach proposed in the work [1]. The model categorizes SG features into three levels of abstraction: high, intermediate, and concrete, as illustrated in Figure 1. The first category includes generic characteristics, which are divided into two sets: The first set involves XR-SG characteristics related to the game aspect, named CSGCs, including Adaptability, Assessment, Enjoyment, Gameplay, Activity, Environment, Interactivity, Collaboration, Game purpose, Application area, Target audience, and Technical features. The second set, SSGCs, details the purpose of the XR-SG, its learning domain, the distinct needs of the learners, and the instructional approach. The specification approach consists of three stages to identify the characteristics of the game. The first stage establishes generic features, serving as the principal XR-SG requirements based on the general game features and learning setting. The second stage outlines game mechanics, including challenges, narrative elements, XR environment, and rewards, which are related to the criteria defined in the first stage. Finally, the last stage presents detailed XR-SG elements and examples (reusable assets or artifacts) associated with the previously identified game mechanics, which could be implemented or prototyped within the current XR-SG. Below, we outline the XR-SG design process with the integration of XR learning environments from the preparation phase through final playtesting.

A. Overview of the XR-SG design process

The XR-SG framework follows a design process structured into five phases: preparation, design, prototyping, development, testing, and evaluation, as previously outlined. Figure 2 illustrates this process, detailing each phase and its corresponding steps.

1) Preparation phase: The first phase defines the main objectives, initializes the lifecycle, and capitalizes on software analysis and requirements engineering to define the purpose and specific content of the XR-SG learning environment. These applications cover various areas, including role-playing, virtual tours, scientific visualizations, and historical reconstructions. XR visualization tools make data exploration immersive and interactive, offering virtual experiences of inaccessible spaces like molecular structures or archaeological sites. Custom XR development is also growing on campuses, especially in visualization-focused disciplines. During this phase, all relevant information and background knowledge is collected. In addition, it involves generating ideas for XR-SG elements that effectively serve the serious objective and the expected outcomes. The preparation phase consists of meetings between designers and educators and starts with defining the overall scope of XR-SG. This includes considerations for accessibility of XR implementation, student abilities, and the technical skills of design participants. The phase concludes with a preparation output document that summarizes the key XR-SG requirements and the data collected.

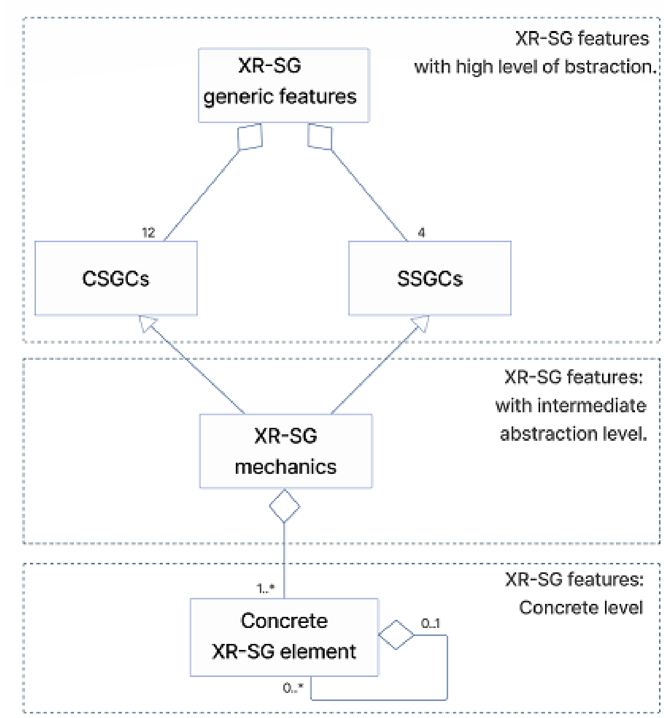


Fig. 1. Model of XR-SG characteristics adapted from [1]

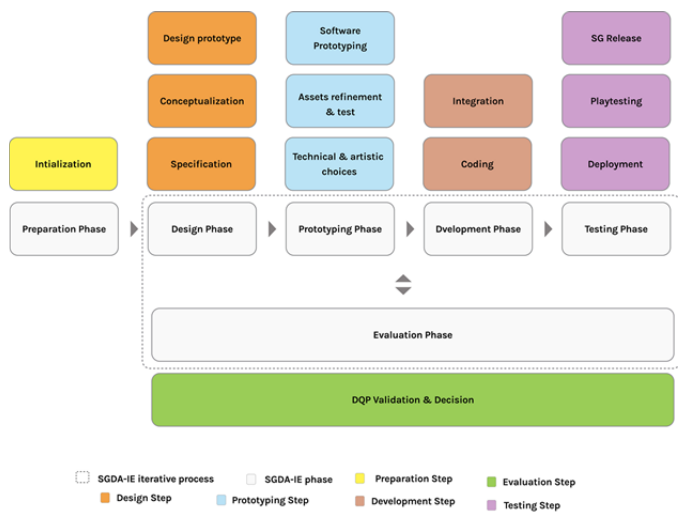


Fig. 2. XR-SG framework based on SGDA-IE approach from [1]

2) Design phase: The iterative design and development cycle begins with three key steps: specification, conceptualization, and prototype design. The specification phase utilizes the XR-SG characteristics model, illustrated in Figure 1. This model facilitates the identification of generic features of XR-SG across three stages, each with varying levels of abstraction regarding the technical aspects of XR implementation. The first stage outlines the generic features. The second stage elaborates on XR-SG mechanics, including challenges, narratives, and rewards, corresponding to the characteristics identified in the first stage. Finally, the last stage presents detailed XR-SG game elements and examples related to the previously defined game mechanics, which can be implemented or prototyped. Table 1 outlines the steps of the design phase for integrating XR-SG characteristics. For example, during the specification phase, generic game characteristics such as interactivity, collaboration, and engagement are enhanced through XR features like virtual agents, real-time feedback, and seamless integration of virtual and real environments. The conceptualization phase focuses on aligning instructional design with XR technologies, promoting learner agency and immersive storytelling to create meaningful interactions. While in the design prototype phase, XR's interactive capabilities are utilized, allowing learners to manipulate 3D objects, explore virtual spaces, and engage in hands-on problem-solving activities. By combining pedagogical objectives with immersive game-based learning techniques, these design steps ensure a captivating and effective learning experience.

3) Prototyping phase: Developing SG within XR technologies goes beyond designing the VR interface and environments; it requires careful planning of the entire intervention, including how players interact with the technology. The prototyping phase is a transition between the design and development phases. It includes three steps: technical and artistic choices, assets refinement and testing, and software prototyping. In particular, it includes testing XR hardware devices, such as motion capture devices, depth-sensing cameras, HMDs, CAVE, and tracking sensors.

4) Development phase: The development phase may proceed in parallel with the prototyping phase, as the same team manages both. The game designer, who supervises the design and development of the serious game, is in charge of planning, managing, and tracking tasks. Design team members collaborate across phases, balancing responsibilities between prototyping and development. This phase involves two main steps: programming and integration.

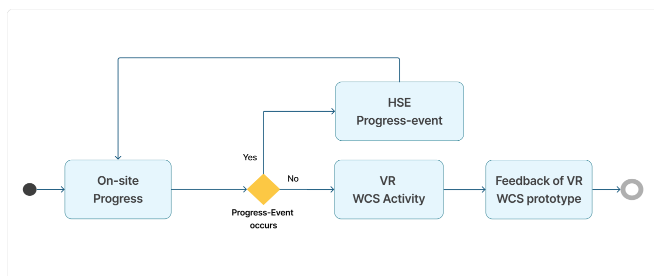
5) Evaluation phase: The evaluation phase is a crucial part of the XR-SG framework and occurs continuously at the end of each phase to ensure the adherence to the quality principles of the design. After each phase, an evaluation stage takes place, creating an iterative subprocess that is repeated until the artifact is validated. Feedback from this stage may prompt iterations that return to earlier phases for refinement. Participants fill out a shared evaluation form for each artifact, which is prepared by the designer.

6) Testing phase: The testing phase evaluates both the quality of the XR-SG developed and the effectiveness of the iterative design process. During this phase, refinements and adjustments are made based on ongoing evaluations. Positive feedback from the playtesting indicates a successful design approach. The primary outcome of this phase is the collection of playtest data for further analysis of learning outcomes and learners' engagement.

IV. XR-SG Framework application

In our previous work [1], we introduced the SGHSE (Serious Game for Health, Safety, and Environment training), which consists of 12 mini-games, each simulating a real-world mission designed to train employees on a specific HSE (Health, Safety, and Environment) rules pertinent to their operational environment. The game begins with a video introduction and player authentication, granting access to a Fuel Storage Site (FSS) simulation where users can select from the 12 missions.

Figure 3 depicts the design prototype of Mission 8, which focuses on safe practices in confined spaces. During the design prototype step, the third step of the XR framework's design phase outlined in Figure 2, a workflow diagram was utilized to represent the various scenarios to be implemented in the prototype. Upon validation in the evaluation phase, the approved prototype is then developed in the subsequent prototyping phase. The "Work in a Confined Space" (WCS) scenario includes activities like cleaning a tank or repairing electronic devices. These occur in a virtual reality simulation of the tank's interior, allowing learners to complete the assigned tasks without any HSE violations and earn a training badge. This scenario has been adapted for VR deployment to realistically simulate activities inside the tank. The proposed XR-SG framework enables designers to implement such VR gameplay by incorporating enhanced realism and real-time feedback.



On_site Progress	The player move, jump, or climb stairs on the FSS scene to reach the mission working place
Progress-Event	The player possibly meets a particular incident/matter on the FSS scene that necessitates HSE rules application, for example, fire, accident, gas issues, and impassable path
HSE Progress-event	The player performs an HSE training scenario related to the Progress-event
VR WCS Activity	The player performs a proposed work in a confined space, for instance, cleaning a storage tank or repairing electronic devices. The activity takes place in a virtual reality simulation of the tank's interior.
Feedback VR WCS prototype	The running feedback of the WCS prototype scenarios, such as data collection, player performance, badges, rewards, score, update database, and more.

Fig. 3. Design prototype of the Mission 8, including the VR scenario: Work in Confined Space (WCS).

This includes context-sensitive visual alerts and auditory cues when approaching hazards. In the latter case, the game simulates potential risks, including asphyxiation due to insufficient ventilation, falls on slippery or uneven surfaces, deflagration caused by the presence of flammable gases, or malfunctioning electronic devices. The gameplay provides interactive prompts and quizzes in response to these high-risk scenarios, as well as contextual guidance through

TABLE I
DESIGN PHASE STEPS AND XR-SG CHARACTERISTICS IN EDUCATION SETTINGS.

Design step	**SG characteristics**	**Additional XR-SG characteristics in education settings**
Specification	• Identify generic features as the SG principal requirements, including Adaptability, Assessment, Enjoyment, Gameplay, Activity, Environment, Interactivity, Collaboration, Game purpose, Application area, Target audience, and Technical features. • Identify specific features, including those related to application area, game purpose, target audience, and theory content. • Identify SG mechanics, such as challenges, fantasy, mystery, Rewards, attractive, and fun game features. • Identify concrete game elements.	• XR systems with virtual agents that learners can interact with enhance social interactivity. These agents can guide learners through activities, offer context and background knowledge, or provide a storyline, helping to engage students in the learning process. • Interact with fellow learners: XR, particularly AR, fosters social learning and collaboration by allowing learners to engage with virtual content while communicating in the real world. • XR systems that provide prompt feedback and encourage social interaction can enhance student engagement by offering immersive experiences and minimizing distractions. In education, immediate feedback is a key factor that significantly improves learning. • Degree of virtuality: To what extent do reality and virtuality coexist in the learning environment?
Conceptualization	• Modeling the domain content: according to the SSGCs established in the previous step, the designer conceives fun and serious game components. • Describing the game structure: for example, sketch the game map. • Describing the game story and defining narrative and storytelling. • Defining the game levels and/or involved mini-games • Defining scenes and scenarios. • Creating the SG Design Document (SGDD): a structured document, which summarizes the game components, such as the scope, objective, and characteristics (including CSGCs, SSGCs, game mechanics, and concrete game elements), game levels, UI (User Interface), and UX (User eXperience).	• Designer and educators adapt the instructional design to the pedagogy and learning objectives. • Defining the XR Environments, if used, spanning from interface-based environments to comprehensive interactive systems that incorporate motion capture and avatars. • In XR technologies, agency (learners' power to act in the learning process) empowers learners to take initiative, influencing both their learning and the system. This fosters active, constructivist learning through exploration. However, the agency is not just about giving control; it requires teachers and designers to create engaging contexts that encourage meaningful learner interaction with the system.
Design prototype	Prototypes are created to test the SGMs and CGEs defined in the specification stage using various methods, including software, paper, and physical prototypes.	Prototypes allow learners to test and manipulate variables and observe real-time changes. XR allows test-player to explore 3D objects by manipulating them in virtual space and solve interactive puzzles that involve applying learning content, potentially integrated into the physical classroom.

animated demonstrations of proper use of personal protective equipment (PPE) and emergency protocols.
After each mission within the VR SG environment, the system provides immersive real-time performance feedback through interactive visual dashboards and spatial audio cues. This includes dynamic safety compliance scores displayed on the virtual interface, context-aware corrective suggestions visualized through virtual instructor guidance, and achievement badges rendered within the virtual world to reward fault-free execution. Using the immersive qualities of VR, this feedback mechanism not only reinforces safety training but also strengthens hazard recognition and promotes safer behavior through experiential learning in realistic, high-risk industrial simulations.

V. CONCLUSIONS

We introduced an XR-SG framework aimed at three main objectives: 1) uncovering implicit design choices in educational XR applications, 2) providing a comprehensive design process for designers, educators, researchers, and developers based on a generic approach to serious game design, and 3) offering a common perspective for future researchers to analyze educational XR-SG systems. This framework includes clear step-by-step design guidelines that are linked to XR-SG principles and informed by relevant educational settings. We present the application of the XR-SG framework through the SGHSE case study, demonstrating its effectiveness in designing immersive, risk-aware training experiences of work in confined space scenarios tailored to high-hazard industrial contexts. Although the framework is not exhaustive, it invites further contributions from researchers to broaden its scope. In summary, the XR-SG design framework assists participants in identifying design choices, draws inspiration from existing approaches, and facilitates the creation of more effective learning environments using XR technologies.

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