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An Immersive Augmented Reality Serious Game for Preventive Health Education

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Abstract

Respiratory infectious diseases remain a major public health challenge due to the persistence of inadequate preventive behaviors and limited awareness of invisible contagion mechanisms. Although augmented reality (AR) has been increasingly adopted in educational applications, there is still a need for structured and user-centered approaches that integrate immersive interaction, pedagogical objectives, and usability-oriented development for preventive health education. This study presents the design and development of an AR serious game, "Covidcito Malhechor", aimed at supporting preventive health education through immersive learning experiences. The proposed contribution combines the iPlus methodology with the Scrum agile framework to provide a structured and replicable process for developing AR-based serious games. The system enables users to visualize virtual representations of viruses and contamination processes within real-world environments while interacting with gamified preventive health scenarios. The solution integrates pedagogical objectives, gamification elements, and AR-based interaction mechanics within a human-centered design approach focused on usability and accessibility. The system was evaluated through performance testing, functional validation, and usability assessment involving 40 students. Results demonstrated stable execution on ARCore-compatible mobile devices, achieving a successful completion of all functional test cases after iterative refinement. The usability evaluation using the Serious Games Usability Evaluation Instrument (SGUEI) yielded an overall score of 83.14%, indicating a high level of perceived usability and interaction quality. These findings demonstrate the technical feasibility and usability of the proposed approach and support its potential as a foundation for future studies on AR-based preventive health education.

Keywords: human–computer interaction; preventive health education; serious games; augmented reality; respiratory infectious diseases

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1. Introduction

In recent decades, respiratory infectious diseases have remained among the most persistent global public health challenges, imposing significant social, economic, and healthcare burdens. Despite advances in medical treatment and vaccination strategies, prevention remains one of the most sustainable and cost-effective approaches for reducing disease incidence and mitigating pressure on healthcare systems. In this context, promoting

preventive health behaviors through accessible and engaging educational strategies has become increasingly important for strengthening long-term public health resilience.

From a sustainability perspective, preventive health education can contribute to broader public health objectives by supporting awareness of protective behaviors and facilitating access to health-related information. In this context, the proposed application aligns with SDG 3 (Good Health and Well-being) through the promotion of preventive health education and with SDG 4 (Quality Education) through the use of immersive and interactive learning technologies [1].

However, one of the major challenges in preventive health education lies in communicating invisible risks. Respiratory viruses cannot be directly observed, which limits risk perception and often leads to inconsistent adoption of preventive behaviors. In Ecuador, national health statistics for 2025 indicate that five of the ten leading causes of morbidity correspond to respiratory infectious diseases, including rhinopharyngitis, tonsillitis, acute pharyngitis, bronchitis, and acute upper respiratory tract infections [2]. These conditions are primarily transmitted through respiratory droplets and contaminated surfaces, yet their invisibility often reduces individuals' awareness of contagion mechanisms.

The persistence and recurrence of these diseases suggest that traditional educational approaches are often insufficient to sustain long-term behavioral awareness. This gap between knowledge and action underscores the need for educational strategies that transform abstract health risks into tangible, experiential learning experiences. In this regard, advances in human–computer interaction (HCI) and immersive systems have enabled the development of interactive educational environments that improve user engagement, accessibility, and experiential understanding.

Within this landscape, serious games have emerged as promising educational tools capable of supporting different outcomes, including user engagement, knowledge acquisition, and, in some cases, awareness of health-related behaviors through interactive experiences. Previous studies have reported improvements in usability, motivation, learning outcomes, and behavioral intentions; however, these dimensions represent distinct constructs that require independent evaluation [3]. Simultaneously, immersive technologies such as augmented reality (AR) have expanded the possibilities of HCI by enabling users to interact naturally with virtual elements integrated into real-world environments.

AR offers a unique opportunity to "make the invisible visible" by allowing users to visualize virtual representations of viruses, contamination processes, and preventive actions within physical spaces [4]. By overlaying digital information onto the real world, AR transforms passive learning into an interactive and contextualized experience. Previous studies suggest that AR-based systems can increase engagement and support understanding of abstract concepts; however, educational effectiveness, knowledge retention, and behavioral outcomes must be evaluated separately from usability and interaction quality [5,6].

From an HCI perspective, usability and accessibility are critical to the effectiveness of immersive educational systems. Educational technologies that are intuitive, engaging, and easy to use are more likely to sustain user interaction and facilitate knowledge transfer. Consequently, the design of immersive health applications must consider not only technical performance but also interaction quality, user experience, and accessibility requirements to ensure effective adoption across diverse populations.

In this context, the present study proposes the design and development of an augmented reality-based serious game for preventive health education, integrating pedagogical objectives, gamification strategies, and immersive AR interactions within a user-centered and agile development process focused on usability and accessibility. The main contributions of this work are threefold: the design and implementation of an AR-based serious game that enables users to visualize contamination processes and preventive ac-

tions through experiential interaction; the integration of the iPlus methodology and Scrum framework into a structured and replicable development approach for immersive educational systems; and a multidimensional evaluation encompassing technical performance, functional validation, and usability assessment using the Serious Games Usability Evaluation Instrument (SGUEI). Collectively, these contributions advance the development of human-centered interactive and immersive systems by providing a methodological and technical framework for the creation and preliminary validation of accessible educational applications in health-related contexts.

The remainder of this paper is structured as follows. Section 2 presents the theoretical background related to respiratory infectious diseases, serious games, immersive technologies, and usability in educational systems. Section 3 describes the methodological approach employed in the design and development of the proposed AR serious game. Section 4 reports the obtained results. Section 5 discusses the study's implications and limitations. Finally, Section 6 concludes the paper and outlines future research directions.

2. Theoretical and Conceptual Background

2.1. Respiratory Infectious Diseases and Preventive Health Literacy

Respiratory infectious diseases (RIDs) represent a persistent global public health challenge due to their high transmissibility, rapid spread, and recurrent outbreaks. Recent epidemics, including severe acute respiratory syndrome (SARS), H1N1 influenza, and, most recently, COVID-19, have demonstrated the significant societal and health system impacts of respiratory pathogens. These events have also revealed ongoing difficulties in achieving widespread compliance with preventive measures and addressing vaccine hesitancy, both of which remain critical barriers to effective disease containment.

RIDs comprise a group of infectious diseases caused by pathogens that invade the human respiratory tract, including the nasal cavity, throat, trachea, and bronchi [7]. Common examples include influenza, tuberculosis, mycoplasma pneumonia, and coronavirus-related illnesses. Due to their highly contagious nature, these diseases exhibit substantial transmission potential within communities and therefore constitute a major global health concern [8]. In low-income regions, respiratory infections remain a significant cause of morbidity and mortality, further emphasizing the need for accessible and scalable prevention strategies [9].

Respiratory infections are commonly transmitted through respiratory droplets expelled during coughing or sneezing, as well as through indirect contact with contaminated surfaces or objects. Consequently, international health authorities recommend both pharmacological and non-pharmacological interventions to reduce transmission risks [10]. Among these measures, preventive behaviors such as regular hand hygiene, respiratory etiquette, and adopting healthy lifestyle practices, including proper nutrition, physical activity, and adequate rest, have proven essential components of infection prevention [11–13]. Environmental factors such as adequate ventilation, temperature control, and humidity management also play an important role in reducing transmission risk in indoor environments [14].

Health education has emerged as one of the most effective strategies for improving preventive behaviors among general population. Defined as a systematic, organized educational process that promotes healthy lifestyles and disease prevention, health education aims to equip individuals with the knowledge and awareness needed to mitigate health risks and improve overall quality of life. Empirical studies have shown that structured educational interventions significantly improve students' knowledge, attitudes, and practices related to respiratory infection prevention. For instance, educational programs have demonstrated measurable increases in awareness of respiratory disease prevention and the adoption of healthy behavioral practices among participants [15].

Despite these efforts, traditional educational approaches frequently struggle to maintain attention, motivation, and long-term retention of preventive practices. As a result, recent research has increasingly explored interactive, technology-enhanced learning environments capable of transforming health education into more engaging, experiential processes. In particular, immersive and interactive systems offer opportunities to improve risk perception, facilitate understanding of invisible contagion mechanisms, and strengthen preventive awareness through active user participation. These characteristics position digital educational technologies as promising tools for supporting sustainable preventive health literacy initiatives across diverse population groups.

2.2. Serious Games in Health Contexts

Serious games have been widely conceptualized as digital applications designed to achieve objectives beyond entertainment. Michael Zyda describes serious games as "a mental contest, played on a computer according to specific rules, that uses entertainment to promote governmental or corporate training, education, health, public policy, and strategic communication goals" [16]. This definition highlights two essential characteristics: the structured nature of gameplay and the intentional pursuit of educational or behavioral outcomes.

Complementarily, ref. [17] defines a serious game as a computer application designed for multiple purposes, including message transmission (educational, informational, persuasive, and subjective), training (mental and physical), and data exchange across diverse domains such as education, health, defense, and public policy. This perspective emphasizes the integration of core video game elements, including narrative (story, characters, rules, and virtual worlds), gamification (badges, challenges, and missions), gameplay mechanics (interaction actions such as avoiding, selecting, or destroying), artistic components, and software infrastructure, all of which are orchestrated to enhance user engagement and experiential learning. Similarly, serious games have been characterized as explicitly educational digital resources whose design is carefully aligned with instructional purposes [18], as well as computer-based applications developed to facilitate structured teaching and learning processes [19,20].

Empirical evidence indicates that serious games can foster cognitive and socio-emotional development by enhancing visual perception, reflex speed, working memory, and problem-solving abilities, while promoting creativity, resilience, and collaborative skills [21,22]. Their pedagogical architecture commonly integrates four core components: a serious dimension grounded in domain-specific content; storytelling to contextualize learning; gameplay mechanics that operationalize user interaction; and gamification elements, such as rewards, challenges, and feedback, to sustain motivation [23]. By enabling players to experiment, fail safely, and learn through iterative feedback, serious games provide an experiential learning environment that contrasts with traditional didactic instruction.

Within healthcare, serious games have demonstrated particular promise. They have been successfully implemented in physical rehabilitation contexts, where game mechanics, such as scoring systems, level progression, and achievement badges, enhance treatment adherence and patient engagement [24]. Foundational work by Djaouti and Zyda [16,25] emphasizes that serious games leverage narrative immersion, challenge-based progression, and real-time feedback to motivate behavioral change. In rehabilitation and clinical training settings, studies report increased motivation, improved engagement, and greater adherence to therapeutic protocols [26,27]. Furthermore, serious games provide a risk-free environment in which high-stakes tasks can be simulated without real-world consequences, thereby enhancing patient safety and potentially reducing training costs [28,29].

Recent research has explored integrating immersive technologies, particularly augmented reality (AR), into serious games for preventive health education. In [30], Saleem et al. iden-

tified multiple serious games focused on COVID-19 awareness and hygiene practices. Similarly, ref. [31] employed interactive decision-making scenarios to improve infection prevention practices among healthcare personnel. Although these studies demonstrate the relevance of immersive serious games in health education, most approaches are centered on pandemic-specific interventions or short-term awareness activities. In addition, existing work often prioritizes educational outcomes while providing limited discussion of usability, accessibility, scalability, and structured development methodologies for immersive health-oriented systems.

Table 1 highlights important differences among existing AR-based serious games for health education. Most previous studies have primarily focused on educational outcomes, awareness improvement, or training effectiveness, while usability evaluation is often limited or treated as a secondary aspect. Furthermore, few studies report structured development methodologies that integrate user-centered design, agile software engineering practices, and multidimensional validation processes. These observations reveal a research gap concerning the systematic development and preliminary validation of AR-based serious games from a usability-oriented perspective. Accordingly, the present study contributes by combining immersive AR interaction, the integration of the iPlus methodology and Scrum framework, and a multidimensional evaluation encompassing technical performance, functional validation, and usability assessment.

Table 1. Comparison of AR-based serious games for health education and the proposed approach.

Study	Health Domain	Target Population	Evaluation Focus	Usability Assessment	Main Limitation
[30]	COVID-19 prevention	General population	Awareness and hygiene practices	Limited	Focused on pandemic-specific scenarios with limited usability evaluation.
[31]	Infection prevention	Healthcare professionals	Decision-making and training	Not reported	Restricted to clinical training contexts and professional users.
[32]	Children's health promotion	Children	Educational effectiveness	Partial	Limited methodological consistency across interventions.
[33]	Health education	Students and patients	Engagement and learning outcomes	Variable	Limited discussion of usability-oriented development processes.
[34]	Human anatomy education	Medical students	Visualization and identification of human skeletal structures	Not reported	Focuses on anatomical visualization through markerless AR; no usability evaluation, learning assessment, or structured development methodology reported.
This Study	Respiratory infectious disease prevention	General population	Technical performance, functional validation, and usability	SGUEI	Focuses on preliminary validation rather than educational effectiveness.

Although the reported benefits of health-oriented serious games are promising, the evaluation dimensions adopted across studies vary considerably. Some investigations primarily focus on usability and user experience, assessing interaction quality, acceptance, and perceived ease of use. Others emphasize engagement and motivation through gameplay-related indicators, while a smaller body of research evaluates educational outcomes such as knowledge acquisition and learning performance. Only a limited number of studies

examine behavioral change or long-term retention of preventive practices. Consequently, positive usability or engagement results should not be interpreted as evidence of educational effectiveness, as these constructs represent distinct dimensions requiring different evaluation methodologies and outcome measures.

User acceptance and usability have emerged as critical determinants of effectiveness in immersive educational systems. Research suggests that healthcare professionals, students, and general users perceive serious games as engaging and valuable educational tools [33,35–39]. Higher engagement levels are frequently associated with intuitive interaction, interactive feedback, and active learning mechanisms embedded within gameplay. Consequently, current research increasingly highlights the need for evidence-based and human-centered design approaches capable of addressing usability, accessibility, and sustained engagement in digital health interventions [40,41].

Several instruments have been used to evaluate serious games, including SUS, UEQ, and domain-specific educational game frameworks. However, many of these instruments focus primarily on general usability or user experience dimensions. The Serious Games Usability Evaluation Instrument (SGUEI) was selected in this study because it incorporates dimensions specifically associated with serious game interaction, including gameplay, gamification, narrative, learning support, and interface usability, providing a more comprehensive assessment framework for immersive educational applications [42].

Despite the growing body of research on AR-based serious games for health education, relatively few studies combine immersive interaction design, structured software development methodologies, and usability-oriented evaluation within a unified framework. Furthermore, existing work frequently prioritizes educational or awareness outcomes while providing limited discussion of accessibility, user-centered design practices, and replicable development processes. In response to these gaps, the present work focuses on integrating immersive AR interactions, a usability-oriented design approach, and a structured development framework to support preventive health literacy through accessible mobile technologies. Rather than evaluating educational effectiveness, the study concentrates on the design, implementation, and preliminary validation of the proposed system through technical, functional, and usability assessments.

2.3. Immersive Technologies and Sustainable Educational Innovation

Immersive technologies have increasingly transformed the landscape of educational innovation by enabling interactive, multisensory learning experiences. Among these technologies, augmented reality (AR) is characterized by its ability to overlay digital information, such as images, 3D objects, animations, and contextual data, onto the real world through devices including smartphones, tablets, and AR headsets. By complementing physical surroundings with interactive digital elements, AR creates blended learning environments that facilitate real-time visualization and experiential engagement [43,44]. For example, students can scan a textbook image and instantly interact with dynamic 3D representations, rendering abstract or complex concepts more tangible and cognitively accessible [45].

In preventive health education, one of the main challenges lies in the limited perception of invisible risks. Respiratory infectious diseases are transmitted through microscopic agents that cannot be directly observed, which frequently reduces awareness and weakens adherence to preventive behaviors. Traditional educational strategies based on verbal explanations or static visual materials often struggle to generate meaningful behavioral engagement [46,47]. In this context, AR offers a distinct advantage by making invisible processes visible, enabling users to visualize virus representations, contamination pathways, and transmission scenarios in their immediate surroundings. This transformation of

abstract risks into tangible and interactive experiences can strengthen awareness, improve understanding, and support preventive health literacy.

Since its creation in the 1990s, AR has evolved from a specialized technological innovation into a widely adopted tool across sectors such as education, science, engineering, tourism, and healthcare [48,49]. In educational settings, AR applications have demonstrated significant potential to enhance instructional quality by supporting the visualization of didactic content that would otherwise be difficult to convey through traditional methods [50]. Theoretical foundations for AR integration in education frequently draw upon constructivist and situated learning theories, emphasizing active knowledge construction through interaction with real-world contexts [51,52]. Within this framework, AR fosters collaborative exploration, problem-solving, and contextualized understanding, thereby strengthening engagement and knowledge retention.

Meta-analytical evidence further supports AR's educational effectiveness. For instance, Radu et al. examined comparative studies between AR-based and non-AR applications, highlighting improvements in learning outcomes and learner motivation [53,54]. Similarly, Parisod et al. synthesized evidence regarding digital games promoting children's health, identifying promising outcomes while underscoring methodological and quality-related gaps [32]. These findings suggest that immersive technologies can contribute meaningfully to educational and health-related awareness when supported by appropriate pedagogical and usability-oriented design.

A notable advantage of AR lies in its accessibility and scalability. Unlike fully immersive virtual reality systems, AR applications can operate on widely available mobile devices, facilitating broader adoption beyond specialized laboratory settings [55,56]. In educational and medical contexts, AR has been used to support interactive visualization, anatomical exploration, and contextual learning experiences [57–60]. This adaptability positions AR as a feasible, cost-conscious option for large-scale educational deployments and human-centered interactive systems.

From a sustainability perspective, AR-based educational interventions may contribute to preventive health strategies by improving awareness and encouraging preventive practices. Strengthening preventive health literacy can support reducing disease transmission and potentially decrease long-term healthcare burdens by promoting early awareness and behavioral reinforcement. Consequently, immersive technologies not only enhance learning experiences but also support broader goals related to sustainable and accessible public health education.

Despite these advantages, the integration of immersive technologies into sustainable health education remains fragmented. Existing studies frequently address AR from either technological or pedagogical perspectives without systematically connecting immersive interaction, usability, preventive health literacy, and sustainability objectives [61]. Additionally, many approaches emphasize educational outcomes while providing limited discussion regarding accessibility, scalability, and structured development methodologies for immersive health-oriented systems.

Existing AR-based health education systems have primarily focused on assessing educational outcomes or awareness interventions in highly specific contexts, while providing limited discussion of usability-oriented development processes, structured software engineering methodologies, accessibility considerations, and multidimensional validation strategies. Furthermore, many studies report educational outcomes without detailing replicable frameworks for the design and evaluation of immersive health applications. Consequently, there remains a need for structured approaches that integrate immersive interaction design, human-centered development practices, and usability-oriented evaluation to support the development of accessible AR serious games for preventive health education.

3. Methodology

This study follows a Design and Development Research (DDR) approach focused on the creation and preliminary validation of an augmented reality serious game for preventive health education. The research emphasizes the design, implementation, and evaluation of a technological artifact rather than the assessment of educational effectiveness or behavioral change outcomes. Within this framework, the proposed system is developed through a structured process that integrates user-centered design principles, serious game design methodologies, and agile software engineering practices.

Beyond the development of a specific application, this work proposes a structured and replicable methodological approach for the design and implementation of serious games in preventive health contexts. By integrating user-centered design principles, pedagogical modeling, and agile software development practices, the approach can be adapted to other domains requiring behavioral awareness and educational intervention.

The development process follows an agile-oriented methodology structured in three stages. First, the iPlus methodology is used to identify system requirements and translate them into design specifications, epic narratives, and user stories [17]. Second, the game is implemented using the Scrum framework, enabling iterative development through short sprints and the delivery of functional increments. Finally, the application is validated through functional, performance, and usability testing to ensure its reliability and educational effectiveness prior to deployment.

The combination of iPlus and Scrum was selected because both methodologies address complementary dimensions of immersive educational system development. iPlus provides a structured framework for identifying educational requirements, defining pedagogical objectives, and translating stakeholder needs into gameplay and interaction specifications. Scrum complements this process by supporting iterative implementation, rapid prototyping, continuous testing, and incremental delivery of functional software components. Compared with purely software-oriented agile approaches, this integration facilitates the alignment of pedagogical goals, usability requirements, and technical development throughout the project lifecycle.

3.1. Game Design

The design of the proposed serious game "Covidcito Malhechor" followed the iPlus methodology, a structured and user-centered framework widely used in the development of educational serious games and interactive systems. The methodology was selected for its ability to integrate end users, domain experts, and technical teams from the early stages of the design process, ensuring that the resulting solution is pedagogically grounded, accessible, and socially relevant [62]. Furthermore, the methodology supports iterative refinement and validation processes, making it suitable for the development of human-centered educational technologies in health contexts.

A key contribution of this work lies not only in the implementation of an augmented reality application but also in the methodological integration of immersive technologies, serious game design principles, and usability-oriented development practices. In this sense, the proposed approach emphasizes the systematic transformation of preventive health concepts into interactive, experiential learning mechanisms supported by augmented reality visualization.

The design process is structured into five interrelated phases, see Figure 1. These phases ensure that the serious game aligns with both the defined educational objectives and the needs of the target users, while supporting the development of sustainable health awareness strategies. Each phase of the process is described below.

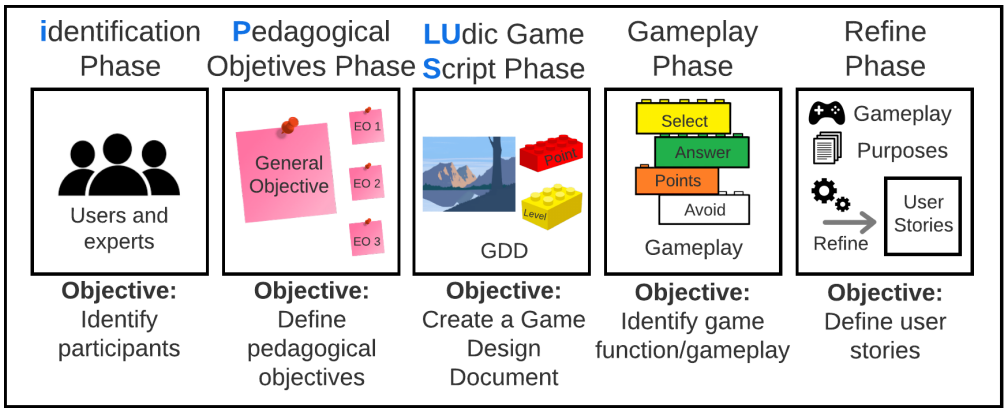


Figure 1. iPlus Methodology.

3.1.1. Identification Phase

The first phase focused on identifying the educational problem and defining the initial system requirements. This process involved collaborative sessions with a multidisciplinary team composed of two specialists in software development, a serious game designer, a pedagogy, and a human–computer interaction expert. Additionally, consultations were conducted with educational stakeholders to discuss common challenges associated with preventive health education and the communication of respiratory infection risks.

The main problem identified was the difficulty of communicating invisible contamination risks associated with respiratory infectious diseases, which often limits risk perception and reduces adherence to preventive behaviors. During these sessions, stakeholders, target users, educational needs, interaction requirements, and usability considerations were analyzed and documented. Particular attention was given to identifying learning situations in which augmented reality could support the visualization of otherwise invisible contagion processes.

The serious game was therefore conceived as an immersive educational application capable of visualizing contamination scenarios and preventive actions within real-world environments through augmented reality interactions. The outcomes of this phase were formalized as a set of functional and educational requirements that served as inputs for the subsequent pedagogical and technical design stages.

3.1.2. Definition of Pedagogical Objectives Phase

In the second phase, pedagogical objectives were collaboratively defined with the support of educational specialists. The objective was to ensure that gameplay interactions were directly linked to preventive health awareness and experiential learning.

The general objective of the system is to promote awareness of preventive behaviors for respiratory infectious diseases through immersive, interactive augmented reality experiences. Specifically, the game was designed to allow users to identify contamination risks, recognize preventive measures, and interact with simulated infection scenarios integrated into real-world environments.

Several specific objectives were also established. First, the game presents everyday scenarios in which players must decide how to manage infection risk. Second, the application incorporates augmented reality technology to visualize virus-related interactions in real-world contexts, reinforcing experiential learning. Finally, the system provides immediate feedback on player actions, enabling users to recognize both correct and incorrect behaviors while learning effective strategies for infection prevention.

To support these objectives, the system incorporates real-time feedback mechanisms, contextual interaction challenges, and visualization of virus-related elements within physical spaces. This design enables users to associate preventive actions with observable

consequences, reinforcing experiential understanding through immersive interaction rather than passive information delivery.

3.1.3. Ludic Game Script Phase

The ludic game script phase focuses on defining the narrative structure, gamification elements, and overall interaction logic of the serious game. During this stage, a collaborative brainstorming session was held with experts and designers to define key elements, including the storyline, characters, game mechanics, and reward systems.

The resulting Game Design Document (GDD) served as the conceptual blueprint for the application, defining narrative elements, interaction sequences, educational objectives, immersive mechanics, and usability considerations. Unlike conventional educational applications that primarily present static information, the proposed system was designed around experiential interaction and contextualized risk visualization.

Based on the identified educational needs, the game was designed around three interactive scenarios that illustrate common infection prevention situations. In the first scenario, players collect protective items, such as masks and hand sanitizer, before leaving home, reinforcing preparedness behaviors. The second scenario requires players to assist an infected individual while maintaining an appropriate distance and using protective measures, emphasizing responsible social interaction. In the third scenario, players must identify and eliminate virus particles represented in augmented reality environments by cleaning contaminated surfaces and avoiding exposure to infectious droplets.

These mechanics extend beyond conventional information-based approaches by combining physical-space interaction, real-time visualization, and experiential decision-making. Additional gamification elements, including rewards, achievements, and progression mechanisms, were integrated to strengthen engagement and sustain user interaction throughout the learning experience. Players can earn badges and virtual coins for completing challenges, which can later be used to unlock additional resources within the game. The application was designed for mobile platforms, ensuring accessibility and scalability across devices widely available in educational environments.

3.1.4. Gameplay Phase

The gameplay phase focused on defining the core interaction mechanics that structure the immersive experience. Gameplay blocks were identified to determine how users interact with augmented reality objects, navigate scenarios, manipulate virtual elements, and complete preventive health challenges.

These gameplay structures were designed to ensure that all interactions directly support the intended educational objectives. The application was classified as an adventure-based serious game due to its emphasis on exploration, interaction, contextual decision-making, and experiential learning.

Particular attention was given to integrating augmented reality as an active interaction component rather than a purely visual enhancement. Users are required to physically move within their environment, identify contamination zones, and interact with virtual health-related elements superimposed onto real-world spaces. This interaction design reinforces immersion and contributes to transforming abstract health risks into perceivable experiences.

3.1.5. Refinement Phase

The final phase focused on refining and validating the design outputs generated in the previous stages. During this stage, design ideas and requirements were reviewed collaboratively by the project team and domain specialists to ensure consistency with the

educational objectives, usability principles, and technical constraints identified throughout the design process.

Validated requirements were subsequently translated into epics and user stories, forming the basis of the Scrum-oriented implementation process. Requirements were prioritized according to three criteria: pedagogical relevance, referring to their contribution to preventive health awareness; usability impact, considering their influence on user interaction and accessibility; and technical feasibility, considering implementation complexity and available resources.

Examples of user stories were derived from the prioritized requirements to guide the implementation process. These stories captured the expected user interactions, educational objectives, and usability requirements of the system. Figure 2 illustrates the structure adopted for user story specification, including the user role, intended functionality, expected benefit, and associated acceptance criteria. Acceptance criteria were defined for each story to verify the correct implementation of educational content, interaction mechanics, and feedback mechanisms throughout the development process.

User Story	
Identifier: H-EPIC 002	**Role:** Player
Story title: Interaction with virtual objects and augmented reality scenarios	
Priority: H (High)	
Description: The player will be able to see and interact with the SARS-CoV-2 virus; therefore, he must avoid and destroy it with his limited arsenal in order not to become infected and ill.	
Acceptance criteria: *R01:* The player will have to disinfect themselves periodically depending on their risk level of infection. *R02:* The player must put on a mask every time they start a task. *R03:* The player must spray alcohol-based disinfectant to eliminate the threat in game. ...	

Figure 2. User story and acceptance criteria defined for the AR serious game.

This structured refinement process enabled the creation of a traceable and human-centered product backlog aligned with pedagogical objectives, immersive interaction requirements, and usability principles. By organizing the requirements in this way, the methodology ensured coherence between educational goals, user needs, and technical implementation, supporting the development of a scalable digital solution for preventive health education.

3.2. Development of Serious Game

The implementation phase focused on transforming the conceptual and pedagogical design into a functional, immersive educational system through an iterative and user-centered development process. In alignment with the objectives of this study, the development stage emphasized usability, accessibility, immersive interaction, and experiential learning rather than the evaluation of clinical or behavioral outcomes. The resulting application was conceived as a human-centered augmented reality serious game, "Covidcito Malhechor", designed to support preventive health education through the interactive visualization of contamination risks and preventive practices.

The development process was guided by the Scrum framework, which supports iterative implementation through short development cycles (sprints), continuous refinement, and incremental delivery of functional components. This approach facilitated constant alignment between pedagogical objectives, gameplay mechanics, usability requirements,

and technical implementation. Through iterative reviews and testing sessions, the development team progressively refined interaction mechanics, interface elements, augmented reality visualization features, and gamification components.

The integration of the iPlus methodology with Scrum provided a complementary framework that combined user-centered educational design with agile software engineering practices. While iPlus structured the definition of pedagogical objectives, interaction strategies, and gameplay logic, Scrum supported the implementation and refinement of immersive functionality through iterative prototyping and validation activities (see Figure 3). This integration represents one of the study's methodological contributions, as it provides a replicable approach for developing immersive serious games oriented toward health education and human-centered interaction systems.

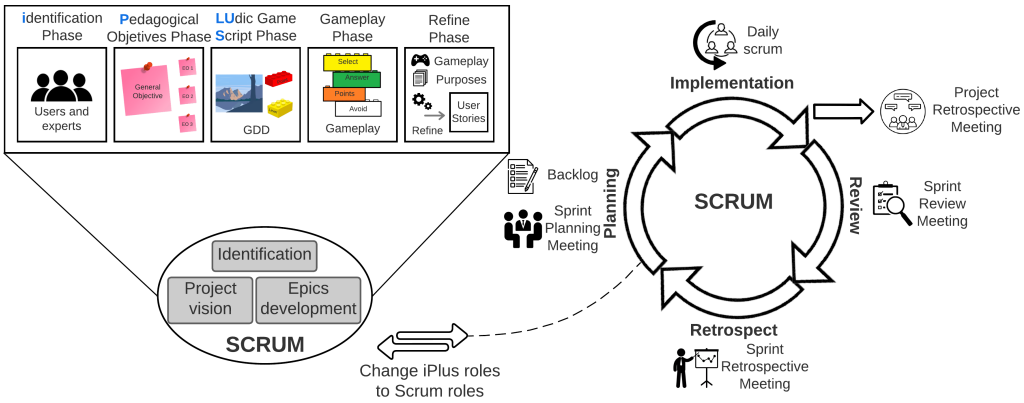
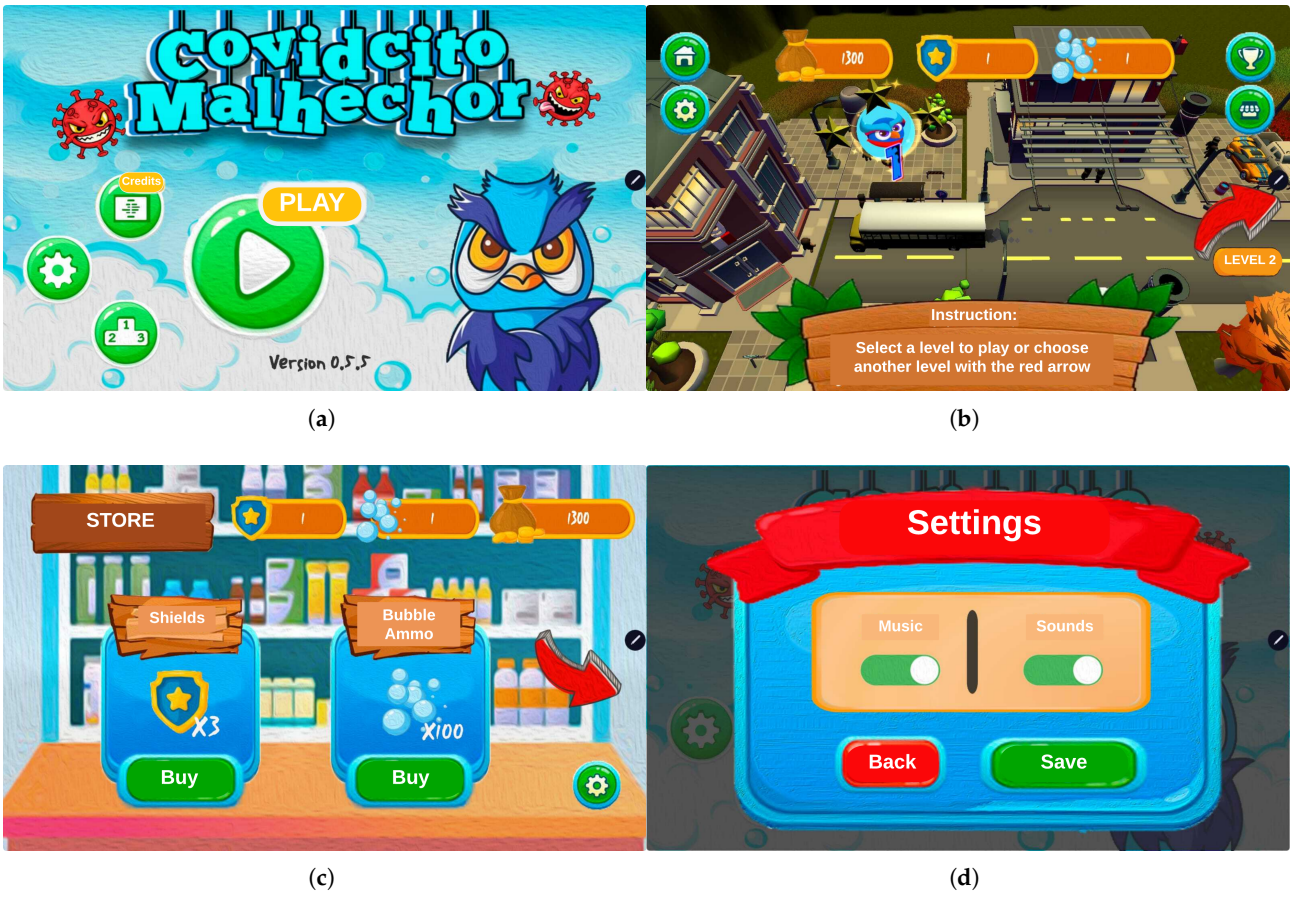


Figure 3. iPlus–Scrum Integration.

The application was developed using Unity 2022.3 LTS and the AR Foundation framework with ARCore support for Android devices, with C# as the primary programming language. The system architecture was organized into presentation, game logic, and augmented reality interaction layers, integrating gameplay mechanics, narrative progression, scoring, achievements, and feedback components into a unified immersive environment. ARCore provided plane detection, environmental tracking, motion tracking, and anchor management, enabling the visualization and interaction of virtual objects within real-world spaces. Visual assets were created using Adobe Illustrator and Blender, while version control was managed through Git. To improve performance on mobile devices, optimization techniques such as texture compression, object pooling, and efficient particle management were applied. The final application was deployed on Android smartphones running Android 11 or later, supporting accessibility and scalability through compatibility with widely available consumer devices.

The game narrative is structured around a virtual journey in which users progress through a series of scenarios related to preventive health. Rather than focusing exclusively on COVID-19, the proposed system addresses broader respiratory infectious disease prevention practices, including hygiene awareness, contamination avoidance, distancing behaviors, and environmental disinfection. The main interface provides access to gameplay progression, achievements, rewards, and configuration settings, while also presenting visual indicators related to user performance and interaction status, see Figure 4.



(**a**) (**b**)

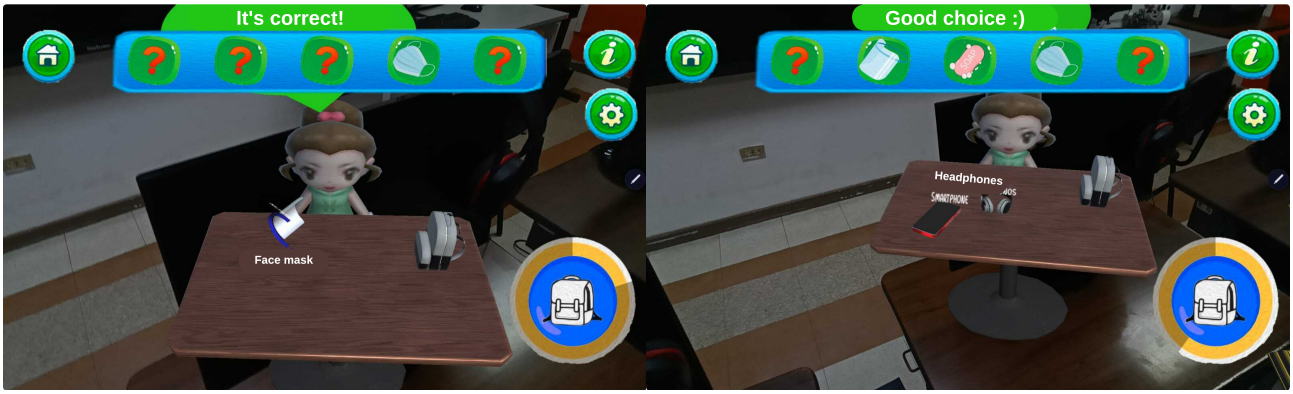
(**c**) (**d**)

Figure 4. User interface screens of the serious game: (**a**) main menu providing access to game modes and navigation options; (**b**) level selection screen displaying available stages and player progression; (**c**) in-game store for acquiring virtual items and resources; and (**d**) settings screen for configuring gameplay and system preferences.

The serious game was structured into three main levels, each designed to reinforce preventive behaviors related to respiratory infectious diseases through interactive augmented reality scenarios.

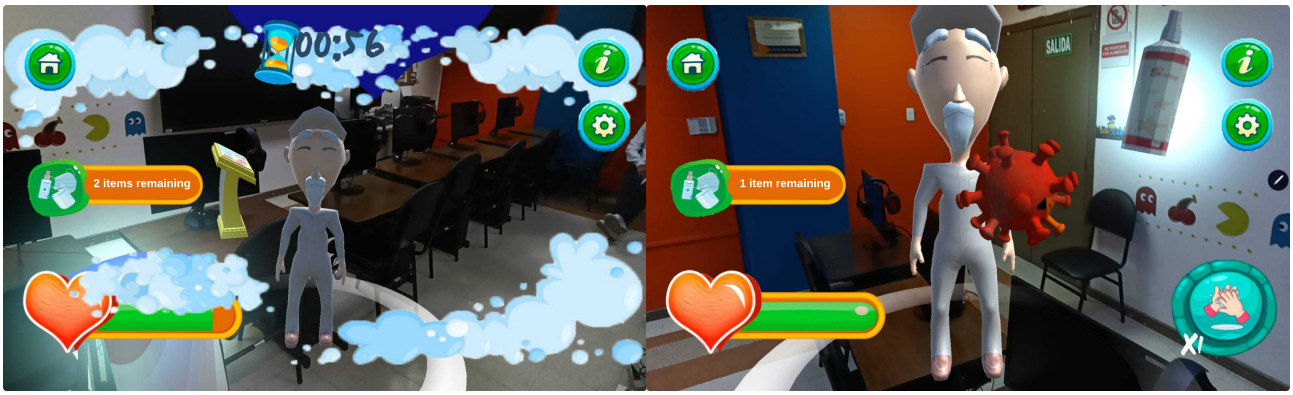
The first level introduces users to preventive hygiene practices through an augmented reality object-selection activity. Virtual objects representing protective resources, such as masks and sanitizing items, are superimposed on the physical environment, requiring users to identify and collect appropriate items while avoiding irrelevant ones. Through real-time feedback and contextual prompts, the level reinforces preparedness and hygiene awareness while familiarizing users with augmented reality interaction mechanics, see Figure 5.

The second level focuses on awareness of contamination and safe social interaction. In this scenario, users interact with a symptomatic virtual character while taking preventive actions, such as maintaining distance and providing protective resources. Augmented reality visualization is used to represent contamination risks surrounding the virtual character, enabling users to perceive otherwise invisible transmission dynamics within the physical environment. The level incorporates interactive mechanics based on distancing, resource management, and time-constrained objectives, reinforcing experiential understanding of preventive practices, see Figure 6.



(**a**) (**b**)

Figure 5. Gameplay scenario of Level 1: (**a**) selection of preventive hygiene items before leaving home; and (**a**) identification and exclusion of unnecessary items.

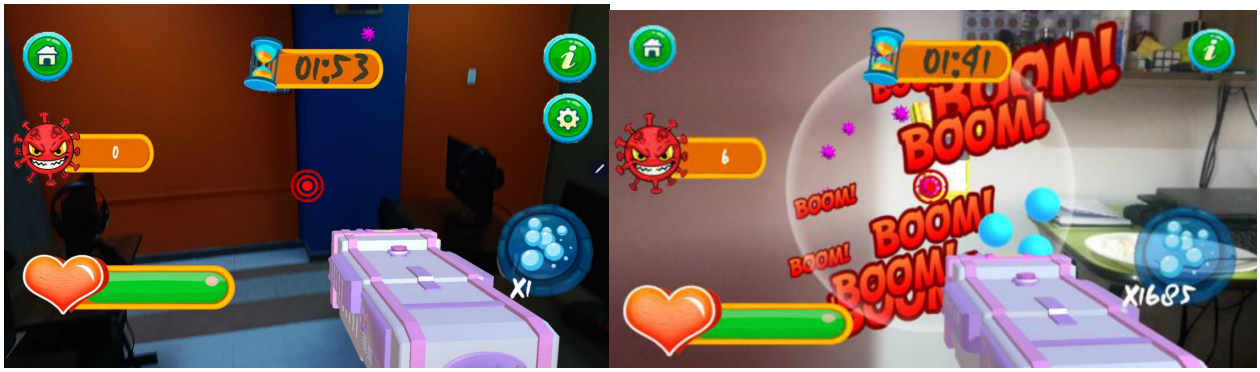


(**a**) (**b**)

Figure 6. Gameplay scenario of Level 2: (**a**) assisting a symptomatic character using appropriate preventive measures; and (**b**) avoiding virus particles while delivering hand sanitizer to the symptomatic individual.

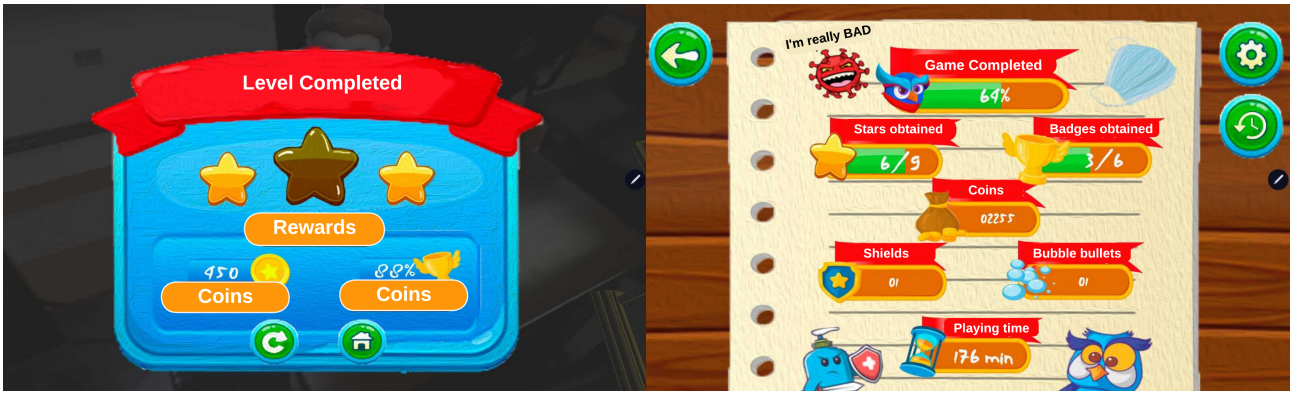
The third level emphasizes awareness of environmental contamination and disinfection practices. In this scenario, augmented reality is used to visualize airborne particles and contamination zones integrated into real-world spaces. Users must identify contaminated areas and eliminate virtual virus representations through interactive cleaning mechanics before the time limit expires. This level was specifically designed to reinforce the concept of invisible contamination and to strengthen the relationship between environmental hygiene and disease prevention through experiential interaction (see Figure 7).

To strengthen engagement and continuity of interaction, the system incorporates gamification mechanisms, including achievement badges, progress indicators, virtual rewards, and performance statistics. Users can monitor gameplay progression, completed challenges, earned resources, and achievement status through dedicated interfaces designed to provide continuous feedback and reinforce participation (see Figure 8). These mechanisms were integrated to support sustained interaction and improve the overall usability and engagement of the immersive educational experience.



(**a**) (**b**)

Figure 7. Gameplay scenario of Level 3: (**a**) identification of airborne particles and virus representations in the environment; and (**b**) elimination of infectious agents through interactive cleaning mechanics.



(**a**) (**b**)

Figure 8. Feedback and progression interfaces: (**a**) level completion screen displaying performance results and feedback; and (**b**) player profile screen presenting achievements, statistics, and overall progression.

Overall, the implementation phase demonstrates how immersive technologies, augmented reality interaction, and serious game mechanics can be systematically integrated through a structured and user-centered development framework. Beyond the resulting application, the proposed process provides a replicable methodology for developing immersive educational systems focused on health awareness, usability, accessibility, and experiential learning. Although the application was not specifically designed for users with disabilities, several accessibility-oriented design decisions were incorporated, including high-contrast interface elements, large text labels to improve readability, simplified touch-based interactions, visual feedback accompanying gameplay events, and compatibility with standard Android accessibility settings. These features were intended to facilitate interaction and accessibility on commonly available mobile devices. However, the current version does not yet provide dedicated support for color-blind users, multilingual interfaces, adaptive difficulty levels, or alternative audio descriptions, which remain opportunities for future development.

To support transparency and reproducibility, demonstration materials, system documentation, and evaluation artifacts are available upon reasonable request for research and academic purposes.

3.3. Evaluation

The evaluation phase aimed to assess the technical performance, functional reliability, and usability of the developed serious game, "Covidcito Malhechor". This multidimensional evaluation approach ensures that the proposed solution not only functions correctly from a technical perspective but also provides an effective and engaging user experience that was designed to support preventive health education through immersive and interactive experiences. Such a comprehensive assessment contributes to the development of sustainable digital learning tools aligned with Sustainable Development Goal 3, which promotes innovative strategies for health awareness and disease prevention. For the usability assessment, participants were university students familiar with mobile devices but with no prior experience using the proposed application. During the evaluation sessions, they were asked to complete the three game levels, interact with the augmented reality components, and access the achievement system. Each session lasted approximately 20–25 min, providing sufficient exposure to the application's core functionalities, gameplay mechanics, immersive interactions, and progression features to support a comprehensive usability evaluation.

This study was conducted under the ethical approval granted by the Human Research Ethics Committee of the Pontifical Catholic University of Ecuador (CEISH-PUCE) under project code EO-083-2025 (Version 2), entitled "Diseño de Juegos Serios y Recursos Centrados en el Usuario". The approval was granted following the committee's evaluation of the ethical, methodological, and legal aspects of the research protocol, confirming compliance with the institutional requirements for research involving human participants. All research activities were conducted in accordance with the approved protocol. Participation was voluntary, and informed consent was obtained from all participants prior to their involvement. No personally identifiable information was collected, and all questionnaire responses and usability data were anonymized before analysis and stored in password-protected institutional repositories accessible only to the research team. Data were processed exclusively for research purposes in accordance with applicable ethical and data protection regulations, and no procedures involving physical or psychological risk were performed.

3.3.1. Performance Evaluation

Performance testing was conducted to evaluate the system's stability, efficiency, and resource consumption under typical operating conditions. These tests are essential for determining an application's speed, scalability, and reliability within a specific execution environment, thereby ensuring software quality prior to deployment. In this study, the performance evaluation focused on CPU consumption and memory utilization, two critical indicators for mobile applications that rely on augmented reality technologies [63].

The evaluation was performed using a mobile device running Android 13 and ARCore version 1.41, equipped with an octa-core processor, 8 GB of RAM, and an Adreno GPU. The application was executed under standardized testing conditions to minimize variations caused by background processes or network activity. During each execution, performance data were collected using the Android profiling tools integrated into the development environment. The monitored indicators included average and peak CPU utilization, memory consumption, frames per second (FPS), and frame-time stability during gameplay.

These indicators were selected because they directly influence application responsiveness, visual stability, and overall user experience in mobile AR environments. The collected measurements enabled the identification of potential performance bottlenecks while verifying the technical feasibility of the proposed serious game under typical operating conditions.

3.3.2. Functional Evaluation

Functional testing was conducted using a black-box testing approach to verify that the implemented functionality met the defined system requirements [64]. This method evaluates system responses to predefined inputs and interaction events without requiring access to the internal implementation logic.

A total of 20 functional test cases were designed and organized into five categories: augmented reality initialization, object interaction, gameplay progression, reward mechanisms, and scene transitions. These test cases evaluated the core functionalities of the application, including object recognition, user interactions, score progression, reward allocation, and gameplay mechanics associated with the three educational scenarios. Each test case specified predefined inputs, expected outputs, and validation criteria, and was considered successful when the observed system behavior matched the corresponding functional requirements. During the initial testing phase, 16 of the 20 test cases were successfully completed, yielding a success rate of 80%. The remaining four test cases revealed functional inconsistencies related to augmented reality interaction sensitivity and gameplay synchronization, which were subsequently addressed through iterative refinements during the development process.

To address these issues, iterative refinements were applied during the Scrum development cycles. After refinement, all previously failed test cases were executed again and successfully passed validation, resulting in a final functional success rate of 100%. This iterative validation process contributed to improving the robustness, reliability, and interaction consistency of the immersive system prior to usability evaluation.

3.3.3. Usability Evaluation

The usability evaluation followed the protocol proposed by Rautela et al., illustrated in Figure 9 [65]. Participants initially received a brief introduction to the interaction dynamics, augmented reality controls, and gameplay objectives. Subsequently, participants completed a predefined set of tasks designed to simulate typical interaction scenarios within the serious game.

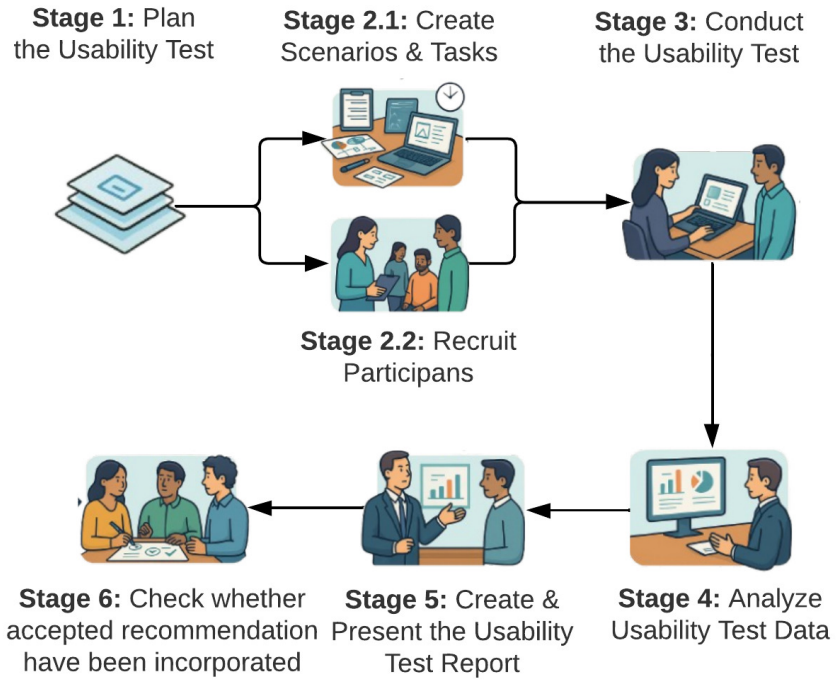


Figure 9. Usability evaluation protocol.

The usability assessment focused on three core dimensions: effectiveness, referring to the accuracy and completeness with which users completed tasks; efficiency, associated with the ease and speed of interaction; and user satisfaction, reflecting participants' overall perception of the immersive experience.

To evaluate usability, the study employed the SGUEI (Serious Games Usability Evaluation Instrument), a validated instrument specifically designed for serious games [42]. The questionnaire evaluates multiple dimensions, including serious objectives, narrative visualization, world representation, character design, gamification techniques, gameplay mechanics, interface quality, and multimedia interaction. Each item was assessed using a five-point Likert scale ranging from strongly disagree to strongly agree. The questionnaire items were translated into Spanish for better understanding for the users.

The participant selection followed the recommendations of Nielsen and Landauer for usability evaluations, which suggest that relatively small samples can identify the majority of usability issues in interactive systems. Similarly, Faulkner reported that evaluations involving five participants can uncover between 55% and 85% of usability problems [66]. Building upon these recommendations, a total of 40 engineering students from the National Polytechnic School, aged between 19 and 22 years, were recruited through convenience sampling. Although smaller samples are generally sufficient for identifying usability problems, a larger sample was intentionally selected to increase the reliability of the usability measurements, reduce the influence of individual variability, and obtain a broader range of user perceptions regarding the augmented reality interactions. Inclusion criteria required participants to be between 18 and 25 years old, have regular experience using smartphones, and provide informed consent. Individuals with prior experience using the proposed application or those unable to complete the evaluation protocol were excluded. Most participants reported frequent use of mobile applications and digital games, while prior experience with augmented reality applications was limited. Since the objective was to conduct a preliminary usability validation rather than assess educational effectiveness, engineering students were considered appropriate participants due to their familiarity with digital technologies. Nevertheless, the authors acknowledge that this sample does not fully represent the broader target population for preventive health education, and future studies should include more diverse demographic groups.

All usability sessions were conducted individually in a controlled indoor environment under researcher supervision. The same mobile device was used for all participants to ensure consistency in hardware performance and AR rendering. The testing area provided stable illumination and sufficient surface features to support ARCore tracking. Prior pilot tests were also conducted under varying lighting conditions to verify the robustness of AR detection and visualization mechanisms. In addition to the quantitative survey data, qualitative feedback was collected through open-ended questions and a post-evaluation discussion session. This mixed-method approach allowed the identification of usability issues, strengths of the interaction design, and potential areas for improvement. The insights from this evaluation help refine the system and strengthen its potential as an accessible, sustainable educational tool for promoting preventive health behaviors through immersive technologies.

4. Results

4.1. Performance Evaluation Results

The performance evaluation analyzed system stability and computational resource consumption under typical operating conditions on ARCore-compatible mobile devices. The obtained results are summarized in Table 2.

Table 2. Summary of performance metrics recorded during gameplay sessions.

Metric	Result
Test Duration	10 min
Average RAM Consumption	215 MB
Average Frame Rate (FPS)	60 FPS
Average Frame Execution Time (ms)	16.62 ms
Average CPU Usage (%)	25%

The results indicate stable application performance during gameplay sessions. The average frame rate of 60 FPS and frame execution time of 16.62 ms demonstrate that the system can maintain adequate graphical responsiveness for real-time augmented reality interactions on conventional mobile devices. Similarly, the observed CPU and memory consumption levels remained within acceptable operational limits throughout the execution of the different gameplay scenarios.

These findings provide preliminary evidence of the technical feasibility of the proposed application on the evaluated device configuration and support its use as a proof-of-concept implementation. From a usability and accessibility perspective, this characteristic is particularly relevant because it facilitates broader adoption across educational and public health contexts where technological resources may be limited.

4.2. Functional Evaluation Results

Functional evaluation was conducted using a black-box testing approach to verify compliance with the defined system requirements. During the initial testing phase, 16 of 20 test cases were successfully completed, yielding an initial success rate of 80%. These issues were addressed through iterative refinements implemented during subsequent Scrum development cycles. The corrective actions included optimization of AR tracking parameters, adjustment of collision detection thresholds, synchronization improvements in event management processes, and refinement of gameplay feedback mechanisms. After refinement, all previously failed test cases were successfully validated, achieving a final success rate of 100%. The results demonstrate that the proposed system achieved a satisfactory level of functional reliability prior to usability testing. This iterative correction process also reflects the effectiveness of integrating the iPlus methodology with Scrum-based development practices for refining immersive educational systems.

4.3. Usability Evaluation Results

The usability evaluation was conducted using the SGUEI instrument with 40 engineering students. The results indicate a high level of perceived usability, with an overall score of 83.14%, corresponding to a classification of “Good” to “Excellent”. The overall SGUEI score was obtained by averaging the scores of all questionnaire items across participants and subsequently transforming the result to a percentage scale. No weighting factors were applied, and all dimensions contributed equally to the final usability score.

Table 3 presents the mean scores and standard deviations obtained for each usability dimension. Multimedia (93%, SD = 5.80) and Interface (87%, SD = 7.60) achieved the highest ratings, indicating positive perceptions regarding audiovisual quality and interaction clarity. In contrast, Gameplay (75%, SD = 11.25) and Gamification Techniques (79%, SD = 12.10) obtained the lowest scores and exhibited the highest variability among participants, suggesting differences in user perceptions related to challenge progression, reward mechanisms, and engagement.

Table 3. SGUEI usability results by dimension.

Dimension	Mean (%)	SD
Multimedia	93	5.80
Interface	87	7.60
Gameplay	75	11.25
Gamification Techniques	79	12.10
Character Visualization	86	6.90
World Visualization	85	7.50
Story Visualization	84	8.11
Serious Objectives	84	7.80

A detailed analysis of the usability dimensions revealed positive results across most evaluation categories. The multimedia and interface dimensions obtained the highest scores, reaching 93% and 87%, respectively, indicating that participants positively perceived the visual design, interaction clarity, and audiovisual presentation of the system (see Figure 10).

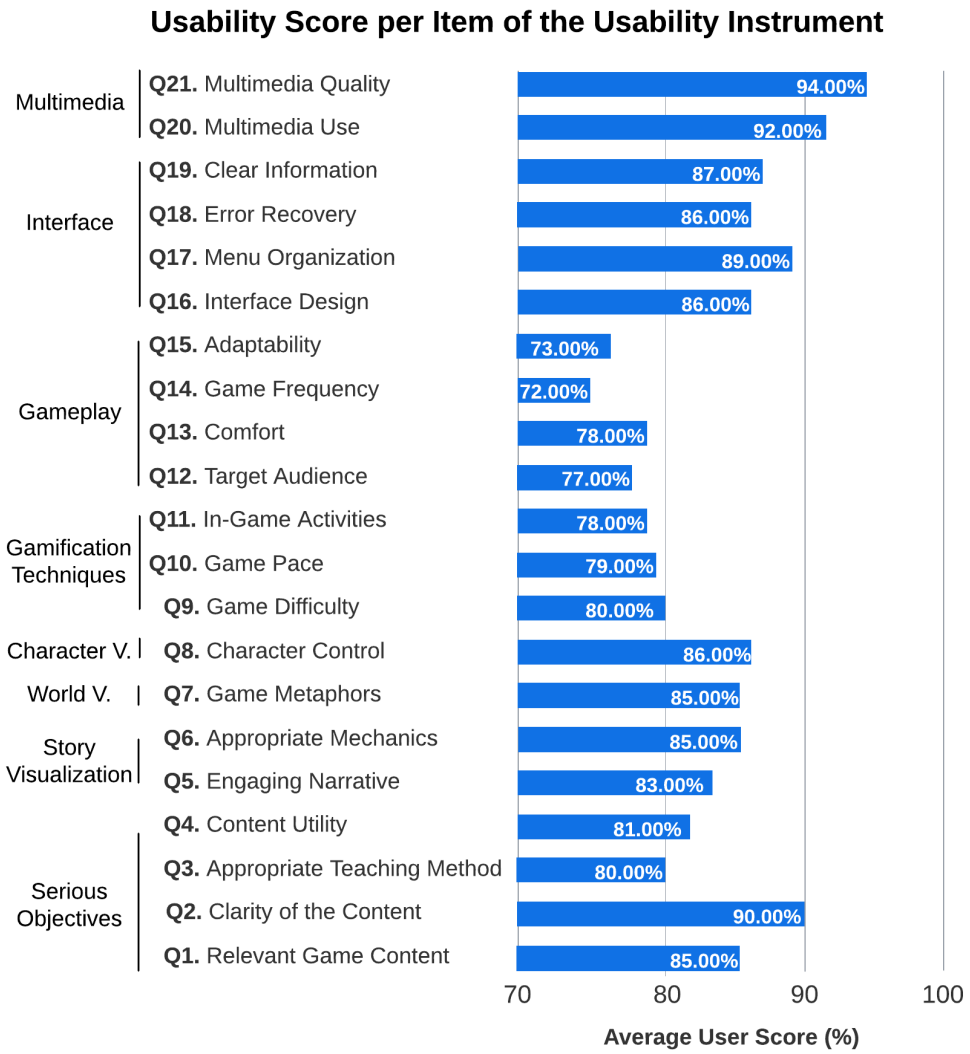


Figure 10. Usability evaluation results by SGUEI dimension.

In contrast, the gameplay and gamification dimensions received comparatively lower scores of 75% and 79%, respectively. Participant feedback suggests that these scores may be associated with the limited number of gameplay levels, the absence of adaptive difficulty

mechanisms, and the relatively simple reward structure available in the current prototype. Several participants indicated interest in additional challenges, more diverse objectives, and expanded progression systems. Although these dimensions achieved acceptable usability levels, the results highlight opportunities to strengthen long-term engagement and replayability in future versions of the application.

The overall SGUEI score of 83.14% indicates a high level of perceived usability. To facilitate interpretation of the obtained score, the Bangor adjective rating scale was used as a qualitative reference framework (see Figure 11). Although the Bangor scale was originally developed for SUS scores, both SUS and SGUEI generate normalized scores on a 0–100 scale. Therefore, the Bangor categories were used only as an illustrative reference for interpreting perceived usability and not as evidence of psychometric equivalence between the two instruments. The obtained score falls within the "Good" usability range, indicating a positive user perception of the proposed system. Reliability estimates were not calculated because the objective of this study was to obtain a preliminary usability assessment of the prototype rather than to revalidate the SGUEI instrument, which has been previously validated in the literature. Future studies with larger and more diverse samples may incorporate reliability analyses for the specific study population.

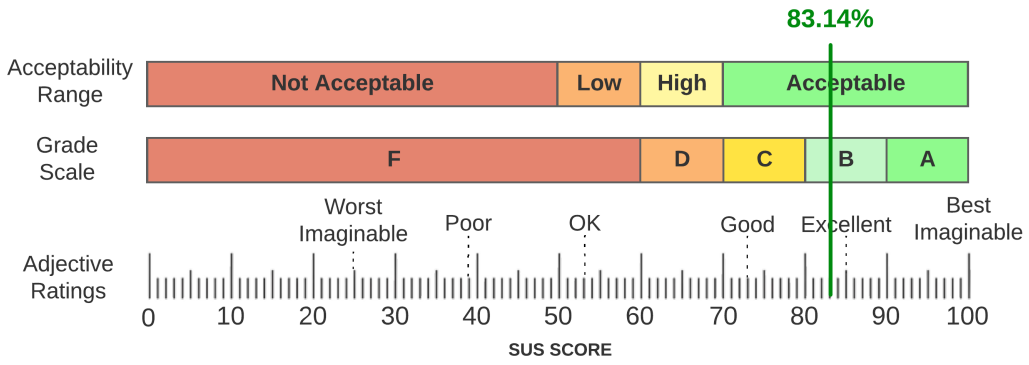


Figure 11. Interpretation of the overall SGUEI score using the Bangor adjective rating scale.

In addition to the quantitative results, qualitative feedback was collected through open-ended questions and post-evaluation discussions. Participant comments were reviewed and grouped into recurring themes related to usability, immersion, educational value, and interaction design. The findings indicated that users perceived the augmented reality interactions as effective for visualizing contamination processes and invisible environmental risks. Participants particularly emphasized that the integration of virus representations and contamination scenarios into real-world environments improved both the clarity of the educational content and the engagement of the overall experience. These observations were used to complement and contextualize the quantitative usability results.

These observations suggest that immersive visualization mechanisms may increase user awareness of preventive health practices. However, it is important to note that this study did not evaluate learning effectiveness, knowledge retention, or long-term behavioral change. Consequently, the findings should be interpreted as preliminary evidence regarding usability, interaction quality, and user perception within the context of immersive preventive health education.

Overall, the results demonstrate that the proposed serious game is technically feasible, functionally reliable, and highly usable, satisfying the fundamental requirements for deployment as a human-centered immersive educational system. Furthermore, the findings support the viability of integrating augmented reality, serious game mechanics, and usability-oriented design methodologies to develop accessible educational technologies for preventive health awareness.

5. Discussion

The results demonstrate that the proposed augmented reality serious game constitutes a technically stable, functionally reliable, and highly usable immersive educational system. Rather than focusing on clinical effectiveness or long-term behavioral outcomes, this study primarily contributes to the design and development of a human-centered framework for creating immersive health-oriented educational applications that integrate augmented reality, gamification, and usability-oriented evaluation. The technical performance observed in this study is consistent with previous mobile AR educational applications, where stable frame rates and moderate resource consumption have been reported as sufficient to support real-time interaction on consumer-grade devices.

One of the most relevant findings is the capacity of augmented reality to visualize otherwise imperceptible health risks. Respiratory infectious diseases are transmitted through microscopic agents that are not directly observable in everyday contexts, which can reduce risk perception and weaken preventive awareness. The integration of AR-based interactions enabled participants to experience simulated contamination scenarios in real-world environments, transforming abstract preventive concepts into interactive and experiential learning activities. Qualitative feedback indicated that participants perceived the AR visualizations as useful for understanding contamination scenarios and preventive actions.

The usability evaluation supports the feasibility of immersive educational systems in preventive health contexts. The overall SGUEI score indicated positive perceptions regarding interface design, multimedia integration, and interaction clarity, highlighting the importance of usability for accessibility and effective interaction in augmented reality environments. These findings are consistent with previous studies on AR-based serious games, which have shown that immersive visualization and contextualized interactions can enhance user engagement, motivation, and perceived ease of use. Similar usability trends have been reported in AR-based educational applications, where multimedia-rich interactions are generally rated positively, while gameplay depth and long-term engagement remain recurring challenges. In particular, the high scores obtained in the multimedia and interface dimensions suggest that the integration of augmented reality contributed positively to the overall user experience.

In contrast, the comparatively lower scores obtained for the gameplay and gamification dimensions indicate opportunities to strengthen challenge progression, reward diversity, and motivational mechanisms. Similar findings have been reported in serious game research, where educational applications often achieve high usability but face difficulties sustaining long-term engagement when game mechanics are simplified to prioritize instructional objectives. Consequently, these results emphasize the importance of balancing educational content with engaging gameplay elements and provide valuable guidance for future iterations of the proposed system.

From a methodological perspective, this study contributes a structured framework for the development of immersive educational systems by integrating the iPlus methodology, Scrum-based agile practices, and user-centered design principles. While many AR-based health education studies primarily report system implementation and usability outcomes, the proposed approach explicitly combines development, iterative refinement, and multidimensional evaluation within a single framework. This integration may facilitate greater traceability throughout the design process and support the preliminary validation of immersive educational applications.

The study also contributes to the growing body of research on immersive technologies for preventive education. Existing AR-based health games frequently focus on specific pandemic-related scenarios or isolated awareness campaigns. In contrast, the proposed system adopts a broader preventive health literacy perspective focused on respiratory infec-

tious diseases while incorporating usability, accessibility, and scalable mobile deployment considerations. This broader approach positions the work within the field of human-centered immersive educational technologies designed for preventive health contexts.

The findings should also be interpreted in the context of previous research on augmented reality and serious games. Consistent with existing literature, the results suggest that immersive visualization can support user engagement and facilitate the understanding of abstract concepts through situated interaction. At the same time, the lower scores observed in gameplay and gamification dimensions reinforce challenges previously reported in educational games, where balancing learning objectives and engaging game mechanics remains a critical design issue. These observations highlight the importance of integrating usability, pedagogical goals, and motivational strategies throughout the development process of immersive learning applications.

Nevertheless, several limitations should be acknowledged. The evaluation focused on technical performance, functionality, and usability rather than on measuring learning gains, behavioral modification, health literacy outcomes, or long-term knowledge retention. Therefore, the results cannot be interpreted as evidence of educational effectiveness or public health impact. Additionally, the usability evaluation was conducted with university students, whose interaction patterns may differ from those of other population groups. Although this decision enabled an initial usability-oriented validation under controlled conditions, future studies should include more diverse participants and educational contexts. Consequently, the present work should be interpreted as a prototype development and preliminary validation study focused on technical feasibility, functional reliability, and usability, rather than as an effectiveness evaluation of a preventive health intervention.

Future research should address these limitations by conducting studies with the intended target population and in real educational or public health settings. In addition to usability assessment, future evaluations should incorporate pre- and post-intervention measures to examine knowledge acquisition, delayed assessments to analyze knowledge retention, and instruments aimed at exploring risk perception and behavioral intention. Comparative studies involving non-AR educational approaches or conventional instructional methods would also provide valuable evidence regarding the specific contribution of immersive technologies to preventive health education.

6. Conclusions

This work presented the design, development, and preliminary validation of an augmented reality-based serious game oriented toward preventive health education for respiratory infectious diseases. The study followed a human-centered design and development research approach integrating the iPlus methodology, Scrum-based agile development, and usability-oriented evaluation.

The results demonstrated that the proposed system is technically feasible, functionally reliable, and highly usable within mobile immersive environments. In particular, the usability evaluation indicated positive user perceptions regarding interface clarity, multimedia integration, and interaction design, supporting the applicability of augmented reality for interactive preventive health education contexts.

Beyond the implementation of a specific application, the main contribution of this work lies in the proposed methodological framework for developing immersive educational systems. The integration of pedagogical objectives, gamification strategies, augmented reality interactions, and iterative development processes provides a structured, transferable approach that can support future development in health-oriented serious games and human–computer interaction research.

Additionally, the study highlights the potential of immersive technologies to facilitate the visualization of invisible health risks through experiential interaction. By allowing users to observe and interact with virtual representations of contagion processes in real-world environments, the proposed approach was evaluated in terms of technical performance, functionality, and usability preventive health awareness and improves user engagement in educational experiences.

Despite these contributions, some limitations must be acknowledged. The evaluation focused primarily on technical performance, functionality, and usability rather than on measuring learning effectiveness, behavioral change, or long-term knowledge retention. Furthermore, the usability evaluation was conducted with university students under controlled conditions, which limits the generalizability of the findings to broader populations and real educational settings.

Future work will therefore focus on conducting longitudinal educational evaluations, incorporating more diverse participant groups, and comparing immersive educational approaches with traditional instructional methods. Additional research may also explore adaptive interaction mechanisms, advanced gamification strategies, and accessibility-oriented features to further enhance the effectiveness and inclusiveness of immersive health education systems.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Research Ethics Committee for Human Beings of the Pontifical Catholic University of Ecuador (Comité de Ética de la Investigación en Seres Humanos de la Pontificia Universidad Católica del Ecuador). The study was approved under project code EO-083-2025, Version 2, entitled "Diseño de Juegos Serios y Recursos Centrados en el Usuario", on the basis that it satisfied the ethical, methodological, and legal requirements established by the committee. All participants provided informed consent prior to their participation, and the study was conducted in accordance with the approved protocol.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Dataset available on request from the authors.

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Conflicts of Interest: The authors declare no conflicts of interest.

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