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Review

Extended Reality (XR) Engines for Developing Gamified Apps and Serious Games: A Scoping Review

Humberto Marín-Vega [1], Giner Alor-Hernández [1,*], Maritza Bustos-López [1], Ignacio López-Martínez [1] and Norma Leticia Hernández-Chaparro [2]

[1] Tecnológico Nacional de México/I. T. Orizaba, Av. Oriente 9, No. 852, Col. Emiliano Zapata, Orizaba 94320, Mexico; humberto.mv@orizaba.tecnm.mx (H.M.-V.); maritbustos@gmail.com (M.B.-L.); ignacio.lm@orizaba.tecnm.mx (I.L.-M.)

[2] Tecnológico Nacional de México/Campus Zongolica, Km 4 Carretera a la Compañía S/N, Tepetitlanapa, Zongolica 95005, Mexico; norma.hernandez.pd183@zongolica.tecnm.mx

* Correspondence: giner.ah@orizaba.tecnm.mx; Tel.: +52-272-725-7056

Abstract: Extended Reality (XR) is an emerging technology that enables enhanced interaction between the real world and virtual environments. In this study, we conduct a scoping review of XR engines for developing gamified apps and serious games. Our study revolves around four aspects: (1) existing XR game engines, (2) their primary features, (3) supported serious game attributes, and (4) supported learning activities. We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model to conduct the scoping review, which included 40 primary studies published between 2019 and 2023. Our findings help us understand how current XR engines support the development of XR-enriched serious games and gamified apps for specific learning activities. Additionally, based on our findings, we suggest a set of pre-established game attributes that could be commonly supported by all XR game engines across the different game categories proposed by Lameras. Hence, this scoping review can help developers (1) select important game attributes for their new games and (2) choose the game engine that provides the most support to these attributes.

Keywords: extended reality; extended reality engines; gamification; gamified apps; mixed reality; serious games

Citation: Marín-Vega, H.; Alor-Hernández, G.; Bustos-López, M.; López-Martínez, I.; Hernández-Chaparro, N.L. Extended Reality (XR) Engines for Developing Gamified Apps and Serious Games: A Scoping Review. *Future Internet* **2023**, *15*, 379. https://doi.org/10.3390/fi15120379

Academic Editors: Tatsuo Nakajima and Kaori Fujinami

Received: 3 October 2023
Revised: 21 November 2023
Accepted: 22 November 2023
Published: 27 November 2023

1. Introduction

Extended Reality (XR), gamification, and serious games are all concepts that involve the integration of technology into interactive experiences. XR is an emerging technology that enables seamless interaction between virtual and real environments. XR includes Virtual Reality (VR) and Augmented Reality (AR). XR technologies have multiple applications, such as site design with virtual walkthroughs, rapid prototyping, dynamic operation simulation, detailed design coordination, and marketing presentations to customers [1]. In the educational domain, XR is an innovative factor in the learning process that allows learners to interact with virtual objects and models within virtual environments to build knowledge and generate a meaningful learning experience while simultaneously reducing cognitive load [2,3].

Gamification incorporates game design elements into non-game contexts, such as business, marketing, work, and education [4]. On the other hand, serious games are digital games that exist for the purpose of learning. Game-based learning, simulated environments, and serious games can promote knowledge acquisition, skill development, and awareness of specific phenomena [5]. Serious gaming uses games to fill needs other than entertainment [6,7]. XR techniques can be exploited in gaming to build knowledge in virtual environments and multimedia content. Gamification for education and training uses game elements in non-game settings, such as apps and systems [8,9], to help learners

learn. In this sense, XR-based serious games can improve learning experiences with the help of virtual models from the real world [10].

Current studies exploring gamification and serious games have reported favorable results on the effectiveness of using game attributes and learning activities for learning purposes in software apps. Given these varied findings, it becomes important to identify and study how XR can impact the development of serious games and gamified apps.

This review of the XR literature is fueled by the advancement in display technology and computing, which has resulted in new devices to overlay digital representations of the real world, integrating all aspects of it into virtual environments. These reviews address the impact of XR-enriched mobile apps in medicine, education, and manufacturing. In their work, Rakkolainen et al. [11] provided an overview of emerging multimodal technologies by summarizing the latest advances in multimodal interaction technology based on head-mounted display (HMD) XR systems. On the other hand, Ratcliffe et al. [12] analyzed concerns common to XR, such as safety and hardware variability, in a survey on the drawbacks and opportunities of XR technologies. Furthermore, other studies [13–16] have explored how XR technologies, such as realistic 3D visualization and touch-free interfaces, impact learning in medical apps.

In this scoping review, our primary objective is to describe the current state of XR engines used for developing gamified apps and serious games. To this end, we analyze four key aspects: (1) existing XR game engines, (2) their main features, (3) supported serious game attributes, and (4) supported learning activities. To ensure comprehensiveness, we examined a body of scientific literature published between 2019 and March 2023, which is when XR-based educational environments started to emerge. The remainder of this research is structured as follows: Section 2 describes the methods and materials used to perform the review. In Section 3, we summarize our findings, whereas in Section 4 we discuss such findings with respect to our research questions. In Section 5, we discuss current challenges in XR with respect to our findings, and in Section 6, our conclusions are summarized.

2. Materials and Methods

This review follows the Arksey and O'Malley methodology [17]. Unlike systematic literature reviews and meta-analyses, scoping reviews facilitate the collation of a diverse range of relevant literature using different methodologies [18,19]. Moreover, the Arksey and O'Malley methodology [15] offers flexibility in defining concepts related to game engines for XR, apps developed with these game engines, and XR features. We also adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model from Moher et al. [20] along with the meta-analysis and extensions of the PRISMA-ScR model. PRISMA focuses on the methods authors use to ensure accurate and thorough reporting of reviews and meta-analyses [21,22].

The development of this scoping review comprised the following steps: (1) define research questions; (2) identify pertinent game engines; (3) choose pertinent game engines; (4) graph data; and (5) summarize and report findings.

2.1. Research Questions

To meet the goals of the review, we developed four research questions, which are listed in Table 1. These questions guided the reviewing process, described the main reasons that gave rise to the review, and served as a reference to organize our findings.

2.2. Inclusion and Exclusion Criteria

At the first stage of the search strategy, we identified the repositories to be used. These were ScienceDirect (Elsevier), SpringerLink, IEEE Xplore Digital Library, MDPI, PubMed, Hindawi, ACM Digital Library, Inderscience, Google Scholar, and Wiley Online Library.

Table 1. Research questions and motivations.

Research Question ID	Question	Motivation
RQ1	Which XR engines are reported in the literature?	Identify the main XR engines reported in the literature.
RQ2	What are the main features of these XR game engines?	Identify the main features of XR engines.
RQ3	What serious game attributes are supported in these XR game engines?	Identify the main game attributes supported by XR engines.
RQ4	What learning activities are supported in each serious game developed with the reviewed XR game engines?	Identify learning activities that support XR in serious games.

At the second stage, we searched for records about learning activities in XR-enriched educational games and serious games using the following keywords and search strings:

1. 'Gamification' AND ('Augmented Reality' OR 'Virtual Reality' OR 'Extended reality') OR 'Serious games' AND ('Virtual Reality' OR 'Extended reality' OR 'Augmented Reality') OR 'educational applications' AND ('Augmented Reality' OR 'Extended reality' OR 'Virtual Reality').
2. 'Mobile application' AND ('Virtual Reality' OR 'Extended reality' OR 'Augmented Reality') OR 'smart application' ('Virtual Reality' OR 'Extended reality' OR 'Augmented Reality') OR 'Mathematics application' AND ('Virtual Reality' OR 'Extended reality' OR 'Augmented Reality').

Table 2 lists the keywords with respect to the research area and the related concepts.

Table 2. Search keywords and related concepts.

Area	Keywords	Related Concepts
Extended reality	Gamification and virtual reality Gamification and augmented reality Gamification and extended reality Serious games with virtual reality Serious games with augmented reality Serious games with extended reality	Gamified apps Serious games Mobile apps Educational apps Educational games

At the third stage of the review, we organized and presented our findings using the PRISMA statement [22].

2.3. Study Selection and Eligibility

At the conclusion of the search process, 553 relevant results were found. The results were as follows: 16 from IEEE Xplore Digital Library, 89 from ScienceDirect (Elsevier), 68 from SpringerLink, 174 from Wiley Online Library, and 206 from Google Scholar. Following the removing of duplicates and articles unrelated to the research, we relied on 107 works for the first analysis. After screening these records based on their title and abstract, we performed a full-text reading of 92 works, which were then assessed for eligibility based on a full-text reading analysis. We excluded 52 of these works since they did not pass the eligibility assessment per our established set of exclusion criteria, which are listed as follows:

1. Studies on XR implementation in areas other than education
2. Studies on XR without gamification techniques
3. Studies on serious games without XR

The remaining 40 records were included in the review (see Figure 1).

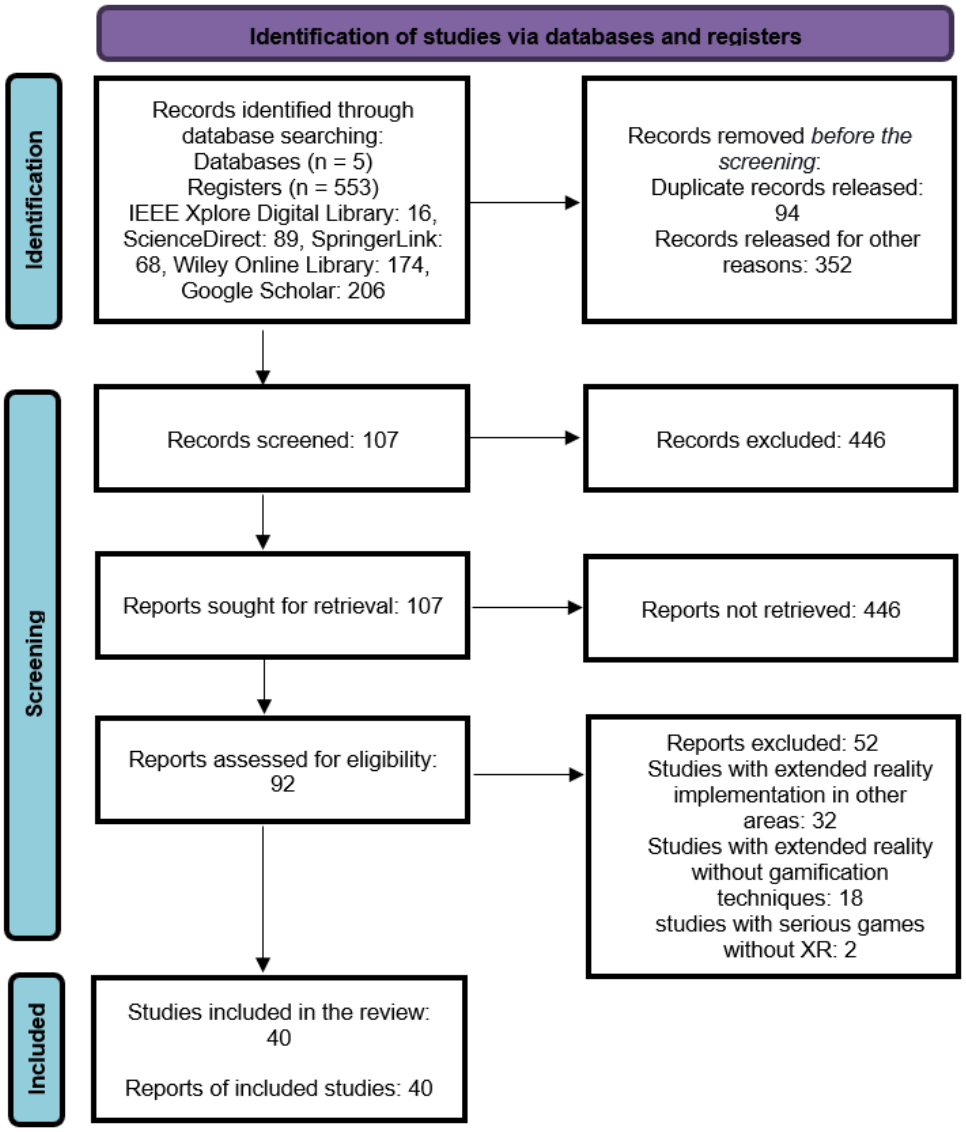

Figure 1. Selection process for studies—PRISMA flow diagram.

We downloaded the entire file of each of the 40 works collected for the review to ensure a proper analysis. We considered papers published between 2019 and 2023, with an upward trend in publishing. We found that most of the records (n = 24) were published in 2022 (see Figure 2). Figure 2 presents the distribution by year of primary studies about XR. As can be observed, XR is an emerging technology. The growth in the research about XR is very important, and it is a tendency that can be observed between the years 2019 and 2023. It is also important to mention that this study encompasses early 2023.

Figure 3 displays the geographical distribution of the primary studies. The top 10 countries with major research on XR are located in Europe, the majority of them are from Germany, followed by the United States of America (USA), as can be observed in Figure 3. In Asia, China is the leader on studies about XR, AR, and virtual environments. Latin America is represented in the geographical distribution of XR studies by emerging countries like Mexico and Brazil. This geographical distribution demonstrates the global interest in technological development using innovative technologies on XR.

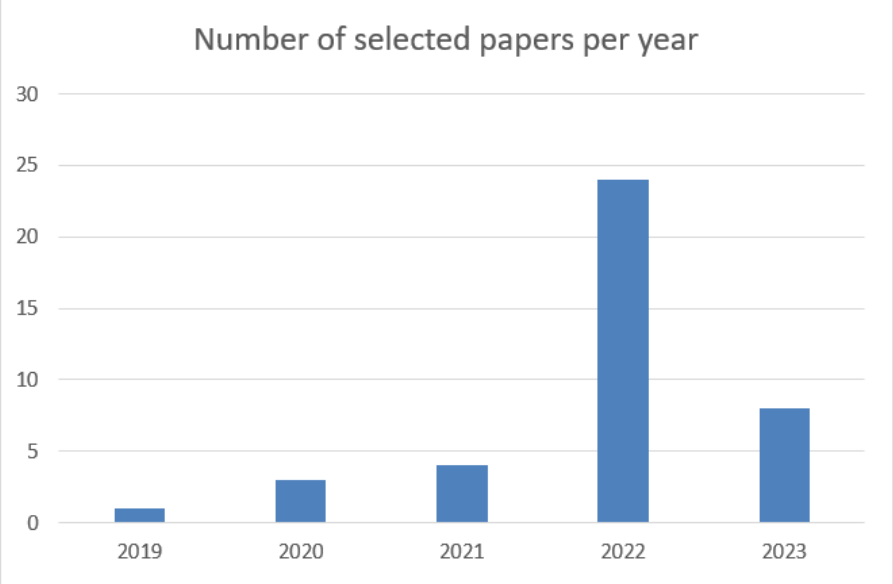

Figure 2. Annual Distribution of Primary Studies.

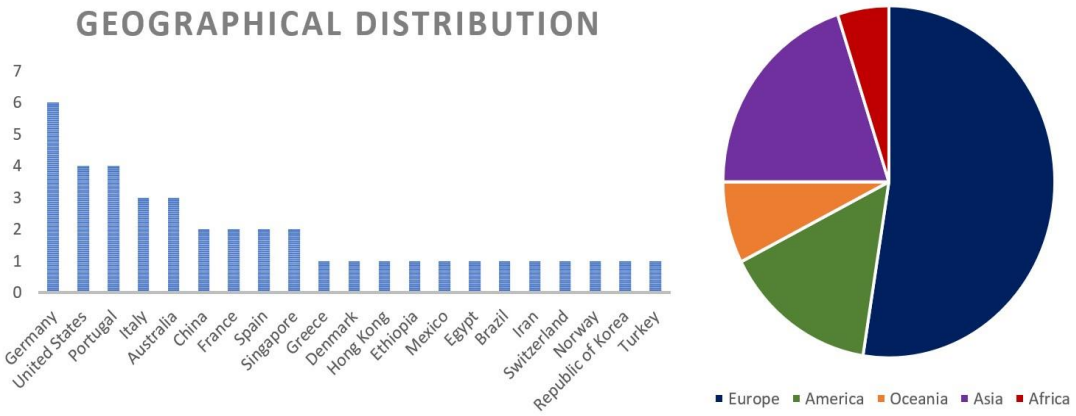

Figure 3. Geographical Distribution of Primary Studies.

The primary studies were mainly retrieved from Wiley Online Library, followed by ScienceDirect and SpringerLink. However, records from IEEE and Google Scholar were less frequent.

3. Results

We conducted a comprehensive review of the 40 included studies (see Table 3) with respect to our four research questions (see Section 2.1). As previously mentioned, the use of XR benefits the learning process [23]. Additionally, using XR in gamified apps and serious games is an opportunity to further study architectures and motivation models and to extend its use [24,25]. According to our findings, gamification trends lean toward the use of gamified apps and the development of game engines for these apps [26–30].

Trends in XR currently revolve around the implementation of XR models, the study of architectures to define the compatibility among development technologies for XR-based gamified apps, and the study of the benefits of these technologies on current XR models [31–37]. Research also focuses on exploring the benefits of intermixing XR, AR, and VR technologies [38], specially by incorporating 3D models in virtual environments in both gamified apps and serious games [39–41].

Table 3. Related Research.

Related Areas	Studies
Gamification and virtual reality	Wei et al. [23], Bucchiarone et al. [24], Ulmer et al. [25].
Gamification	Keepers et al. [26], Yang et al. [27], Patricio et al. [28], Degirmenci et al. [29], Bräuer et al. [30].
Extended Reality	Han et al. [31], Krause-Glau et al. [32], Anastasiou et al. [33], Carberry et al. [34], Gazzotti et al. [35], Tsang et al. [36], Hunde et al. [37], Cárdenas-Robledo et al. [38], Burian et al. [39], Stacchio et al. [40], Darwish et al. [41].
Serious games and Extended Reality	Brauner et al. [42], Ferreira et al. [43], Hassan et al. [44], Urgo et al. [45], Rodríguez et al. [46], Thangavelu et al. [47], Allal-Chérif et al. [48], Antunes et al. [49], Khaleghi et al. [50], Rosenthal et al. [51], Pistono et al. [52], Jaccard et al. [53], Ullah et al. [54], Ahmad et al. [55], Altan et al. [56], Cappannari et al. [57], Cook et al. [58], Parra et al. [59], Moro et al. [60].
Virtual reality games	Soares et al. [61].
Virtual education	Liebermann et al. [62].
Related Areas	Studies

Game engines are the leading technology for XR implementation. Some XR engines are game engines that initially implemented either AR or VR and were then upgraded to provide support for the entire XR umbrella. Examples of these engines include Vuforia [63], Unity [64], and Three.js [65]. Game engines purposely developed to support XR, such as ReactXR [66] and Babilon.JS [67], mainly combine XR features such as 3D models or 3D scenes with real-world settings.

4. Discussion

This section presents our findings, which have been categorized based on our research questions (see Section 2.1).

4.1. RQ1. What Game Engines for XR Are Reported in the Literature?

The literature reports multiple technologies for developing XR-enriched apps. Some of these technologies support XR natively, whereas others are assisted by some components. We classified these technologies for developing XR apps in two categories: proprietary engines for XR and JavaScript-based engines for XR. Proprietary engines use a native programming language to generate XR-based apps, whereas JavaScript-based engines, as the name suggests, use JavaScript to generate XR-based apps.

According to our findings, the proprietary engines for developing XR-enriched gamified apps and serious games are as follows:

- Google ARCore: Google's ARCore platform is used to create AR experiences. ARCore uses a variety of APIs to allow smartphones to sense their surroundings, understand the outside world, and interact with information. To share AR experiences, Android and iOS both have APIs available [68–70]. Google ARCode offers code samples licensed under the Apache 2.0 License and documentation licensed under the Creative Commons Attribution 4.0 License [71].
- Apple ARKit: Apple's AR Kit is a potent feature library and tool that enables users to take already written code and modify it to meet their functional needs. After using its animation tools to create a 2D sketch on any surface, the AR suite enables users to create anything in 3D. The two primary components of ARKit are the location of the camera in 3D space and the detection of horizontal planes [72,73]. ARKit is an API with tools that are free to download but need the user to have an annual Developer Program account for store distribution [74].

- Unity 3D: This engine functions as both a full-featured professional game engine and a cross-platform game development tool. With this engine, it is possible to provide a rendering engine, entity engine, scripting engine, lightmap, scene control, and other features [64,75]. Unity is a proprietary game engine with AR and XR tools that has a 30-day free trial and empowers development teams to develop and operate immersive games and interactive experiences with a powerful and production-proven set of tools [76].
- Vuforia: This engine is an AR software development kit released by Qualcomm. In addition to enabling developers to place virtual objects through the camera's viewfinder and adjust the object's position based on the background of the camera, it uses computer vision technology to instantly identify and capture flat images or 3D objects. The Vuforia SDK supports a variety of target configurations, unsigned images, and frame labels, as well as 2D and 3D object types [63,77]. Vuforia is a proprietary XR engine, but it only offers a basic free plan, which users need to register for a Vuforia developer account to use. It also offers a premium plan with a higher cost and more functionalities like production support, among others [78].
- Unreal Engine 5: The most recent version of Unreal Engine includes XR features, a technology that combines real-world experiences with 3D virtual interfaces for wearable technologies and remote controls to interact with machines. The three types of XR are VR, AR, and mixed reality [79,80]. Unreal Engine is a source-available software released through a source code distribution model that includes arrangements where the source can be viewed, and in some cases modified, but without necessarily meeting the criteria to be called open-source. Also, Unreal Engine has an enterprise program and custom license with premium support, options for private training, and additional procurement options [81].
- Nuke: This engine is a node-based digital compositing and visual effects app. Nuke offers a flexible node-based composite approach with native multi-pass workflows and a powerful integrated 3D environment to meet the needs of developers [82]. Nuke is a proprietary XR engine with some versions having a cost and a free 30-day trial [83].
- HeroMirror: This engine is a standalone AR engine that provides visitors and guests to any space with an immersive and personal AR experience featuring animated, green-screen, or volumetric AR content and characters [84,85]. HeroMirror uses a proprietary license [86].
- Godot: This engine is a modern game engine that provides features such as 2D and 3D rendering, platform support, and a common development environment. It is free and open source, released under the permissive MIT License [87,88]. Godot engine is free and open-source software released under the permissive MIT license [89].
- Verge3D: This engine is an instant renderer and toolkit for building interactive 3D web experiences. It allows users to convert content from 3D modeling tools to view in a web browser [90,91]. Verge3D uses a trialware license, during which Verge3D is a fully functional software that is made available for a limited time or a limited number of executions as a marketing tool [92].
- Amazon Sumerian (AS): Offered by Amazon Web Services (AWS), AS allows users to create and share AR and VR scenes using URLs that are reachable from the most recent Chrome or Firefox versions or other compatible browsers. It supports the most popular virtual reality (VR) headsets available today, such as the now-open-source Google Cardboard and HTC Vive headsets [93,94]. Amazon Sumerian uses the Apache License Version 2.0 [95].

JavaScript-based engines for developing XR gamified apps and serious games are listed as follows:

- A-Frame: This engine is an HTML-based web framework for building VR experiences [96]. A-Frame uses the MIT License. The MIT License is a permissive free software license originating at the Massachusetts Institute of Technology (MIT). As a

permissive license, it puts only very limited restrictions on reuse and it, therefore, has a high license compatibility [97].

- Three.JS: This engine is a JavaScript library for creating 3D graphics intuitively. Users can create and animate 3D scenes directly on the browser, taking full advantage of WebGL and modern browsers. To create Three.Js WebGL apps, users merely need a text editor and one of the supported browsers to render the results [65,98,99]. Three.JS uses the MIT License [100].
- AR.JS: This engine is a lightweight library for augmented reality on the web, which includes features like image tracking, location based AR and marker tracking [99]. AR.JS uses the MIT License [101].
- PlayCanvas: PlayCanvas is a game engine developed using web-based graphics processing with real-time shaders [8]. Contents created by PlayCanvas are readily available and perform excellently [102]. PlayCanvas uses the MIT License [103].
- Babylon.js: This engine is a TypeScript-based JavaScript framework that enables the creation of full 3D apps and web-based 3D video games. Babylon.js is an easy-to-use framework that only requires a few lines of code to configure these features [67,104]. Babylon.js uses the Apache License Version 2.0 [105].
- React XR: React XR is a library for building user interfaces. React XR uses JSX, which is a syntax extension to JavaScript that combines JavaScript, HTML, and CSS, allowing the user to write JavaScript that looks like HTML. React XR uses components in a functional-based syntax and includes attributes that describe them. These are called props. The return value of the part will be rendered as a react element [66]. React XR uses the MIT License [106].
- Wonderland Engine: This engine is a development platform for web-based graphics apps that supports VR, AR, and XR. Wonderland Engine has an accessible 3D editor app—the Wonderland Editor—and an efficient web assembly based runtime that runs on the browser [107]. Wonderland Engine uses the MIT License [108].

The engines listed are all distributed under licenses that permit developers to use them for free for non-commercial purposes. These game engines support AR overlay, QR decoding, marker recognition, tracking, handling, and drawing interfaces.

4.2. RQ2. What Are the Main Features of XR Game Engines?

The main features of XR game engines are listed as follows:

- AR Marker with QR: The AR tag includes a QR code that encodes the unique resource ID of the object identified by the AR tag. Users can create their own AR marker models and objects regardless of the viewing device. It also allows AR markups to be recognized by viewers of an AR environment without embedding the design into the program. The AR tag can have the QR code on the back or incorporated into the text of the AR tag [109,110].
- Projection-Based Augmented Reality: As the name suggests, this engine is a projection-based AR technique that produces an immersive light field on a flat surface to generate a 3D image. For instance, projection-based AR can be used to create holograms for educational purposes [111].
- Location-Based Augmented Reality: In this engine, the content is fixed to a specific physical space with location-based AR. It maps the real environment and determines the visual position of the user in the surrounding environment. When the device matches the map location, it overlays the digital image [112].
- Contour-Based AR: This engine outlines the silhouettes of objects and simulates real human interaction [113].

As a part of the review, we conducted a comparative analysis of the game engines with respect to their XR features. The results are summarized in Table 4.

Table 4. XR features supported in game engines.

Extended Reality Engine	Licensing	VR	AR Marker + QR	Projection-Based AR	Location-Based AR	Contour-Based AR
Google ARCore	Apache License 2.0	Yes	Yes	Yes	Yes	Yes
Apple ARKit	Proprietary License	Yes	Yes	Yes	Yes	Yes
Unity 3D	Proprietary License	Yes	Yes	Yes	Yes	Yes
Vuforia	Proprietary License	No	Yes	Yes	Yes	Yes
Unreal Engine 5	Source available	Yes	Yes	Yes	Yes	Yes
Nuke	Proprietary License	Yes	No	Yes	No	No
HeroMirror	Proprietary License	Yes	Yes	Yes	No	Yes
Godot	MIT License	Yes	Yes	Yes	No	Yes
Verge3D	Trialware license	Yes	Yes	No	No	Yes
Amazon Sumerian	Apache License 2.0	Yes	Yes	Yes	No	Yes
A-Frame	MIT License	Yes	Yes	No	Yes	No
Three.JS	MIT License	Yes	Yes	No	No	No
AR.JS	MIT License	No	Yes	Yes	Yes	No
PlayCanvas	MIT License	Yes	Yes	Yes	No	No
Babylon.js	Apache License 2.0	Yes	Yes	Yes	No	Yes
ReactXR	MIT License	Yes	Yes	No	No	Yes
Wonderlan Engine	MIT License	Yes	Yes	No	No	Yes

Table 4 presents an analysis of the XR features supported in each game engine. The analysis involved verifying the suitability of each feature in each game engine by developing an example of these features to find out what they support. The majority of game engines used in the research support almost all features due to the increasing use of XR. The proprietary engines, Unity 3D and Unreal Engine 5, support all the XR features identified in this research. This can be explained by the fact that they both use native programming languages for app development and have an established presence in the market.

4.3. RQ3. What Serious Game Attributes Are Supported in XR Game Engines?

All the engines reported in this review (see Section 4.1) offer XR support in both web apps and mobile apps. Moreover, all of them provide reusable software components and a set of visual development tools. To respond to our third research question, we identified which serious game attributes are supported by each XR game engine across

different game categories. The game categories used in this review were proposed by Lameras et al. [114] based on game design features and learning properties and include the following features: rules, tasks/challenges, collaboration and competition, goals and choices, and feedback/assessment.

A game attribute is a piece of data that describes a component or element in a game. These elements have their own characteristics, functionality, and behavior. We present the game attributes for every game category as follows:

- Rules: scoring, moving, timers, levels, progress bars, and game instructions, including victory conditions.
- Goals and Choices: game journal, missions, objective cards, storytelling, nested dialogues, puzzles, and Non-Player Characters (NPCs)/avatars.
- Tasks/challenges: NPC-based task description, progress bars, multiple choice, major tasks, branch tasks, puzzles, research points, study, and requirements.
- Collaboration and competition: role-play, community collaboration, epic meaning, bonuses, contest, scoring, timers, coins, inventories, leaderboards, and communal discovery.
- Feedback/assessment: game hints, NPCs, game levels, gaining/losing lives, progress bars, dashboards, lives/virtual currencies to be used for buying game items from an online inventory, and progress trees.

Table 5 shows the abbreviations of game attributes for every game category for a better understanding of Tables 6 and 7. Our results for proprietary game engines and JavaScript-based game engines are summarized in Tables 6 and 7, respectively. Note that other game features, not listed in these tables, may require XR support depending on the characteristics and scope of the game(s) to be developed.

Table 5. Abbreviations of game attributes for every game category.

Rules	Goals and Choices	Task/Challenges	Collaboration and Competition	Feedback/ Assessment
RL1—Scoring RL2—Moving RL3—Timers RL4—Levels RL5—Progress bars RL6—Game instructions, including victory conditions	GC1—Game journal GC2—Missions GC3—Objective cards GC4—Storytelling GC5—Nested dialogues GC6—Puzzles GC7—NPCs/avatars	TC1—NPC-based task description TC2—Progress bars TC3—Multiple choice TC4—Major tasks TC5—Branch tasks TC6—Puzzles TC7—Research points TC8—Study TC9—Requirements.	CC1—Role-play CC2—Community collaboration CC3—Epic meaning CC4—Bonuses CC5—Contest CC6—Scoring CC7—Timers CC8—Coins CC9—Inventories CC10—Leaderboards CC11—Communal discovery	FA1—Game hints FA2—NPCs FA3—Game levels FA4—Gaining/losing lives FA5—Progress bars FA6—Dashboards FA7—Lives/virtual currencies to be used for buying game items from an online inventory FA8—Progress trees

The results summarized in Tables 6 and 7 show the relationship between game attributes and game categories and provide a practical list for identifying which game engines provide the most support to a given set of attributes based on the type of game being developed.

As can be seen, Tables 6 and 7 present an analysis of the game attributes supported by each game category of the Lameras' classification.

Game rules provide context in terms of the challenges, objectives, and actions of the game and how these are formalized in relation to the game design. In this sense, game rules can be characterized as constraints that limit the player's actions. The game attributes defined for this game category are as follows: scoring, which is the record of points or strokes made by competitors in a game or match; moving, which involves changing the location of a player along with levels and worlds, among others; timer levels, which are blocks that automatically define player time; progress bars, which can be used

to show users either how far along they are in a process or their life level; and game instructions, which can include victory conditions—instructions that help players fulfill the conditions required to gain a victory. The game attribute support obtained by game rules is very similar among all of the XR engines; however, Vuforia—the proprietary XR game engine—offers less game attribute support, and A-Frame—the JavaScript-based XR engine—offers fewer game attributes.

Table 6. Serious game attributes supported by proprietary XR game engines.

Extended Reality Engine	Rules	Goals and Choices	Task/Challenges	Collaboration and Competition	Feedback/ Assessment
Google ARCore	RL1, RL3 RL6, RL2, RL5	GC1, GC2, GC3, GC4, GC5, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC7	CC10, CC3, CC4, CC6, CC7, CC8	FA1, FA2, FA5, FA6, FA8
Apple ARKit	RL1, RL2, RL3, RL5, RL6	GC3, GC4, GC7	TC1, TC2, TC7	CC10, CC3, CC4, CC6, CC7, CC8	FA1, FA2, FA6, FA8
Unity 3D	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC4, GC5, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC3, CC4, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA4, FA5, FA6, FA7, FA8
Vuforia	RL1, RL3, RL5, RL6	GC1, GC2, GC3, GC4, GC5, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7	CC1, CC10, CC3, CC4, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA4, FA5, FA6, FA8
Unreal Engine 5	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC4, GC6, GC7	TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC11, CC2, CC4, CC5, CC6, CC7, CC8, CC9	FA2, FA3, FA4, FA5, FA8
Nuke	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC4, CC5, CC8, CC9, CC6, CC7	FA3, FA4, FA5, FA6, FA8
HeroMirror	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC4, GC5, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC4, CC5, CC6, CC7, CC8	FA1, FA2, FA3, FA4, FA5, FA6, FA8
Godot	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC10, CC3, CC4, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA4, FA5, FA6, FA8
Verge3D	RL1, RL2, RL3, RL5, RL6	GC2, GC3, GC6, GC7	TC2, TC6, TC8, TC9	CC10, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA5, FA6, FA8
Amazon Sumerian	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC3, GC4, GC5, GC6, GC7	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC11, CC2, CC3, CC4, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA4, FA5, FA6, FA7, FA8

The "Goals and Choices" category indicates that games should be goal-directed, competitive, and designed within a framework of rules, choices, and feedback to enable teachers and students to monitor progress toward the goal. Goals are achieved through specific choices that need to be made by the player, and these in-game choices refer to the number of decisions a player can make before and during gameplay. The game attributes for the Goals and Choices category are game journals, missions, objective cards, storytelling, nested dialogues, puzzles, and NPCs/avatars. For this category, Apple ARKit is the proprietary XR engine with the least support, followed by Verge 3D. The game attributes with less support in proprietary XR engines are storytelling and the nested dialogues. In the JavaScript-based XR Engines, React XR offers less support for game attributes, and the game attribute with the least support is storytelling.

Table 7. Serious game attributes supported by JavaScript-based XR engines.

Extended Reality Engine	Rules	Goals and Choices	Task/Challenges	Collaboration and Competition	Feedback/ Assessment
A-Frame	RL1, RL2, RL3, RL5	GC1, GC2, GC7, GC3, GC6	TC1, TC2, TC3, TC4, TC6, TC7, TC8, TC9	CC3, CC4, CC6, CC7, CC8, CC9	FA3, FA4, FA5, FA6, FA8
Three.JS	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC5, GC7, GC3, GC6	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC10, CC3, CC4, CC5, CC6, CC7, CC8	FA1, FA2, FA3, FA4, FA5, FA6, FA8
PlayCanvas	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC5, GC7, GC3, GC6, GC4	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC11, CC2, CC3, CC4, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA4, FA5, FA6, FA7, FA8
Babylon.js	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC5, GC7, GC3, GC6, GC4	TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9	CC1, CC10, CC3, CC4, CC5, CC6, CC7, CC8	FA1, FA2, FA3, FA4, FA5, FA6, FA8
React XR	RL1, RL2, RL3, RL5, RL6	GC2, GC7, GC3, GC6	TC2, TC3, TC4, TC6, TC7, TC8, TC9	CC1, CC10, CC4, CC5, CC6, CC7, CC8	FA3, FA5, FA6, FA8
Wonderland Engine	RL1, RL2, RL3, RL5, RL6	GC1, GC2, GC7, GC3, GC6	TC1, TC2, TC3, TC6, TC8, TC9	CC10, CC5, CC6, CC7, CC8, CC9	FA1, FA2, FA3, FA5, FA6, FA8

In the Tasks/challenges category, the objective stems from learning that originates from task completion. During a serious game, the player needs to separate task-relevant from task-redundant information and determine the inherent complexity of game tasks. An overarching task of the player is to become familiar with the rules, controls, and logic of each level for adjusting gameplay. The game attributes for this category are NPC-based task descriptions, progress bars, multiple choice, major tasks, branch tasks, puzzles, research points, study, and requirements. The proprietary XR game engines with weaker game attribute support are Apple ARKit and Verge3D. In this category, the XR game engines Unity, Nuke, HeroMirror, Godot, and Amazon Sumerian support all game attributes. The game attribute progress bars are the only game attribute supported in all of the proprietary XR game engines. In the JavaScript-based XR engines, all game attributes are supported except branch tasks, which are unsupported by A-Frame, React XR, and the Wonderland Engine.

The Collaboration and Competition category establishes that collaboration is a key factor in multiplayer gameplay, and while competition is at the core of most online games, working with other players is often just as compelling as working against them. The Collaboration and Competition category is the category with the most game attributes, which include role-play, community collaboration, epic meaning, bonuses, contests, scoring, timers, coins, inventories, leaderboards, and communal discovery. In this category, the sense of teamwork and being part of something bigger than the individual player are all motivations to add collaborative elements to online gameplay. This category provides players with another unique reason to play online titles, as the alliances formed add a new dynamic to the gameplay. In the Javascript-based XR engines, the XR games engines with the least game attribute support are A-Frame and the Wonderline Engine, with almost half of the game attributes being supported; however, PlayCanvas supports all game attributes of collaboration and competition. On the other hand, in the proprietary XR game engines, HerrorMirror just supports bonuses, content, scoring, timers, and coins. Unreal Engine 5 and Amazon Sumerian support all of the game attributes in this category.

Feedback/assessment can improve learning, help the learner make decisions about his strategy, and encourage the learner's motivation. The game attributes for this category are game hints, NPCs, game levels, gaining and losing lives, progress bars, dashboards,

progress trees, and lives/virtual currencies to be used for buying game items from an online inventory. In this category, Three.JS, PlayCanvas, and Babylon.js offer the most support for the game attributes in the Feedback/assessment category. In the proprietary XR game engines, Unity 3D, and Amazon Sumerian support all game attributes for this category, and Apple ARKit just supports game hints, NPCs, Dashboards, and progress trees.

Based on the support presented by each game engine, we can establish the following conclusions: "Rules" and "Task/challenges" are the most common game category classification, and the categories "Goals and Choices", "Collaboration and Competition", and "Feedback/assessment" have fewer game attribute supports in the XR engines.

Regarding proprietary XR engines, Unity 3D, Vuforia, Unreal Engine 5, and Amazon Sumerian have the most game attribute support. Google AR Core, Apple ARKit, and Verge3D offer fewer game attributes. Concerning the game attributes, the support of the JavaScript-based XR engines is very similar because they use JavaScript as the programming language. In some cases, it is necessary to change the game's attribute configurations, like height or width, in the XR engines.

4.4. RQ4. What Learning Activities for Serious Games Are Supported in XR Game Engines?

The learning activities referenced in this review were identified by Beetham [115]. The authors define a learning activity as a "specific interaction among students using specific tools and resources, orientated toward specific outcomes". Beetham's classification of learning activities comprises the following categories: information transmission activities, individual activities, collaborative activities, and discussion and argumentation activities.

- Information transmission activities allow students to reflect on information for learning [115,116].
- Individual (constructivist) activities evidence that learning is more successful when students are actively involved rather than just trying to learn passively [114].
- Collaborative (constructivist) activities aid in the acquisition of knowledge and promote mediated and structured interactions [114].
- Discussion and argumentation activities encourage learning through discussions and questions of new information to evaluate, express, and discuss their ideas [114].

Designing serious games and gamified apps with XR revolves around creating engaging learning activities that incorporate interactive gaming elements to enhance the overall learning experience [117]. Tables 8 and 9 show the learning activities that are supported in the reviewed proprietary engines and JavaScript-based engines, respectively.

Table 8. Learning activities supported in proprietary XR game engines.

Proprietary XR Game Engines	Information Transmission	Individual Activities	Collaborative Activities	Discussion and Argumentation Activities
Google ARCore	No	Yes	Yes	Yes
Apple ARKit	Yes	No	Yes	Yes
Unity 3D	Yes	Yes	Yes	Yes
Vuforia	Yes	Yes	No	Yes
Unreal Engine 5	Yes	No	Yes	Yes
Nuke	Yes	No	Yes	Yes
HeroMirror	Yes	Yes	Yes	Yes
Godot	Yes	No	Yes	Yes
Verge3D	Yes	No	Yes	Yes
Amazon Sumerian	Yes	Yes	Yes	Yes

Table 9. Learning activities supported in JavaScript-based XR game engines.

JavaScript-Based XR Game Engines	Information Transmission	Individual Activities	Collaborative Activities	Discussion and Argumentation Activities
A-Frame	Yes	Yes	No	Yes
Three.JS	Yes	No	No	Yes
PlayCanvas	Yes	No	Yes	Yes
Babylon.js	Yes	Yes	Yes	Yes
React XR	Yes	Yes	No	Yes
Wonderland Engine	Yes	Yes	No	Yes

5. Trends, Challenges, and Emerging Solutions

5.1. Challenges and Trends of Game Attributes for XR

XR engines allow developers to build serious games and gamified apps quickly and easily without building everything from the ground up. Whether 2D or 3D based, XR engines offer features such as object creation and placement tools that enrich the resulting game or app. Despite growing research on XR and its increasing expansion in multiple areas, the following four main challenges remain to be overcome: (1) the identification of additional characteristics in XR engines, (2)the optimization of the process of incorporating XR characteristics into XR engines, (3) the development of platforms to incorporate XR characteristics into serious games or gamified apps quickly and easily, and (4) the challenge of increasing the number of devices/hardware supporting XR experiences from serious games and gamified apps.

Our review contributes to efforts that seek to understand to what extent current XR engines support the development of serious games and gamified apps through XR-enriched features for specific learning activities. This overview therefore enables game developers to decide which attributes to include in their new games and select the XR game engine that provides the most support to those attributes accordingly. Serious games and gamified apps with XR-enriched attributes are not limited to the educational domain; they can be implemented in any other app whose purpose is to assist learning and training.

5.2. Emerging Solutions

Based on our findings reported in Tables 6 and 7 (see Section 4.3), we suggest a set of pre-established game attributes to be supported by XR game engines in each game category, which are listed in Figure 4. By associating game attributes to a particular game category, we seek to contribute to current efforts that promote the compatibility of future XR game engines with existing ones.

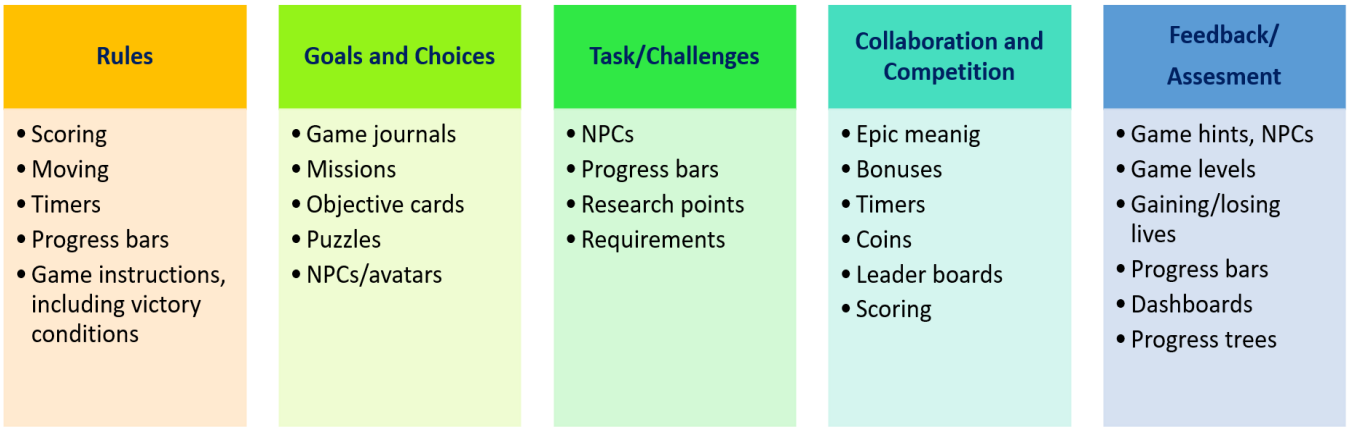

Figure 4. Core XR game attributes per game category.

Figure 4 presents our categorization of the main game attributes in each game category. This categorization may serve as a basis for developers to decide which game attributes they can incorporate into their serious games or gamified apps.

5.3. Limitations

This review has four limitations. Firstly, this work does not seek to explore how developers can impact XR-enriched serious games and gamified apps in the learning process; this study investigates game attribute support on the XR game engines. For an impact study, it would be necessary to develop several case studies and apply them to a population of students to measure the impact before and after the use of a serious game. Secondly, this review does not analyze the learning experiences of the users of serious games and gamified apps. To measure the learning experience, it would be necessary to apply case studies to identify the learning experiences of students who use serious games. Third, this review does not examine XR engines that are still under development. Finally, this review does not explore how a game engine can impact the usability of the serious games or gamified apps developed using it. For future work, we have considered implementing case studies to evaluate usability.

6. Conclusions

XR offers a promising opportunity for innovation in the teaching–learning process by integrating virtual objects into real or virtual environments. Various technologies are currently available for implementing XR, one of them being game engines. An XR engine is an independent, but externally controllable, piece of code that encapsulates the powerful logic behind the design to incorporate virtual objects, images, videos, and content augmented in several environments.

This scoping review includes a range of scientific literature published between 2019 and early 2023. Amid the rising trend of XR, this review aimed to identify how XR game engines have impact the characteristics of serious games and gamified apps for educational purposes. To this end, wtablee reviewed the current state of XR game engines for developing serious games and gamified apps through four aspects: (1) existing XR game engines, (2) the main features of these engines, (3) the serious game attributes supported in these XR game engines, and (4) the supported learning activities.

We reported our findings as responses to our research questions and emphasized the information presented in Section 4.3, where we reviewed the serious game attributes supported by the XR engines across a set of game categories proposed by Lameras et al. [114]. Furthermore, we classified XR engines into two categories: proprietary game engines—which use native programming languages mixed with other technologies—and JavaScript-based game engines—which use JavaScript for developing XR-enriched serious games and gamified apps.

This review also maps the reviewed XR engines to the type of learning activities that they support for an enriched XR-experience (see Tables 8 and 9), thus providing developers with a quick and easy guide to identify suitable learning activities for their serious games or gamified apps depending on the XR engine that they choose to use. Finally, based on all the findings presented in the review, we propose a set of pre-established game attributes to be supported by XR game engines in each game category in Figure 4. By associating game attributes to particular game categories, we seek to contribute to current efforts that promote the compatibility of future XR game engines with existing ones.

Author Contributions: Conceptualization, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; methodology, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; software, H.M.-V.; validation, G.A.-H.; formal analysis, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; investigation, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; resources, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; data curation, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; writing—original draft preparation, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; writing—review and editing, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; visualization, H.M.-V., G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; supervision, H.M.-V.,

G.A.-H., M.B.-L., I.L.-M. and N.L.H.-C.; project administration, G.A.-H.; funding acquisition, G.A.-H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Council of Humanities, Science and Technology (CONAHCYT) for the scholarship awarded by participating in the call for POST-DOCTORAL STAYS FOR MEXICO MODE 1, application number 2420859, to develop the project titled "Development of learning tools based on serious games, gamification and extended reality for teaching mathematics in basic education".

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy concerns of the users involved in the study.

Acknowledgments: This work was supported by Mexico's National Technological Institute (TecNM) and sponsored by both Mexico's National Council of Humanities, Science and Technology (CONAHCYT) and the Secretariat of Public Education (SEP) through the PRODEP project (Programa para el Desarrollo Profesional Docente).

Conflicts of Interest: The authors have no conflict of interest to declare. They have seen and agreed with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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