Review

A Systematic Literature Review on the User Experience Design for Game-Based Interventions via 3D Virtual Worlds in K-12 Education

Nikolaos Pellas [1,*] **, Stylianos Mystakidis** [2] **and Athanasios Christopoulos** [3]

1 Department of Primary Education, University of Western Macedonia, 53100 Florina, Greece
2 School of Natural Sciences, University of Patras, 26504 Patras, Greece; smyst@upatras.gr
3 Department of Future Technologies, University of Turku, 20014 Turku, Finland; atchri@utu.fi
* Correspondence: aff00192@uowm.gr

Abstract: A substantial body of literature has well-documented and demonstrated the potential of using three-dimensional (3D) virtual worlds (VWs) across various learning subjects and contexts in primary and secondary (K-12) education. However, little is known when it comes to issues related to child-interaction research and the impact that design decisions have on the user experience (UX), especially when game-based learning approaches are employed in 3DVWs. Hence, in this systematic literature review, we appraise and summarize the most relevant research articles (n = 30) conducted in K-12 settings, published between 2006–2020 and that elicit information related to (a) the interaction design (ID) of game events and trends associated with game elements and features that were utilized for the development and creation of game prototypes, (b) the research methods which were followed to empirically evaluate their teaching interventions, and (c) the design-related issues and factors affecting ID and UX by identifying the most frequent set of learning and game mechanics that were adopted in various game prototypes in different learning subjects. The vast majority of game prototypes enhanced students' engagement and participation, affecting their achievements positively. This systematic literature review provides clear guidelines regarding the design decisions that educational stakeholders should consider, and provides recommendations on how to assess and evaluate the students' learning experience (i.e., performance, achievements, outcomes) using 3DVWs.

Keywords: game-based learning; K-12 education; 3D virtual worlds; systematic literature review

1. Introduction

Game-based learning (GBL) enables new forms of teaching that transform the learning experience through simulated (real-world) tasks both in primary and secondary (K-12) education [1]. For the design and development of digital GBL interventions, instructional designers consider, concurrently, multiple instructional approaches aimed at improving learners' cognitive and practical skills via problem-solving activities [2,3].

An innovative way to create game prototypes is associated with the utilization of simulated realistic representational fidelity of visual objects/elements generated by three-dimensional (3D) computer graphics. In particular, the utilization of 3D "virtual worlds" (3DVWs) provided opportunities to advanced (and less advanced) programmers for the creation and development of simulation games. A 3DVW is a computer-supported environment, in which users can provide solutions to simulated problems and track their errors visually and acoustically to understand the consequences of their actions in real time [1]. Some indicative examples of 3DVWs can be categorized as "social" *Quest Atlantis, Second Life*, and "open source", such as *OpenSimulator or Open Wonderland* [4]. Each user has an embodied presence as an avatar (i.e., a digital representation with human or non-human characteristics) to interact in real-time, and explore its features using visual objects and participate in a wide range of simulated activities or tasks. Users can communicate with

other peers asynchronously with specific tools, written chat messages, and synchronously, through gestures, VoIP calls to (co-) design and/or program visual objects with geometric shapes using the scripting language of 3DVWs or the visual palette of Scratch4SL [1].

Much written evidence has been provided by a substantial body of literature [5–8] about the impact of 3DVWs on various educational practices and tasks. Indicative examples include the conduct of gamified collaborative and cooperative learning activities and reduced financial cost for the conduct of simulations which otherwise involve hands-on experimentation with expensive/special equipment. While considering the latter, additional benefits are identified with regards to the mitigation of the environmental concerns (e.g., reduced production of hazardous waste) as well as the elimination of laboratory injuries which govern the education fields related to Science, Technology, Engineering and Mathematics (STEM).

The use of 3DVWs can increase students' learning motivation and improve the quality of the learning experience for various reasons. For instance, Dalgarno and Lee [7] proposed several affordances that 3DVWs provide in contrast to other two-dimensional (2D) platforms. These are the enhanced spatial knowledge representation to assist the development of several tasks, the experiential learning to practice in visually rich tasks, the increased user motivation/engagement with an improved contextualization of abstract concepts, and a 3D persistent environment, in which users can communicate and construct something meaningful in collaborative (or non-collaborative) instructional design contexts. Aligned with such valuable affordances, and due to the wide number of easy-to-use tools, 3DVWs have gained prominence in recent years for designing and developing game prototypes. A game prototype made in a 3DVW comprises certain rules, mechanisms, and objectives that can permit users as avatars to participate actively having specific task information and a "*learn by doing*" approach within interactive and playable simulated realistic problem-solving contexts [1]. To this end, several studies have developed and utilized various game prototypes in 3DVWs. From a total of thirty studies ($n = 30$), twelve ($n = 12$) in primary education (PE) have used 3DVWs in several learning subjects, such as Natural science topics [8–12], Applied science topics, such as Computer Science [12,13] or Mathematics [14], and Social science topics [15–19], such as Language learning [17]. Additionally, in secondary education (SE), eighteen ($n = 18$) encompass several experiments made in the following learning subjects: Natural Science topics [20–29], Applied science topics, such as Mathematics [30], Computer science [1,5,6,31], or interdisciplinary STEM topics [32], and Social science topics, such as Language learning [33].

Although the aforementioned studies provide significant information and future perspectives about the use of 3DVWs in education, there was no explicit focus identified regarding the description of using GBL approaches. Furthermore, a shortage is also identified in studies that explore systematically the potential benefits of using 3DVWs in different instructional contexts with a lens adjusted to the field of STEM education. Thence, there is a lack of reviews which analyze any empirical evidence from previous studies on the impact of game design on learning outcomes, and which identify how the design of GBL may affect students' learning and engagement. Literature reviews focused on user interfaces for issues related to K-12 education are also under-researched. Another inadequacy in the relevant literature (3DVWs) concerns the lack of studies that examine the benefits that emerge from the User Experience/User Interface Design (UX/ID) field (i.e., usability) but have not been assessed concurrently with the added value that GBL (i.e., entertainment) brings to the learning process. It is argued, however, for the need for design-driven research to explore such opportunities and examine relevant concerns in the context of game design problems to understand the impact of GBL by mentioning the findings illustrated by key gaming features and elements at both cognitive and emotional levels in teaching and learning [4,34].

According to the aforementioned rationale, the current study presents a systematic literature review of experimental studies providing qualitative and/or quantitative data and/or information originating from studies utilizing mixed methods. It also seeks to investigate factors affecting course objectives and learning outcomes in terms of: (a) trends and learning approaches that are aligned with GBL with 3DVWs support, (b) the most frequent set of learning and game mechanics that have been adopted in game prototypes depending on learning subjects, (c) information about interaction design processes that UX/ID designers should pay attention correlating with effective teaching interventions, (d) elements and underpinning attributes which can offer students to be cognitively and emotionally engaged in educational gameplay, and (e) the research method and data analyzes approaches which were applied. To this end, the current review tends to advance the body of knowledge by filtering previous works as good design learning practices, which were evaluated and found to be effective, making them sufficient examples to identify any issues and inform further game developers or designers from a UX/ID perspective.

2. Related Work

During the last ten years, several studies have been published to review the relevant literature of 3DVWs in education. However, none of these focused on the use of GBL in VWs for K-12 education from previous works published in the period 2006–2020. Liaw et al. [35] noticed the growth of studies on the use of 3DVWs for collaborative learning has been increased in healthcare educational settings. Nevertheless, there is a need to understand more about the application of theories to inform the learning activities employed by a more rigorous and broader ID approach to evaluate UX and students' learning performance compared to conventional ones. Pellas and Mystakidis [4] focused on the analysis of the use of games created via 3DVWs. Nevertheless, the same authors did not analyze factors affecting game applications associated with learning content, design elements, or prototypes. Lastly, Ghanbarzadeh and Ghapanchi [36] studied a variety of 3DVWs exclusively in Higher Education from 165 papers. The same authors reported findings from different disciplines over the last decade; however, without considering the use of learning approaches that were widely utilized and their effects on UX in K-12 education.

Based on the above, there is a justifiable need to conduct a systematic synthesis of relevant studies focusing on the use of GBL-aligned with learning approaches in 3DVWs and delve into a critical look at the use of game design elements and features, UX/ID approaches, usability issues, research methods, and students' learning performance/outcomes in different K-12 subjects. Therefore, to fulfil this review's objectives, a specific number of steps should be undertaken: (a) to acknowledge the ID game events and trends associated with gameplay elements and features that were utilized for the development and creation of game prototypes, (b) to present the research methods which were followed to evaluate empirically their teaching interventions for knowledge acquisition and skill training, and (c) to disseminate any relevant design-related issues and factors affecting ID and UX by identifying the most frequent set of learning and game mechanics that were adopted in various game prototypes in different learning subjects.

2.1. Knowledge Acquisition and Skill Training in Game-Based Learning Settings

There is a broad agreement among educators, scholars and researchers that GBL has immense potential in this contemporary era. On these grounds, much discussion has begun to define and classify the main characteristics of computer games. By aggregating and blending different terms identified in previous reviews [37–39], we suggest that computer games need to satisfy the following criteria: (a) provide ample opportunities for interaction both between the users and the users and the digital content and (b) offer immediate and continuous feedback to the engaged users (players). The first criterion is achieved by integrating preset rules and constraints or via predefined objectives and challenges that the players must attain, whereas the provided feedback is usually associated with visual changes made within the environment as a response to users' actions [3].

Herz [40] classifies the "game genres" in accordance with the following distinct categories: (1) action games related to players' interaction with the system, (2) adventure games, (3) simulation games, (4) fighting games, (5) puzzle games, (6) sports games, and (7) strategy games. Nevertheless, the surge of innovative technologies and the need to identify new methods to deliver educational content has led to the emergence of the so-called 'Serious Games' (SGs). Therein, while building on the main characteristics and effects (e.g., immersion, enjoyment) that digital games present, researchers and instructional designers identified new opportunities to integrate educational elements into otherwise leisure-based digital content [4].

The multifaceted nature of SGs has allowed for their adoption in various educational contexts (formal, informal, non-formal) and fields (e.g., health, business, public policy) [38]. In most cases, such prototypes allow players to accomplish a number of objectives through activities that involve 3D modeling and programming, training via simulations and/or experimentation with topics that are difficult or even impossible to be explored in the conventional classroom, scenario-based virtual field trips or guided explorations via story-telling, and assessment of users' skills and competencies in real-time.

Although a portion of researchers consider student engagement in SG as a self-evident outcome due to the mental and physical effort that students put in achieving their goals, it is not widely known whether the increased degree of engagement is directly related with better learning outcomes or performance. In view of this consideration, researchers [38,39] recommend that SGs should be first examined from the usability perspective and accordingly from the learnability point of view, referring to the learning outcomes, i.e., ease of use (software), understanding development on the game mechanics. To this end, relevant literature reviews have attempted to understand the way that students learn within playable contexts by summarizing empirical evidence and conclusions emerging from previous primary studies. The results of such studies (e.g., [4,37]) indicate that the added value of the GBL approach in SGs can lead learners to engage more with the subject under investigation and achieve better outcomes or achievements, many times alike or even better than the conventional instruction methods. Other reviews (e.g., [38,39]) identify connections between learning and engagement which can potentially indicate positive links between the knowledge acquisition and performance. For example, the findings described in [4,38] point out that learning phases and outcomes are associated with student engagement. The same authors also conclude that learners' emotional engagement is also associated with behavioral changes and motivational outcomes, thus indicating anticipation for knowledge acquisition. In the same vein, cognition engagement is associated with knowledge and skills acquisition as well as conceptual understanding [39].

2.2. Gameplay and Game Mechanics

The integration of GBL in the educational process enables learners to develop their knowledge and skills via gamified educational scenarios. To achieve this goal, different gameplay techniques are utilized to satisfy users' preferences, needs and expectations. According to Salen and Zimmerman [41], "*gameplay*" is the process via which players interact through a (computer) game. The main characteristics that connect gameplay and instruction are summarized as follows [2–4]:

- *Learning objectives*: Educational games are designed with a specific purpose in mind and clearly defined learning goals aligned to the needs of the learning subject in consideration.
- *Specific instructions and rules*: Predefined rules and boundaries so as to prevent the development of misconceptions.
- *Interactivity*: The essence of (educational) games relies on the active involvement of (learners) players in achieving specific goals and objectives. Therein, diverse opportunities for decisions and actions should be offered during the engagement time.

- *Feedback*: The game should have predefined reinforcement (positive, negative) mechanisms (e.g., award, punishment) to compliment the actions of the engaged players.
- *Challenge*: Every challenge has to do with uncertainty on specific goal achievements, hidden information, and multiple levels of difficulty. The degree of challenges should be proportional to the level and potential of players which support (or not) directly their actions.

The gameplay mechanisms are 'translated' to the end users via the integrated "*game mechanics*" which aim at supporting player's interactivity during the in-game activities [41]. When it comes to "game mechanics", the development of patterns via game rules, instructions, and challenges can facilitate players' understanding of scenes and storylines that are revealed within games. Considering this, gameplay in SGs heavily relies on the experiential nature of learning wherein knowledge acquisition and skill development is obtained via gamified activities which involve active participation, critical thinking and decision making (e.g., quests, goals, levels, role play, tokens). Thus, the need to explore how the relationships between game and learning mechanics in SGs overlap emerges, as also noted in relevant studies (e.g., [4,37,42]).

3. Materials and Methods

The guidelines and protocol templates proposed by Kitchenham et al. [43] were used in this review for two reasons: (a) this study is one of the most well-documented and cited works for conducting a systematic review and (b) it entails specific steps for the presentation of an unbiased synthesis and interpretation made by reading findings from previous works in a balanced manner. Additionally, the main software tool to extract the information in this systematic review's protocol was StArt (State of the Art through Systematic Review).

3.1. Rationale and Research Questions

This systematic review presents evidence provided exclusively by experimental studies (empirical, case, and pilot studies), which analyzed the game development process to assist game designers and UX and interaction designers concerning some of the most important key aspects and perspectives of using 3DVWs for the development of games in different K-12 learning subjects. It also considers the challenges provided by Read and Markopoulos [44]. The first challenge is associated with the lack of explicit design models and guidelines that can be suggested for the design of interactive artefacts with a focus on Child–Computer Interaction (CCI) and more broadly, the Human–Computer Interaction (HCI) field of research. The second is related to K-12 students' participation, specifically as users, on how to pave a pathway to understand better the demands and support of interactive technology on UX design issues that are still underexplored. The same authors claimed, additionally, that there is a lively interest to understand factors affecting theory, design and practices pertaining to children's participation. Particularly, the concepts are related to the "Theory to Design" process which is associated with theoretical works and interaction design practices that can facilitate students' cognitive and emotional participation. Such processes reflect a shift in the general UX/ID community, not only to fully understand instructional practices' effectiveness, but also what motivates children to become engaged and learn actively within specific contexts [45]. Within GBL contexts developed in 3DVWs, students can learn by doing, and therefore practice their knowledge gained from the theoretical parts of courses to avoid becoming passive recipients of the instructor's guidance. Thus, the research questions (*RQs*) formulated to fulfill the main purpose of this review are as follows:

- RQ1: What is the most frequent set of learning and game mechanics adopted in game prototypes?
- RQ2: What in-game events and trends are of great interest to instructional designers for effective teaching interventions?
- RQ3: What elements and underpinning attributes were provided as the most crucial for students to be cognitively and emotionally engaged in educational gameplay within different instructional settings?
- RQ4: What research methods and data collection instruments were utilized to measure cognitive, affective, and behavioral aspects of learning?

3.2. Search Strategy

At the beginning of the search strategy, this study's authors conducted a systematic search to identify previous works from the relevant literature using several electronic databases. The focus of this search was mainly educational technology, computer science, and social science databases with the purpose to perform an exhaustive search. The most relevant were ACM, JSTOR, SCOPUS, ScienceDirect, EBSCO, ERIC, Wiley, Web of Science, and IEEEXplore. All searches were made separately using each database between December 2006 to December 2020, as the educational uses of 3DVWs have gained popularity and attracted researchers' interest since 2006 [4].

Google Scholar and the Directory of Open Access Journals were also used as open access databases to identify any other primary sources within gray literature, offering electronic access to most published literature [46]. In favor of widening and combining literature searches, several were also the techniques that were utilized to search key terms included the use of Boolean operators such as "OR" to identify any synonyms or "AND" to combine any search term for each of the four main concepts. The Boolean expression search criteria were "C1 AND C2." The search string was composed in each database manually based on the search functionality offered by each one. Table 1 below outlines the key search terms.

Table 1. Search terms.

("Virtual Worlds*" OR "3D Virtual Worlds")
AND ("Science*") ("Technology") ("Engineering*") ("Mathematics") ("Language Learning*")
("Computer Science") ("History")
AND ("Child-Computer Interaction*")
("Primary education*" OR "Secondary education") ("Virtual Worlds*" OR "3D Virtual Worlds")
("Engineering*") ("Mathematics") ("Language Learning*") ("Computer Science") ("History")

Lastly, a hand search of the reference lists of the identified articles was also undertaken to identify other relevant articles that had not been in the regular search.

3.3. Study Search and Selection Criteria

During the search strategy, eight electronic databases were selected to search for scientific articles. Figure 1 depicts the four steps based on the PRISMA statement [47] to select the studies, which were finally reviewed. After identifying articles using the various search procedures described above and removing duplicates, several sources included and excluded at each phase should be tabulated. One option for presenting information regarding thirty (*n* = 30) articles that met this review's inclusion criteria is illustrated in Figure 1.
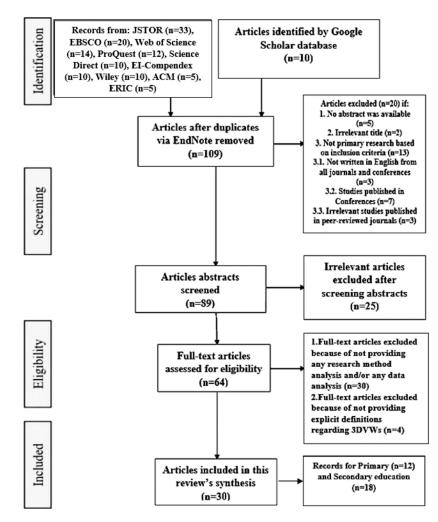
Figure 1. A flow diagram of the article selection process.

All articles were subject to first and second-round screening. As Table 2 shows, articles which did not meet the eligibility criteria were screened out in hierarchical order, depending on the type of article, study concept, and focus, and lastly on population and sample. When all articles were aggregated, the three authors discussed with consensus any possible disagreements in the selection of studies.

Table 2. Inclusion/exclusion criteria (a posteriori).

Criteria	Inclusion	Exclusion
Time	December 2006 to December 2020	Studies outside these dates
Language	English	Non-English articles
Type of articles	Original research, published in international peer-reviewed journals	Articles that were not well-documented in terms of using 3DVWs or other articles published in editorials/opinion works or in conferences
Type of method	Qualitative and/or quantitative or mixed	No method described
Study focus	Articles where their overwhelming theme related to Primary and Secondary (K-12) instructional design contexts supported by 3DVWs	Articles which have not well-documented the use of 3DVWs in (in-)formal contexts
Sample	K-12 students	Higher education, P-12, and Pre-service students
Study concept	All K-12 subjects	Articles that did not refer anything on what subject a 3DVW was utilised

3.4. Collection of Unbiased Studies

Three criteria under consideration were taken to eliminate the impact of bias in this review's search strategy [43], as Figure 2 depicts.

Figure 2. A process of collecting unbiased studies.

3.5. Study Quality Assessment

In order to further assess the methodological quality of all studies reviewed, a set of quality criteria developed by Guyatt et al. [48] was adopted and tabulated in Table 3. The assessment of each study was conducted using specific questions to designate the extent that each study can give answers to this review's questions.

Table 3. Quality criteria for study selection.

Criteria	Response Grading	Percentage Acceptance of the Included Articles
1. Are the research questions and objectives of this study clearly defined?	[1, 0.5, 0] (Yes, Nominally, No)	81%
2. Does this study's context address the main research adequately?	[1, 0.5, 0] (Yes, Nominally, No)	79%
3. Are the results clearly stated?	[1, 0.5, 0] (Yes, Nominally, No)	78%
4. Can this study's results provide valuable information?	>80% = 1, <20% and in-between = 0.5	88%

All the examined articles had normalized scores based on specific criteria. All authors agreed that more than a 60% quality score was the minimum score for accepting studies, following Guyatt et al.'s [48] guidelines. Since all the included studies were published in peer-reviewed international journals, there was not identifying any of the thirty articles (*n* = 30) to be excluded.
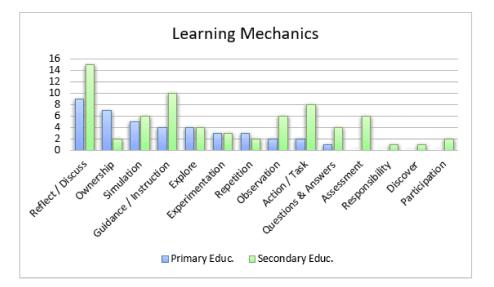
When the initial search and screening process was finished, all articles were chosen and coded for qualitative analysis to define the final analytic sample that builds the main data set. To strengthen the total weight of evidence, each study was calculated by adding

the scores on each of the abovementioned criteria. To assess the inter-rater reliability for the quality coding of the selected articles, a sub-sample of twenty-six from a total of thirty included articles (86%) were coded independently by all authors of this review. The inter-rater reliability (r) for the total scores was 0.81, showing a good agreement among the authors about the quality of the articles reviewed, which finally included.

4. Results

A wide range of potential benefits and challenges in K-12 settings were provided by the extracted data. To elaborate on the discussion around these benefits and shortcomings, an aggregation of information and report was made using a state-of-art overview from the analysis of all the included studies in order to answer the main *RQs*.

4.1. Learning and Game Mechanics (RQ1: What Is the Most Frequent Set of Learning and Game Mechanics Adopted in Game Prototypes?)

To answer the *RQ1*, we adopted the proposition of Arnab et al. [49] that pedagogy-driven game-based interventions should link learning goals and practices with game activities. Following their comprehensive "*Learning Mechanics—Game Mechanics*" model, we analyzed which of those were used most frequently in researched game prototypes within K-12 settings (Figure 3).

	Reflect / Discuss	Ownership	Simulation	Guidance / Instruction
Primary	[8-11] [15-19]	[8-9] [11] [14] [16-17] [19]	[9-10] [15] [18-19]	[9-10] [13-14]
Secondary	[5-6] [20-29] [31] [33-34]	[20-21]	[23-26] [30] [34]	[1] [5-6] [24-27] [30-32]
	Explore	Experimentation	Repetition	Observation
Primary	[8] [10] [12] [13]	[10] [15] [18]	[9] [17] [19]	[10] [13]
Secondary	[22] [24] [26] [29]	[24] [28] [34]	[23-24]	[22-26] [29]
	Action / Task	Questions & Answers	Assessment	Responsibility
Primary	[8] [17]	[17]	-	-
Secondary	[1] [5-6] [27] [30-32] [34]	[20-21] [28] [33]	[1] [5-6] [27] [31-32]	[21]
	Discover	Participation		
Primary	-	-		
Secondary	[24]	[20-21]		

Figure 3. Learning Mechanics (LM) used in primary and secondary education studies.

The most prevalent learning mechanics in primary education was *reflection* and *discussion* and (*n* = 9) followed by *action tasks* (*n* = 7), *observation* (*n* = 5), *experimentation* (*n* = 4), *repetition* (*n* = 4), *exploration* (*n* = 3), and *instructional guidance* (*n* = 3) as illustrated in Figure 3. GBL was just one component of the overall learning experience that was supplemented by debriefing sessions for reflection and discussion. For instance, Barab et al. [8] implemented a module into the game for students to record and upload their reflections, whereas Mystakidis et al. [16] facilitated students' creative reflection through the collaborative creation of a digital artefact. In another study of Barab et al. [20], students had the chance to present different narrative in-game events and endings with actual consequences. Within "semi-structured" storylines, students tend to become persuasive writers as they have specific characters and treated players differently based on the alignment between players' decisions and the characters' personal agendas.

Seven out of twelve studied game experiences were centered on various actions or tasks that students undertook. For instance, Kim et al. [14] expected primary education students to acquire knowledge by performing mathematical calculations with fractions [4], whereas Mystakidis [16] expected them to do so by using English vocabulary to formulate sentences [15]. In almost half of primary studies, 3DVWs were used as virtual fields for observation and collection of relevant information. Merchant et al. [15] created a game that provided clues and evidence so that students can follow official literacy curriculum activities.

Regarding secondary education, the most popular learning mechanics involved some sort of *simulation* (*n* = 6) or *action tasks* (*n* = 8) (e.g., programming, experimentation, simulation, roleplaying, problem-solving) combined with *observational* (*n* = 6) or *instructional cues* (*n* = 10). In most cases, these techniques were employed by providing fertile ground for *exploration* (*n* = 4) and *discovery* (*n* = 1). Most of the examined studies (*n* = 15) utilized *reflective* practice methods with particular emphasis on the *discussion* of the findings and the lessons learned (e.g., observation, argumentation, exploration). Finally, nearly one in three studies involved some sort of virtual *assessment* (*n* = 6).

Previous studies that aimed at providing learners with "*hands-on*" experience documented the design and animation of 3D prototypes [1,6,30,31], as well as the creation of digital posters [34] or concept maps [27]. Others [24,28,34] developed educational games which enabled students to undertake the role of 'scientists' to examine different hypotheses through collaborative experimentation and practice. Additionally, Jacobson et al. [22] and Şimşek [30] improved the simulation process by adding pedagogical agents to offer additional guidance and support to learners. Moon et al. [27] explored the potential of 3DVWs in the context of special education where adolescents within the autism spectrum undertook problem-solving activities related to STEM education. Under the aid of the greatest feature that such environments can offer, the avatars, Twining [30] engaged students in different (adult-related) real-life acting scenarios (e.g., a wedding ceremony), whereas Loula et al. [25], 'transformed' the students into reptiles in the context of an ecological survivability simulation. Finally, Zheng et al. [33] blended their students, or, their avatars to be more precise, with users from different geolocations (native English speakers) to promote the development of linguistic capacity via argumentation. On the other hand, those who explored exclusively the potential of these environments from a more theory-oriented perspective emphasized the process of acquiring knowledge via observation (e.g., natural phenomena) [21] or exploration (e.g., ecosystems dynamics) [23].

According to the above-mentioned analysis and the comparison provided in Figure 3, a significant body of literature [8–11,15–19] related to primary education, utilized reflection and discussion, perhaps because students at this age (under 12-years-old) want to immediately engage and discuss their own experiences, thus facilitating their creative reflection by interacting with 3D visual objects. While, in secondary education, a number of studies (e.g., [20–29]) utilized the same learning mechanics to a large extent for collaborative tasks, while some others (e.g., [31,32]) have also integrated assessment tools to measure
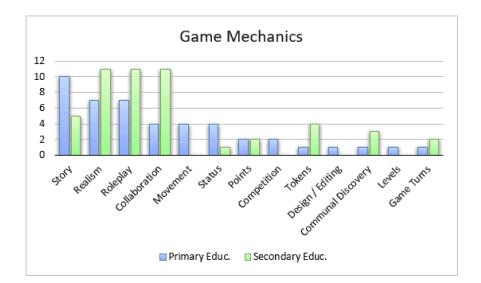
students' outcomes and achievements in-game (i.e., correcting and applying coding tasks or integration of puzzle-based tasks).

Learning goals were expressed in gameplay elements through the construction of game prototypes around game mechanics, such as *story* ($n = 10$), *realism* ($n = 7$), *roleplay* ($n = 7$), *collaboration* ($n = 4$), *rewards* ($n = 4$), and *movement* ($n = 4$). Game mechanics in primary and secondary education settings are described in Figure 4. A story in a relevant, simulated authentic context was the omnipresent element in almost all studied games in primary education. Students became heroes in stories and were challenged to complete missions and quests to achieve their avatar's objectives, e.g., identifying the underlying mechanisms influencing a pond ecosystem [10]. Half of the studies replicated aspects of physical settings with realistic fidelity to facilitate learning outcomes, e.g., a hospital or the interior of a personal computer [8]. Several studies utilized the social, collaborative aspect of virtual worlds, e.g., by organizing students' work in pairs and encouraging pupils to collaborate and enable peer learning [9]. When a student completed their quests, in some instances, they received regalia in form of badges [11] or virtual money [14]. It is worth noting that, although three primary education studies utilized Quest Atlantis, different learning and gaming mechanics were activated by the researchers' instructional design and arrangement of learning activities. Tüzün et al. [18] relied mainly on the exploration of 3D spaces for information retrieval through observation using a subset of the available mechanics. Lim et al. [11] used tasks and reflection, while Barab et al. [8] added the element of experimentation in simulated practices, deploying all platform capabilities.

The multifaceted nature of 3DVWs and the student-centered essence of the activities demanded the use of very diverse and interconnected game mechanics, which was also seen in secondary education contexts (Figure 4). This has been rendered clear from all the studies as none of them utilized an all-exclusive approach. To be more precise, the presence of avatars enabled instructional designers to introduce storytelling ($n = 5$) activities that required some sort of *roleplaying* ($n = 6$) or *collaboration* with other users ($n = 8$). The integration of such instructional techniques enabled students to *discover knowledge collectively* ($n = 3$) or in a *competitive manner* ($n = 3$). An equally large portion of instructional designers ($n = 10$) took advantage of the intuitive and vivid graphics that 3DVWs offer and based their experiments on the *realistic* recreation of structures that exist in the real world. Lastly, in contrast to the inherent nature of 'virtual games', only a few studies ($n = 4$) reported the use of *tokens* as the means to increase the motivational incentives.

Considering the above, it becomes evident that the nature of the games was dynamic and complex to enable learners to have the protagonist role. The various action-points [25,28] (e.g., mini-tasks), game turns (e.g., difficulty level increase) [22,24], and narration-control mechanisms (e.g., game zones) [20–23,33] that were in place to ensure participants' smooth progress influenced students' actions and decisions, especially in experimental or exploratory learning activities [20,24,26]. Conversely, studies which involved content creation exploited to the maximum the native 3D modeling tools that 3DVWs offer [27,28,35], whereas those who focused on the programming knowledge development, relied also on the integration of third-party software [5,31] and the distribution of awards or indicative changes in students' status [1]. Knowledge, information, or opinion exchange was also achieved inside a virtual (social) space. Thanks to the readily available communication tools, collaborative activities [21,34] and discovery of knowledge under the community of inquiry concept were also facilitated [28,30,31]. Finally, providing learners virtually authentic scenarios enabled them to undertake different roles to explore cases and experience situations that would otherwise be impossible to do in the real world [22,28,29].

Based on Figure 4, primary (e.g., [8–12]) and secondary education studies (e.g., [21–24]) have clearly utilized story, realism, and roleplay in collaborative tasks to support students' attendance, engagement, and participation. To this end, a portion of researchers have concluded that in-game activities, as in real life, assisted students not only to be engaged but also to "learn by doing".

	Story	Realism	Roleplay	Collaboration
Primary	[8 -12] [14-15] [17-19]	[8-11] [15] [18-19]	[8] [10-12] [14] [17] [19]	[8] [11] [13-14]
Secondary	[20] [21-23] [33]	[20-29] [34]	[1] [20-26] [28-29] [34]	[5] [6] [13] [22-24] [26] [28] [31-33]
	Movement	Status	Points	Competition
Primary	[12] [16-17] [19]	[9] [13] [15] [18]	[8] [11]	[8] [11]
Secondary	-	[1]	[25] [28]	-
	Tokens	Design/Editing	Communal Discovery	Levels
Primary	[16]	[16]	[17]	[16]
Secondary	[1] [5] [6] [31]	-	[28] [32] [30]	-
	Game Turns			
Primary	[13]			
Secondary	[22] [24]			

Figure 4. Game Mechanics (GM) used in primary and secondary education studies.

4.2. Game Events and Trends (RQ2: What In-Game Events and Trends Are of Great Interest to Instructional Designers for Effective Teaching Interventions?)

To answer the *RQ2*, this review adapted the guidelines provided by Jabbar and Felicia [50] to identify how the design of game-based activities may affect students' learning and engagement. More specifically, we collected and analyzed the learning subject, type, genre, and technical features of the virtual world games of the included studies.

The analysis revealed that game-based interventions with 3DVWs in PE have taken place in subjects of both Natural Science and Social sciences. The majority of recorded games took place in STEM fields (*n* = 9), such as Computer Science (*n* = 3), Science (*n* = 2), Mathematics (*n* = 2), and Environmental Education (*n* = 2). The second cluster of 'gameful' tasks in PE orbited around fields of Humanities such as Language (*n* = 2), Literacy (*n* = 2), and Culture (*n* = 1). This wide dispersion is an indication of the potential fitness of the medium for multiple fields and disciplines. It is of great importance to mention that two studies reported multiple case studies involving gameful experiences in multiple domains [8,18].

Two game types in primary education were applied in 3DVWs: roleplaying games (RPG) (*n* = 10) and puzzles (*n* = 2). Puzzles were used to set up simpler spaces for skills exercise and problem-solving (e.g., [9,11]). RPGs enabled more elaborate stories with

multiple levels and non-player characters (NPCs) (e.g., [8,19]). Other studies also note that RPGs enabled more elaborate stories with multiple levels and pedagogical agents or NPCs (e.g., [9,11,19]). The predominant game genre was Science Fiction (*n* = 4), whereas Mystery (*n* = 3) and Fantasy (*n* = 2) follow.

Multiplayer games tended to allow non-linear and collaborative exploration of the narrative and activities (e.g., [9,19]), while single-player games were often combined with a linear structure of gameplay (e.g., [13,14]). Multiplayer platforms were not always used for collaborative tasks, as in certain cases students participated simultaneously in multiple instances of the game. Some notable, advanced game features that were applied in PE were the following: (a) sophisticated 3D platform providing incentives for engagement with multiple gameful learning experiences via avatars to facilitate the player's identification [8], (b) the interactive, context-aware behavior of the game environment reflecting players' decisions [10], (c) the increasing complexity of tasks through subsequent game levels in problem-based settings [13], and (d) an active approach toward a story, prompting students to create stories in 3DVWs [17].

Previous studies related to Science (*n* = 10), Technology (*n* = 6), and Mathematics (*n* = 1) dominated in secondary education contexts; an outcome that confirms the crucial role that 3DVWs play in these subject areas. Nevertheless, few studies were identified from other fields, such as the Humanities (Language learning, *n* = 2). Regarding the game genre and type, most studies can be classified under the Science fiction category with elements that originate from RPG (*n* = 12), simulations (*n* = 3), and puzzles (*n* = 2).

However, a great contradiction between the examined educational levels is observed when examining the gameplay technical features (Figure 4). The secondary education studies described non-linear events (e.g., [20,21]), collaborative learning approaches (e.g., [33,34]), competitive tasks [5,6], context-aware of scientific inquiry tasks (e.g., [23,27]), while less (multiplayer) games followed a linear approach (e.g., [29,34]).

The secondary education studies introduced methods and techniques that allowed: (a) the personalization of the learning experience using third-party software and tools, such as Scratch4SL [1,5], data visualization [21] or concept mapping tools [27] and (b) the promotion of situated learning by blending the real-world (scientific) procedures and practices within 3DVWs [21,33].

Based on the generic game features, a list of instructions that designers should consider the UX/ID perspective in primary and secondary education is provided (Table 4).

Table 4. Basic clusters of game features.

Primary Education	Secondary Education
Multiplayer: Taking advantage of the affordance that 3DVWs have so as to structure interest-driven shared spaces in which users can occupy the same environment and generate visual effects (e.g., [8,17]).	Multiplayer: Having a partner to perform unusual tasks (e.g., travel in time, solve mysteries) and communicate ideas can boost students' confidence and Forster their critical thinking (e.g., [20,24]).
Single-player: Each student can become the in-game central figure and ne ready to succeed in a number of challenges by identifying sub-parts of a problem, analyze the problem0solving context, collect evidence, hypothesise and finally experiment to generate possible solutions (e.g., [1,13,14])	Single player: Computer-based agents (puppeteers) provide a great alternative to populate 3DVWs with virtual inhabitants (social characters), increasing students' interest towards the subject and support the learning process (e.g., [27,30]).
Collaboration: Working in pairs or with their peers to analyze tasks, users can discuss and/or negotiate at the same time and environment possible solutions to succeed specific learning objectives (e.g., [5,19]).	Competitiveness: A game, be it leisure or educational, have a ludic and amusing nature. Nonetheless, competitiveness is also an inherited element that can be found in most modern games. Thence, providing users with the right incentives to compete each other (e.g., awards, trophies) can greatly impact their motivation and engagement (e.g., [1,4]).

Table 4. *Cont.*

Primary Education	Secondary Education
Linear events: Students are engaged in pre-defined activities and perform a series of tasks that can be sequentially organized (e.g., [13,14]).	Linear events: the order of the provided information, guidelines and virtual tasks should always be consistent with the order of the hypotheses that the students are examining in each time (e.g., [22,28]).
Non-linear events: the organized presence of multiple data sources, evidence, exhibits and learning paths (e.g., [10,18]).	Non-linear events: Offering users multiple alternate paths and freedom to choose or take complete control over the game scenario can help them in developing deeper understanding (learn by their mistakes) and cause emotional regulation (e.g., [20,24]).
	Context-aware: Users within context-aware can collaborate and study together using contextual information, such as data visualization tools [21] and concept mapping [27].

4.3. Design Elements (RQ3: What Elements and Underpinning Attributes Were Provided as the Most Crucial for Students to Be Cognitively and Emotionally Engaged in Educational Gameplay within Different Instructional Settings?)

To analyze the trends and key drivers of engagement created by the gaming features in 3DVWs as well as the external factors affecting engagement and learning to answer *RQ3*, we also utilized the classification provided by Jabbar and Felicia [50]. We definitively coded motivational, interactive, and fun elements corresponding to usefulness, interactivity, and playfulness, respectively. Following this, we classified the included games in terms of their learning and motivational outcomes, as well as their position in the cognitive and affective learning phases. Indicatively, the same authors discern three cognitive learning phases, including knowledge acquisition, practicing and processing, and knowledge application. In the first phase, students can actively understand the content by searching and skimming. While processing, they can explore content more deeply and master essential skills that lead to understanding, e.g., by observing visuals or intensive reading. In the final phase, students could cultivate learning, subject-area, or problem-solving skills through strategies, such as analysis, synthesis, and inference.

All game prototypes in primary education settings featured one common motivational element; they operated around specific objectives that dictated the player's action. Several of them offered a degree of the player's freedom through choices ($n = 6$), decisions in structured dialogs or simple patterns of exploration (e.g., [13,17]). Games with more complex gameplay had specific rules ($n = 3$) that governed the flow of the game and the progression between levels [8,10]. Similarly, all included prototypes applied predominantly the interactive elements of roleplaying, utilizing various resources and objects of 3DVWs (e.g., [12,16]). More advanced implementations also deployed conflicts that the player had to solve (e.g., [8,13]). The recorded fun elements of game prototypes are presented in Figure 5. The common denominator was the combination of a *story* with a series of academically meaningful *challenges* that players had to face (e.g., [12,19]). More advanced implementations involved non-player *characters* [9,10], as well as the freedom of *playful roaming*, exploration, and action in the open environment of 3DVWs [16,18].

Examining the cognitive and affective impact of gameful experiences in 3DVWs, we noticed that seven of the twelve included studies opted to use them for knowledge application related to higher-order skills cultivation. For instance, Jakoš and Verber [11] provided a series of coding skill-building tasks, translated in the programmed movement of a flying carpet in a fantasy setting. The educational game prototypes in primary education addressed the learning phases that can be seen in Figure 5. Some games activated knowledge acquisition and processing used a 3DVW as a "canvas" to provide information and materials that were supplemented with additional offline activities linked with the curriculum (e.g., [12,18]).
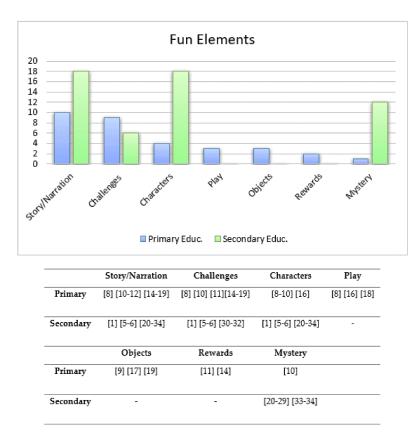
	Story/Narration	Challenges	Characters	Play
Primary	[8] [10-12] [14-19]	[8] [10] [11][14-19]	[8-10] [16]	[8] [16] [18]
Secondary	[1] [5-6] [20-34]	[1] [5-6] [30-32]	[1] [5-6] [20-34]	-

	Objects	Rewards	Mystery
Primary	[9] [17] [19]	[11] [14]	[10]
Secondary	-	-	[20-29] [33-34]

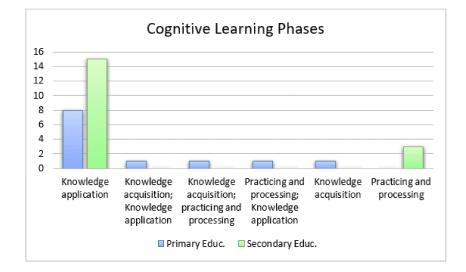**Figure 5.** Fun elements used in primary and secondary education studies.

As a result, students were able to master subject-area specific skills, such as programming [12] and language [19] (Figure 6). In certain cases, learners could build horizontal, transferable learning skills, such as data collection, hypothesis formulation, and testing [8] as well as problem-solving skills [10]. Two articles combined multiple cognitive outcomes. Fokides and Chachlaki [9] featured both content acquisition and understanding while Kamarainen et al. [10] addressed subject-area and problem-solving skills.

In the affective domain, it was evident that not all researchers and practitioners chose to pursue any motivational outcomes; certain gameful applications (*n* = 4) focused exclusively on cognitive stimuli and the setting to provide specific knowledge application activities (e.g., [14,15]). GBL contexts in the majority of previous studies were active in the affective domain aimed at facilitating a profound *behavioral change* (*n* = 5) related to a specific role-model or modeled set of values [10,11]. Another cluster of experiences positively impacted students' *attitudes and awareness* toward the studied subject (e.g., [9,16]).

Although the nature of the games and the respective disciplines differ, a set of common motivational elements (*objectives*) and emotional engagement techniques (*rules*) is identified across all (*n* = 18) the secondary education studies. However, because of the cognitive maturity and abilities that adolescents have, the abovementioned features were embedded in a way that did not restrict their freedom to make their own *choices* (*n* = 18). The above notwithstanding, studies related to Computer Science and Mathematics education had some means of *progress* control (*n* = 6) though such mechanisms were in place to facilitate the learning process and thus, enabled students to achieve the desired *outcomes* (e.g., [1,6,32,33]).

Instructional designers who focused on secondary education contexts relied equally on the *roleplay* element (*n* = 18) to make the learning activities more enjoyable and entertaining (e.g., [11,35]), encourage participation in group tasks (e.g., [21,27]), and facilitate the emergence of group discussions (e.g., [20,34]). Nonetheless, the nature of some educational tasks (e.g., argumentation, experimentation) as well as the necessity to collaborate generated *conflicts* (*n* = 13) that had to be dealt with either inside or outside 3DVWs (e.g., [20,23,29,33]).

Lastly, on some occasions (e.g., [1,5,6,20]), students were highly encouraged to use third-party *tools* and *resources* (*n* = 7) to overcome the "*steep learning curve*".

Cognitive Learning Phases

	Knowledge application	Knowledge acquisition; Knowledge application	Knowledge acquisition; practicing and processing	Practicing and processing; Knowledge application
Primary	[10] [12-17] [19]	[8]	[9]	[15]
Secondary	[1] [20-30] [32-34]	-	-	-

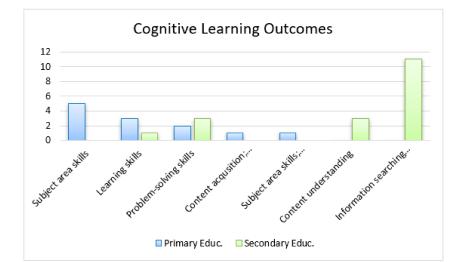|	Knowledge acquisition	Practicing and processing		
Primary	[18]	-		
Secondary	-	[5] [6] [31]		

Figure 6. Cognitive learning phases primary and secondary education studies.

3DVWs offer multiple opportunities (Figure 7), which can be both pedagogically informative and enjoyable. For instance, students within roleplaying settings were turned into scientists, reporters, or historians provides students with experiences that would otherwise be impossible to be implemented in the context of a classroom [24,26,30]. Moreover, even when students maintain in a more passive role, they can still enjoy the pedagogically manufactured storylines due to the high-quality graphics that such environments display [11,20,32].

Finally, the traditional learning context might not always provide fertile ground for teaching students the skills that are related to the process of scientific inquiry. Offering students the required (virtual) tools to make the initial assumptions as well as to collect, examine, and analyze primary data provides a more 'authentic' scientific experience, which usually emerges within application contexts [22,23,27,31].

Many secondary education studies (Figure 7) were framed under the same cognitive objective—the application of learners' understanding (*n* = 14). To achieve this goal, different structured (e.g., [20,25,34]) and unstructured (e.g., [30,31,34]) activities or tasks were utilized. Nevertheless, the potential of these artificial environments is not limited only

to the application of knowledge. Although to a lesser degree, a portion of studies (*n* = 5) described the efforts made by the researchers and educators to support students' scientific knowledge construction, even from scratch, utilizing real data and concepts [21,26,32].

Cognitive Learning Outcomes

	Subject area skills	Learning skills	Problem solving skills	Content acquisition; Content understanding
Primary	[11] [12] [15] [18-19]	[8] [16-17]	[13-14]	[9]
Secondary	-	[20]	[1] [30] [32]	-

	Subject area skills; Problem solving skills	Content understanding	Information searching skills
Primary	[10]	-	-
Secondary	-	[5-6] [31]	[21-30] [34]

Figure 7. Cognitive learning outcomes presented via primary and secondary education studies.

Grotzer et al. [23] raised the bar even more as the primary reason for using a 3DVW was to reinforce learners' misconceptions toward certain scientific subjects. Equally frequent (*n* = 5) was the integration of 3DVWs to facilitate hands-on activities that require continuous practicing (e.g., programming) [1,6,33] or repetition of certain processes (e.g., biological experimentation) [22]. Such tasks are perfectly aligned to the experimental nature that such 3D artificial environments inherently have based on different cognitive skills and abilities (*n* = 6), which can be developed via exploration (*n* = 11) or observation (*n* = 4) of the digital content (Figure 7).

To promote the attainment of the learning objectives, different motivational and engagement techniques were utilized. A strong tendency toward the behavioristic approach (i.e., drill and practice) is observed across most studies (*n* = 13) (e.g., [20,28,33]) whereas, on some occasions (e.g., [1,22,31,33]), additional incentives for participation and interaction were also offered via external tools and resources (e.g., Learning Management Systems).

4.4. Research Designs (RQ4: What Research Methods and Data Collection Instruments Were Utilized to Measure Cognitive, Affective, and Behavioral Aspects of Learning?)

To answer *RQ4*, we analyzed the UX research in the included studies utilized to identify a variety of instruments that are used to evaluate cognitive, affective, and behavioral aspects of learning. Therein, an effort is made to classify the evaluation metrics that have

been implemented under the following broad categories: (a) student engagement, (b) student performance, and (c) student (user) experience.

A number of studies (*n* = 8) in primary education assessed the impact of 3DVWs on students' satisfaction [12], motivation [11], engagement [10], and autonomy [17]. A minority of studies (*n* = 4) focused on the impact of learning outcomes and achievement in comparison to other learning methods and media, such as printed material [13,14] and UX [9].

Data collection approaches were balanced and almost evenly distributed across three categories. Two equal segments of studies (*n* = 4) involved quantitative (e.g., surveys, tests) and qualitative instruments (e.g., observation, recordings, student work), while a considerable cluster (*n* = 3) reported the use of a combination of both previous methods. Expectedly, studies that assessed performance employed exclusively quantitative data collection and analysis methods [13,14]. The two largest segments of studies involved qualitative (*n* = 5) (e.g., observation, recordings, student work) and quantitative instruments (*n* = 4) (e.g., surveys, tests), while a considerable cluster (*n* = 3) reported the use of a combination of both previous methods. The students' engagement and participation assessment have relied on qualitative and mixed methods. One qualitative research approach associated prominently with games in 3DVWs was design-based research, a suitable method for researching to assess the impact of an innovative solution in a real-life setting [8,18].

The secondary education studies that have undergone thorough audits demonstrate researchers' diverse understanding of the investigation of the so-called "learning behavior". Most studies emphasized the factors that can influence student engagement, such as self-efficacy and interactivity (e.g., [5,20,21,24]), whereas, fewer made efforts to evaluate the potential of 3DVWs concerning the learning performance (e.g., knowledge gains, outcomes) (e.g., [1,26,28,33]). In most cases, the primary data collection approach involved at least some quantitative methods (e.g., survey, tests; *n* = 17), while considerably less were studies that reported the use of qualitative (e.g., observations, interviews; *n* = 8) or mixed (*n* = 4) data collection methods. The results and conclusions from previous studies are limited to the context or the nature of the utilized 3DVWs. Hence, for the reader's information, we list the evaluation methods and provide the respective references for further reading in the Supplementary Materials.

5. Discussion and Conclusions

This review presents a systematic literature review by aggregating the results from experimental studies. It also aims to contribute a number of factors affecting course objectives and learning outcomes from a UX perspective, in favor of presenting (a) trends in interaction design methods associated with GBL via 3DVWs, (b) the most frequent set of learning and game mechanics that have been adopted in game prototypes depending on different learning subjects, and (c) UX/ID processes correlating with elements and underpinning attributes which can facilitate cognitive and emotional engagement with educational gameplay in students.

From the UX/ID perspective, many interactive games—such as puzzles, simulations, and virtual robots—have been designed and developed in 3DVWs to facilitate the knowledge acquisition process and foster the advancement of skills. Such technology can offer a realistic representation of elements and objects into a virtual environment, in which users can provide solutions to simulated problems, tracking their errors visually and acoustically to understand better the consequences of their actions as they occur. Therefore, the digital features and elements of 3DVWs allow UX and interaction designers to design, develop, and apply a wide range of learning activities. According to previous studies in K-12 education, the most well-known are the following:

- to design and develop using content creation tools and practice for students' learning through "hands-on" competencies [4–6,31,32];
- to identify the spatial association of visual objects' rules to provide prompt feedback on users' actions within high representational fidelity virtual contexts and therefore

- to enhance spatial knowledge representation in problem-solving and inquiry-based contexts [1,2,5,6,11,14,25];
- to recognize more easily the metaphorical representations (metaphors) of their ideas without spatial-temporal physical constraints through embodied actions, such as view control, navigation or object manipulation to promote students' learning motivation and interest [1,12,30,34];
- to develop a 3D digital and interactive game prototype to conduct a remote usability evaluation that can potentially lead to students' learning performance and outcomes improvement by transferring any learning material into realistic simulations [8,10,25,26];
- to help users (students and instructors) consistently understand how to achieve better outcomes, due to the visual and acoustic feedback as well as reflection experienced during the design project's lifetime [9,11,16,20,33];
- to encourage exploratory tasks, in which students need to use cognitive skills related to higher-order, critical thinking, and computational thinking in a persistent 3D environment without having a "save" button or "wait" online peers to achieve specific goals [1,11,17,22,26];
- to construct user interface design features and elements with high representational fidelity and a view of changes on elements/objects' motion by exploiting the intuitive modality that 3DVWs offer with a realistic display in a three-dimensional visually rich environment [13,31,32];
- to create GBL contexts with spatial reasoning and perception activities using simulation-based and problem-solving tasks with visually appealing challenges, such as exploring the most relevant match and displaying 3D objects in a puzzle to enhance visual reasoning [5,17,19];
- to provide modeling and simulation in test IDs and assessment due to the immediacy of controlling events and objects/elements within a 3D environment to assist in-world interaction among users and virtual objects [11,18,21].

Empirical research and experimental studies to identify UX/ID practices and perspectives are of great importance to the multidisciplinary research community, as it is directly connected with other research areas, such as psychology, education, product, and systems design engineering. There was much lively debate on whether visually appealing design elements with high representational fidelity can facilitate students' ability to learn and practice their mandatory material within formal curriculum settings [5,10,26]. Fundamental works in UX/ID fields [44,45] argued that there is still rising an ongoing interest to invest in innovative resources to fully understand the impact of developing visually rich and appealing graphics (visual design) for educational game development on students' motivation and learning in K-12 education.

This review provides the empirical evidence from previous studies which are related to the effects of learning the game's visual design on students' motivation, perceived attractiveness, learning outcomes, and/or performance. More specifically, two fundamental instructional strategies were observed in K-12 GBL contexts. Game prototypes in PE settings with lower complexity relied upon the use of a 3DVW as a contextualized, simulated space for observation, exploration, and information collection around predefined tasks (e.g., [15,18]). Most of the time, these experiences are single-player and linear [13]. GBL with higher complexity provided a richer gaming experience, often with open-ended scenarios where learners' agency determines the outcome of the game (e.g., [8,10]). Most of these experiences are multiplayer and non-linear [8]. Both approaches yielded positive results in terms of students' engagement and learning performance, hence one should not be considered automatically superior over the other. Another notable finding in games related to primary education settings was the low integration of otherwise popular game mechanics, such as points, rewards, and leader boards. Researchers did not resort to the technical availability of various game components and built systems of varying complexity

around learning outcomes and academically meaningful activities, both in the virtual and the physical world.

The findings from this review indicate that most studies in secondary education settings showcased a strong preference toward the framing of event-based activities where challenges and conflicts provided a means to support and enhance students' competencies (e.g., [22,30,34]). An element that played a crucial role in this outcome was the use of avatars. The existence of these virtual figures facilitated the conduct of roleplaying (e.g., [20,26,30]) to support collaborative learning activities (e.g., [21,24,26]), and thus, provide the necessary effective support which is an essential part of the learning process. Likewise, the presence of intelligent agents (NPCs), mediated the space between the virtual and the real world or, otherwise, the distance between the students and instructors (e.g., [22,28,30]). Nevertheless, such features were heavily grounded under the notion of narrative-intense and scaffold-oriented storyline scenarios (e.g., [11,20,34]).

Considering the above, it can be concluded that the affordances of 3DVWs in learning should be considered both while designing learning mechanisms and gameplay features. Therein, design and developmental decisions should be made in line with both the educational level and particular needs that educational subjects present. The synthesis from the existing research findings below advances the knowledge by bringing several implications to the design and development of games via 3DVWs. It can also give a list of design guidelines and recommendations to clarify different types of problems and propose solutions that could give valuable answers for the UX/ID community (Table 5).

Table 5. Implications and recommendations for design and practice.

Primary Education	Secondary Education
Learning within curriculum-aligned tasks can assist students to actively engage in "learn by doing" tasks and easily study any subject area. To this end, students' interest is increased in a subject area and thus enhance their initiatives, when they can explore and experiment with virtual objects [4].	The knowledge construction should not be limited by the "borders" of a 3D VW. Therefore, there should be not all the game objectives announced at the beginning. Instead, a "hybrid" learning scenario, where students collect information from external sources and undertake activities in both environments (i.e., physical and virtual) should be considered as appropriate option [6,35].
The activation of students' agency through meaningful choices reflecting on their autonomy is beneficial for their engagement. Multiple choices in-game can invoice isolated gaming aspects, such as avatars [10] either influence decisively a learning path [12]	Students should have enough freedom to choose their learning path. This may extend further students' initiatives to explore a gaming environment and to interact with other peers or learning objects to learn how to collect information and understand further visual object created into 3DVWs [24,30].
Collaborative activities in 3DVWs enhance students' cognitive engagement and critical discourse with academic content and subject skills as well as improving largely their satisfaction [13].	Integrating tools to identify students' emotional and cognitive states can enable educators and instructional designers to promote competencies (e.g., scientific problem-solving tasks) better and improve the learning assessment focus [28].
The students' learning performance and achievements can be amplified in gaming. Thence, students need to formulate and test hypotheses through experimentation and spaced practice repetition [11,14].	User design features and elements with natural intuitive modality can be used to engage especially high school students into realistic problem-solving learning conditions. Another relevant condition, which is also relevant, is the simulation of embodied experiences via avatars to serve their ideas like in real life [4,20].

6. Limitations and Future Work

There are some limitations worth noting in this review. First, due to the often-sparse definitions of 3DVWs, we searched specific databases that include peer-reviewed international journals without considering other articles, which have been published in conference proceedings or book chapters. Second, many articles had a small sample size of participants with limited aspects, and thus, their results could not be easily generalized. Based on this review's results, a limited number of studies (e.g., [5,32]) investigated factors affecting students' behavior and engagement in 3DVWs-supported instruction, such as the age distinction and the socio-cognitive background, to understand better any potential association

between their performance and willingness to learn actively. There was no information gathered regarding the roles that instructors/educators and researchers had within the educational 3DVWs, how they obtained information during the experimentation process, or how they mitigated the impact of their presence during the teaching and learning process.

In terms of future lines of research, firstly, we propose controlled mixed-method longitudinal studies on 3DVWs-supported instruction with a larger sample size to investigate the efficacy of game prototypes. Secondly, the combination of 3DVWs with data analytics and tracking tools are recommended to have a more holistic research approach and measure students' learning performance and engagement toward personalized immersive learning. Such an action can assist UX researchers, designers, and developers to investigate any further differences and any association related to students' engagement and learning outcomes or performances using 3DVWs in contrast to other commercial immersive VR applications with similar features.

Due to the limited number of studies, which utilized mixed research methods, less evidence could be gained about the students' assessment measures. For example, there were fewer studies that gathered and presented data based on students' observation in sessions. To this end, we can gain information focusing on any game-based treatment where observation would confirm its appropriateness and effectiveness. Another interesting finding can be observed in the potential students' activities, collaboration with other peers and instructors, or even their engagement of low and high performing students when compared to any typical lecture-based teaching practices in control classrooms. With this in mind, instructors and educators can associate any student activity (collaboratively or not) to understand if any active participation is truly related to their learning outcomes and/or performance.

References

1. Pellas, N.; Vosinakis, S. The effect of simulation games on learning computer programming: A comparative study on high school students' learning performance by assessing computational problem-solving strategies. *Educ. Inf. Technol.* **2018**, *23*, 2423–2452. [CrossRef]
2. Gee, J.P. *Good Video Games and Good Learning*; Peter Lang: Frankfurt am Main, Germany, 2007.
3. Prensky, M. Digital game-based learning. *Comput. Entertain.* **2003**, *1*, 21. [CrossRef]
4. Pellas, N.; Mystakidis, S. A systematic review of research about game-based learning in virtual worlds. Special Issue: "Ex-ploring Immersive Technologies in Learning". *J. Univ. Comput. Sci.* **2020**, *26*, 1017–1042.
5. Pellas, N. Exploring interrelationships among high school students' engagement factors in introductory programming courses via a 3D multi-user serious game created in OpenSim. *J. Univ. Comput. Sci.* **2014**, *20*, 1608–1628. [CrossRef]
6. Pellas, N.; Peroutseas, E. Gaming in Second Life via Scratch4SL. *J. Educ. Comput. Res.* **2016**, *54*, 108–143. [CrossRef]
7. Dalgarno, B.; Lee, M.J.W. What are the learning affordances of 3-D virtual environments? *Br. J. Educ. Technol.* **2009**, *41*, 10–32. [CrossRef]
8. Barab, S.; Thomas, M.; Dodge, T.; Carteaux, R.; Tuzun, H. Making learning fun: Quest Atlantis, a game without guns. *Educ. Technol. Res. Dev.* **2005**, *53*, 86–107. [CrossRef]
9. Fokides, E.; Chachlaki, F. 3D Multiuser Virtual Environments and Environmental Education: The Virtual Island of the Mediter-ranean Monk Seal. *Technol. Knowl. Learn.* **2019**, *25*, 1–24. [CrossRef]
10. Kamarainen, A.M.; Metcalf, S.; Grotzer, T.; DeDe, C. Exploring Ecosystems from the Inside: How Immersive Multi-user Virtual Environments Can Support Development of Epistemologically Grounded Modeling Practices in Ecosystem Science Instruction. *J. Sci. Educ. Technol.* **2014**, *24*, 148–167. [CrossRef]

11. Lim, C.P.; Nonis, D.; Hedberg, J. Gaming in a 3D multiuser virtual environment: engaging students in Science lessons. *Br. J. Educ. Technol.* **2006**, *37*, 211–231. [CrossRef]

12. Battal, A.; Tokel, S.T. Investigating the Factors Affecting Students' Satisfaction in a Programming Course Designed in 3D Virtual Worlds. *Turk. Online J. Qual. Inq.* **2020**, *11*, 218–246. [CrossRef]

13. Jakoš, F.; Verber, D. Learning Basic Programing Skills with Educational Games. *J. Educ. Comput. Res.* **2017**, *55*, 673–698. [CrossRef]

14. Kim, H.; Ke, F. Effects of game-based learning in an OpenSim-supported virtual environment on mathematical performance. *Interact. Learn. Environ.* **2017**, *25*, 543–557. [CrossRef]

15. Merchant, G. 3D virtual worlds as environments for literacy learning. *Educ. Res.* **2010**, *52*, 135–150. [CrossRef]

16. Mystakidis, S.; Berki, E. The Case of Literacy Motivation: Playful 3D immersive learning environments and problem-focused education for blended digital storytelling. *Int. J. Web-Based Learn. Teach. Technol.* **2018**, *13*, 64–79. [CrossRef]

17. Yeh, Y.-L.; Lan, Y.-J. Fostering student autonomy in English learning through creations in a 3D virtual world. *Educ. Technol. Res. Dev.* **2017**, *66*, 693–708. [CrossRef]

18. Tüzün, H. Blending video games with learning: Issues and challenges with classroom implementations in the Turkish context. *Br. J. Educ. Technol.* **2007**, *38*, 465–477. [CrossRef]

19. Wang, X.; Xing, W.; Laffey, J.M. Autistic youth in 3D game-based collaborative virtual learning: Associating avatar interaction patterns with embodied social presence. *Br. J. Educ. Technol.* **2018**, *49*, 742–760. [CrossRef]

20. Barab, S.; Pettyjohn, P.; Gresalfi, M.; Volk, C.; Solomou, M. Game-based curriculum and transformational play: Designing to meaningfully positioning person, content, and context. *Comput. Educ.* **2012**, *58*, 518–533. [CrossRef]

21. Dede, C.; Grotzer, T.A.; Kamarainen, A.; Metcalf, S. EcoXPT: Designing for Deeper Learning through Experimentation in an Immersive Virtual Ecosystem. *Educ. Tech. Soc.* **2017**, *20*, 166–178.

22. Jacobson, M.J.; Taylor, C.E.; Richards, D. Computational scientific inquiry with virtual worlds and agent-based models: new ways of doing science to learn science. *Interact. Learn. Environ.* **2015**, *24*, 2080–2108. [CrossRef]

23. Grotzer, T.A.; Kamarainen, A.M.; Tutwiler, M.S.; Metcalf, S.; DeDe, C. Learning to Reason about Ecosystems Dynamics over Time: The Challenges of an Event-Based Causal Focus. *BioScience.* **2013**, *63*, 288–296. [CrossRef]

24. Ketelhut, D.J. The Impact of Student Self-efficacy on Scientific Inquiry Skills: An Exploratory Investigation in River City, a Multi-user Virtual Environment. *J. Sci. Educ. Technol.* **2007**, *16*, 99–111. [CrossRef]

25. Loula, A.C.; De Castro, L.N.; Da Rocha, P.L.B.; Carneiro, M.D.C.L.; Reis, V.P.G.S.; Machado, R.F.; Sepúlveda, C.; Apolinario, A.L.; El-Hani, C.N. Modeling a Virtual World for the Educational Game Calangos. *Int. J. Comput. Games Technol.* **2014**, *2014*, 1–14. [CrossRef]

26. Metcalf, S.J.; Reilly, J.M.; Kamarainen, A.M.; King, J.; Grotzer, T.A.; Dede, C. Supports for deeper learning of inquiry-based ecosystem science in virtual environments—Comparing virtual and physical concept mapping. *Comput. Hum. Behav.* **2018**, *87*, 459–469. [CrossRef]

27. Moon, J.; Ke, F.; Sokolikj, Z. Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism. *Br. J. Educ. Technol.* **2020**, *51*, 1766–1784. [CrossRef]

28. Nelson, B.C. Exploring the Use of Individualized, Reflective Guidance in an Educational Multi-User Virtual Environment. *J. Sci. Educ. Technol.* **2006**, *16*, 83–97. [CrossRef]

29. Twining, P. Exploring the educational potential of virtual worlds-Some reflections from the SPP. *Br. J. Educ. Technol.* **2009**, *40*, 496–514. [CrossRef]

30. Şimşek, I. The effect of 3D virtual learning environment on secondary school third grade students' attitudes toward mathe-matics. *Turk. Online J. Educ. Tech.* **2016**, *15*, 162–168. Available online: https://files.eric.ed.gov/fulltext/EJ1106361.pdf (accessed on 10 March 2021).

31. Rico, M.; Martínez-Muñoz, G.; Alaman, X.; Camacho, D.; Pulido, E. Improving the programming experience of high school students by means of virtual worlds. *Int. J. Eng. Educ.* **2011**, *27*, 52–60.

32. Pellas, N. An exploration of interrelationships among presence indicators of a community of inquiry in a 3D game-like environ-ment for high school programming courses. *Interact. Learn. Environ.* **2016**, *25*, 1–18. [CrossRef]

33. Zheng, D.; Young, M.F.; Wagner, M.M.; Brewer, R.A. Negotiation for Action: English Language Learning in Game-Based Virtual Worlds. *Mod. Lang. J.* **2009**, *93*, 489–511. [CrossRef]

34. Young, W.; Franklin, T.; Cooper, T.; Carroll, S.; Liu, C. Game-based learning aids in Second Life. *J. Interact. Learn. Res.* **2012**, *23*, 57–80.

35. Liaw, S.Y.; Carpio, G.A.C.; Lau, Y.; Tan, S.C.; Lim, W.S.; Goh, P.S. Multiuser virtual worlds in healthcare education: A systematic review. *Nurse Educ. Today* **2018**, *65*, 136–149. [CrossRef]

36. Ghanbarzadeh, R.; Ghapanchi, A.H. Investigating various application areas of three-dimensional virtual worlds for higher education. *Br. J. Educ. Technol.* **2016**, *49*, 370–384. [CrossRef]

37. De Freitas, S. Are Games Effective Learning Tools? A Review of Educational Games. *Educ. Technol. Soc.* **2018**, *21*, 74–84.

38. Wouters, P.; van Nimwegen, C.; van Oostendorp, H.; van der Spek, E.D. A meta-analysis of the cognitive and motivation-al effects of serious games. *J. Educ. Psych.* **2013**, *105*, 249–265. [CrossRef]

39. Connolly, T.M.; Boyle, E.A.; MacArthur, E.; Hainey, T.; Boyle, J.M. A systematic literature review of empirical evi-dence on computer games and serious games. *Comput. Educ.* **2012**, *59*, 661–686. [CrossRef]

40. Herz, J.C. *Joystick Nation: How Videogames Ate Our Quarters, Won Our Hearts, and Rewired Our Minds*; Little, Brown and Company: Boston, MA, USA, 1997.

41. Salen, K.; Zimmerman, E. *Rules of Play: Game Design Fundamentals*; MIT press: Cambridge, MA, USA, 2004.

42. Fabricatore, C. Gameplay and game mechanics: A key to quality in videogames. In *ENLACES (MINEDUC Chile) -OECD Expert Meeting on Videogames and Education*; Santiago, Chile, 2007. Available online: http://eprints.hud.ac.uk/id/eprint/20927/ (accessed on 11 March 2021).

43. Kitchenham, B.; Brereton, O.P.; Budgen, D.; Turner, M.; Bailey, J.; Linkman, S. Systematic literature reviews in software engineering A systematic literature review. *Inf. Softw. Technol.* **2009**, *51*, 7–15. [CrossRef]

44. Read, J.; Markopoulos, P. Child–computer interaction. *Int. J. Child Comput. Interact.* **2013**, *1*, 2–6. [CrossRef]

45. Read, J.C.; Bekker, M.M. The Nature of Child Computer Interaction. In *HCI2011*; BCS Learning and Development Limited: Swindon, UK, 2011.

46. Norris, M.; Oppenheim, C.; Rowland, F. Finding open access articles using Google, Google Scholar, OAIster and OpenDOAR. *Online Inf. Rev.* **2008**, *32*, 709–715. [CrossRef]

47. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*. [CrossRef] [PubMed]

48. Guyatt, G.; Rennie, D.; Meade, M.; Cook, D. Users' Guides to the Medical Literature. Essentials of Evidence-Based Clinical Practice. *Health Inf. Lib. J.* **2003**, *20*. Available online: https://www.ebcp.com.br/simple/upfiles/livros/005EEBM.pdf (accessed on 14 April 2021).

49. Arnab, S.; Lim, T.; Carvalho, M.B.; Bellotti, F.; De Freitas, S.; Louchart, S.; Suttie, N.; Berta, R.; De Gloria, A. Mapping learning and game mechanics for serious games analysis. *Br. J. Educ. Technol.* **2015**, *46*, 391–411. [CrossRef]

50. Jabbar, A.I.A.; Felicia, P. Gameplay Engagement and Learning in Game-Based Learning. *Rev. Educ. Res.* **2015**, *85*, 740–779. [CrossRef]