Identifying Requirements for a Virtual Reality Virtual World Serious Game Toolkit

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Contents

Abstract

This article examines potential improvements for the virtual reality (VR) serious game development process by using virtual worlds (VWs). The current state of VR serious game development is presented along with a potential future state incorporating VW content development pipelines. VR serious games by subject area are then examined to determine key functional requirements necessary for VR serious game development using virtual reality virtual worlds (VRVWs). Analysis of those functional requirements provides the basis for a discussion of a toolkit to improve the VR serious game process building off of the VRVW content development process.

Key Words: virtual reality, virtual world, development, training, education, serious games

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Introduction

Developing virtual reality serious games can be challenging even for an experienced developer because of the complexity of game engines and virtual reality frameworks. Fortunately, virtual world platforms often provide capabilities for serious game developers who do not have the level of technical expertise to implement all the functionality of their games from scratch. However, these tools are still rarely chosen as platforms for serious games because of the lack of familiarity with the development process of these tools and their ability to satisfy the requirements of the implementation of serious games. With an understanding of the VR serious game development process and identification of general functional requirements for VR serious games, these platforms can provide a base for educators and trainers to put together engaging immersive experiences.

Definitions

This paperx will use terms that may have alternate meanings depending on context. The definitions used here will be more restrictive than commonly used definitions, because this paper focuses on commercially available and developer-accessible tools.

Virtual Reality (VR): For this article, the definition of virtual reality is limited to VR supported though head-mounted displays (HMDs). This VR type requires users to wear a headset that places the screen in front of their eyes, and the gaze direction in the game updates as users move their head in different directions. This technology is often supported by hand-held controllers which represent the user's hands, but it is not a requirement for VR. This definition of VR excludes "Virtual Reality" technologies such as 3D glasses, CAVE technology, or other custom-developed VR solutions. Because HMDs represent the primary commercial base and popularly available VR form, other types of virtual reality technology will not be discussed in this paper.

Virtual World (VW): A virtual world is an online platform which allows for communication between avatar-represented users and the uploading of interactive content by its users. This excludes online worlds that do not allow the uploading of interactive content, such as many commercial online massively multiplayer games like World of Warcraft. The virtual world definition used here requires users to be essential in the content creation process for the platform.

Virtual Reality Virtual World (VRVW): Virtual reality virtual worlds combine both of these definitions. They include the ability for users to upload custom content to the platform and VR interactions inside those environments. Many of these platforms do not require users to use VR to enter the environment, but it is often beneficial for the user to do.

Serious Game: A serious game is a video game created for the purpose of education or training.

Toolkit: A toolkit is a collection of premade functionality that can be used inside of a game without major alteration.

General Development Tools and Processes

The development process for games can be complicated, but game engines can provide a way for developers to create reusable code for their games. Selecting the right tools provides developers with a much easier prototyping cycle in the development process. This section will cover how using existing tools can improve the development process.

Serious Game Development Tool Evaluation Process

In the process of serious game development, the design should precede the selection of a development tool. However, familiarity with the capabilities of specific development tools inevitably informs developers' reactions to the game's design as they veto functionality difficult to achieve in their familiar tools.

When developers want to pick the right tool for the serious game as designed, they will consult research on the capabilities of tool engines agnostic of developers' past game engine development experience. Pavkov et al. (2017) compared five game engines in the following five major categories: basic features, price, support, flexibility, and functionality criteria, with the serious game design relevant categories being flexibility and functionality. Flexibility covered capabilities such as integration with learning management systems and multiplayer support, while functionality covered game engine capabilities such inclusion of a dialogue editor and an inventory system. Marin-Vega et al. (2017) compared ten HTML5-based game engines and game development frameworks and eight proprietary game engines to improve the selection process of game engines for serious games. They used a combination of the following three aspects: basic architecture, game attributes, and game categories as collections of game attributes. Basic architecture included capabilities such as 2D/3D support, game attributes included more detailed functionality such as dialogue and scoring systems. Cowan and Kapralos (2017) compared ten game engines from a usage approach and identified Unity3D, Flash, Second Life, and Unreal as commonly used game engines for serious games. Then, they broke the engines down by functionality such as inclusion of a physics engine, capability to export to different platforms, and licensing for commercial and non-commercial applications. Instead of providing a broad survey of all tools, Mehm et al. (2016) focuses on understanding the creation process and compares Unity3D and StoryTec as two alternatives for serious game development. Each of them has use cases for different styles of games, and the critical evaluation of the game's requirements and experience of the development team must be taken into account with the game development process.

The serious game engine evaluation processes provided by these sources break down game engines into their basic capabilities. VRVW platforms as serious game deployment environments have not yet been extensively studied because of the inexperience of serious game developers with VRVW platforms and the cost of hardware associated with providing VR-centric experiences to users.

Present State VR Serious Game Development Process

In the current state of VR serious game development, the desire for creating new experiences comes from educators and trainers wwho want to improve the learning processes for their fields. However, game engines and hardware-specific VR frameworks define the working parameters of the game's design. These tools can only be effectively used by experienced game developers with deep knowledge of the frameworks and the serious game development process. While this collaboration between educators and trainers and game developers can yield interesting games, it increases the cost and time to develop serious games as learning experiences. The below figure illustrates the relationship between developers and educators and trainers in creating VR games.

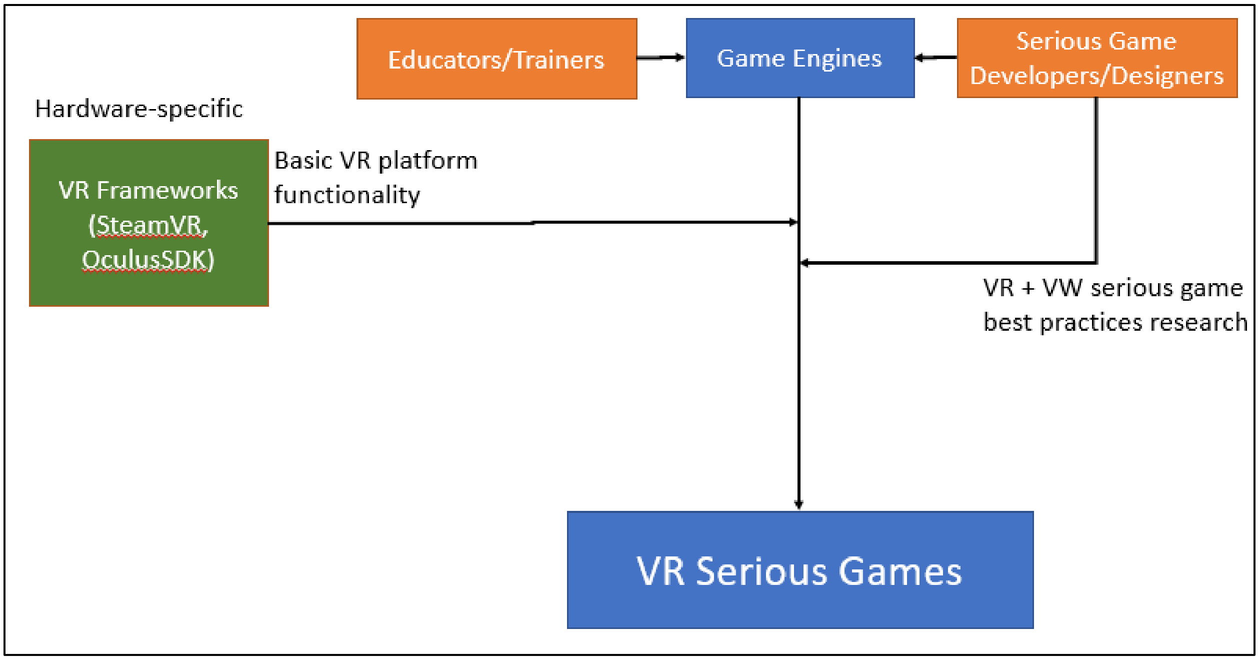

Figure 1: Present State VR Serious Game Development Process

Creation of Toolkits and Frameworks to simplify game development

Toolkits and frameworks for serious game development can make the serious game development process easier. Westera et al. (2008) provides a framework of definitions for serious game development to reduce the complexity of building a system architecture for a serious game. While the framework does not provide specific code implementations, the architecture framework can be used by a serious game developer within a compatible game engine to create "controlled complexity in support of effective learning." Bellotti et al. (2010) created a tool for the development of serious games as a series of tasks performed in a VW. Their tool allowed educators to put learning information into an easy-to-use graphical interface to generate the lesson structure inside a VW engine. As an extra benefit to their research how VRChat can be used for crowdsourced VR experiments, Saffo et al. (2020) released the functionality of their VRChat world publicly, which includes functionality involving remote observation of experiments and experiment facilitator controls. These frameworks and toolkits are written with a research and education focus in mind. The desire to abstract the technical implementation of functionality allows serious game development to be performed by educators and trainers with less technical expertise.

Proposed Future State VR Serious Game Development Process

If educators and trainers can own more of the development process, they can create experiences that are a good fit for their subject area without depending on support from contracted serious game developers. The proposed future state incorporates the VR development pipelines which have been streamlined by VRVW platforms. In addition, community developed functionality can provide the basis for serious game functionality without requiring advanced code implementations. Once educators and trainers are able to create experiences on their own without developer support, they will be free to implement their visions and make changes to improve learning outcomes with unique serious games.

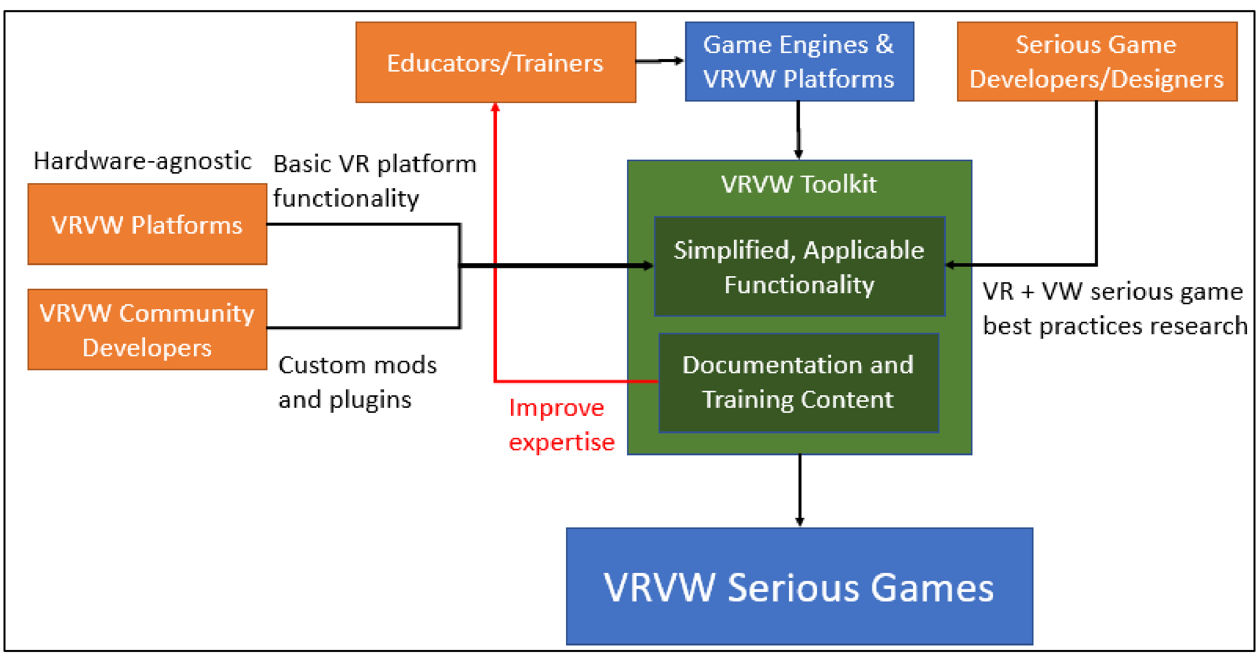

Figure 2:Proposed Future State VR Serious Game Development Process

Serious Game Types

Challenges related to specific serious game types can enable those game types to be easy or difficult to implement for serious game developers. Adding qualifications like VR interactivity adds to the complexity of the development process. Evaluating VR elements of serious games separately will show how challenges in the development process are overcome for those different game types.

Virtual Reality Serious Games

VR serious games using head-mounted displays (HMDs) give a different set of controls and functionality than digital serious games. Firstly, camera rotational movement in HMD VR games is always controlled through head movement. While camera rotational movement can theoretically be done with a traditional controller, and in some cases head movement camera control is augmented with controller interactions, the sense of gaze offered to users through physical head movement is the primary draw of VR games creating a sense of place for their players. Positional movement is sometimes controlled through head positional movement in a limited capacity and can usually be augmented with controller support. In modern HMD setups, hand-based controllers that provide a representation of the player's hands in 3D space can be used to allow the player to interact with the world, although point-and-click systems involving raycasts are also common in VR user experience design.

The serious games developed in VR usually reflect the advantages of using these design elements in their games. Checa & Bustillo (2019) reviewed the prevalence of serious games for education and training purposes over time to show an increase of VR serious games since the release of the commercially available Oculus Rift HMD VR system in 2014. Nearly 50% of the games studied were developed with Unity3D, with a majority of them focusing on interactive experiences. They found a majority of the serious games studied identified positive learning outcomes. Davey and Hancock (2019) identify four major subject areas for VR serious games, pain therapy, traumatic experiences and illnesses, skill learning, and artistic experiences. The types of interactions available in VR are displayed through affordances on the object and be enhanced through effective visual design. Developers can determine the level of simulation realism or allow for non-real interactions inside the serious game.

Some VR serious games also implement collaboration functionality, creating additional challenges for building serious games. However, some examples have been created which show the benefit of learning in collaborative VR serious games. Xu et al. (2020) developed a game with VR synchronous multiplayer to train railway accident rescuers on proper signaling techniques. However, they had a limitation because their game was based on offline multiplayer that they could only support one headset inside the experience. Eller et al. (2018) explored VR for collaborative serious games for emergence response purposes. They identified development of custom tools on top of VR platforms as a necessity for training development, including administrative operations to manipulate the training scenario. They used a combination of Unity3D for game development, AutoDesk 3DS for modeling, Photon for multiplayer systems, and VRTK for VR functionality to create the multiplayer VR environment. They also developed a hierarchy of roles for participants in the training and object interaction to prevent network overload, and a multi-room architecture for their game world to allow for pre-training and post-training activities. These two examples show the range of tools necessary for multiplayer VR development, one through an offline experience and one through an online experience. Crossing the threshold from offline to online multiplayer development requires adding new tools and making decisions which require tradeoffs between game performance and functionality. When using a VW platform, implementation of online functionality can be simplified for non-developers.

VW Platforms for Education and Training

VW applications developed in the 90s and 2000s provided platforms for experimenting with online avatar-driven training and education. Girvan (2018) provides a definition for a VW as a simulated space shared with other users who can all interact with objects and each other to construct a shared understanding of the space. The interactivity with both people and things provided by a VW creates the potential for the development of learning experiences that can replicate or enhance real-world learning experiences. Farley (2016) identifies situations where VWs provide more effective simulations than classroom activities as authentic learning experiences. However, she also states that authentic VW learning environments need more than just representation of a physical space to be effective, because they must also take into account social, cultural, emotional, and symbolic factors.

The functionality provided by different VW tools can impact the design and development process of educational experiences in VWs. Campbell and Cameron (2016) compared two different VW tools, Second Life and OpenSimulator and the guided scaffolding necessary to generate meaningful learning outcomes in those environments. For both tools, scaffolding provided by external tools improved the ability of students to stay on-task in the VW to achieve learning outcomes. Kuznetcov and Glassman (2020) also discuss the pitfalls of VW learning implementations that only use the VW as a communication tool rather than providing a transformative experience to learners through their functionality. In particular, the ability of VWs to break down traditional hierarchical learning relationships created new methods of collaborative learning. This can generate new ideas, but without the right guidance and direction learning in these environments can deviate from intended learning outcomes.

VRVW Platforms

With the release of the Oculus Rift in 2015, one of the first widely available and affordable head-mounted display (HMD) VR systems, existing VW applications began to support HMD VR and new VW applications originated focused on VR. Second Life now supports VR in its tool, and AltSpaceVR, VRChat, and RecRoom focus on VR functionality as a core tenet of their platforms. These platforms rely on users to create content for the platform to attract other players and try to make their development and publishing processes easy for users. This presents an opportunity for serious game developers to create VR serious game without requiring game engine or VR framework expertise. Identifying a specific VRVW that would best be applicable for toolkit development is beyond the scope of this paper.

Key Functionality Identification

This section will identify what key functional elements are necessary for ensuring that a VW platform can satisfy requirements for creating VR serious games There are some generic aspects of game development that have been excluded from this level of functional analysis. While many serious games depend on in-world user interface elements such as the display of text and images and playing audio clips, this functionality is supported by every 3D game tool to some extent. However, games where the user interface is based on contextual information, such as picking up an object or traveling to a specific location have been called out with that functionality, because implementing contextual user interfaces usually requires some degree of development regardless of chosen platform. Research into learning applicability for VR using commercial-off-the-shelf (COTS) VR applications was not included.

Subject Areas

A toolkit to allow for serious game development in VRVWs should focus on basic mechanics that are applicable across different subject areas. By identifying commonly used functionality features, prioritization for toolkit development can be performed. This research focuses on the following four different areas provided by Young et al. (2012): science, language learning, physical education, and history. The way they outline how the different learning requirements for these fields illustrates how VRVWs might provide benefits to serious games in these areas. Example games were selected in each of these subject areas. In each of these games, key functional aspects were identified as potential cases for toolkit functionality generation. An additional topic was also included of training, as the goal of training is to train users on specific tasks which makes the assessment process distinct from education-focused serious games. A survey of VR serious games by Checa (2020) and additional research provided the games to be evaluated.

Science Education

Santos et al. (2017) created a simulation to test different modes of learning robotic arm operation to compare VR and non-VR solutions. While they configured the game to work with a VR HMD, the users still used mouse and keyboard and joystick controls for game operation. Their technology stack involved using C++, OpenGL, and other low-level code frameworks to build the experience, which involves operating the robotic arm and setting up the correct serious of actions for the arm to perform. Isabwe et al. (2018) created an interactive chemistry learning experience in VR. Their experience included hints for the users on what to do next and combining objects present in the world with a reaction mimicking real-world reactions. In addition, informational audio clips play on object pickup, and additional information related to the molecule and atom makeup displays on object interaction. It also had an in-game book with experiment instructions and teleportation locomotion. Madden et al. (2018) created an interactive VR experience to teach the different phases of the moon through realistic visualizations. In the VR simulation users could use hand controllers to control time as well as grab and manipulate objects using the hand controllers. They could change their movement position, but how users changed position is not disclosed. Seo et al. (2017) created a VR learning environment for learning anatomy using Unity and the VIVE VR platform. The users assemble a model by picking up bones and placing them in the proper place on a skeleton. Proximity checks are performed to determine accurate placement of the bones on the skeleton, and users follow instructions placed inside the virtual space. Physics simulations were turned on and off based on positions of the objects in the space. Stepan et al. (2017) created a VR experience to teach aspects of neuroanatomy. Their experience allowed the users to move their position using the handheld controller, although the movement type is not specified. The game has “fully interactive, handheld controller VR features”, but there is no explanation provided as to the degree of interactivity provided to the players.

For the science VR games reviewed here, most of them involved some degree of picking up and manipulating objects with hand controllers. From there, they deviated with the degree of interactivity with those objects and other objects in the world. The authors often used existing toolkits that provided VR functionality, which means they are familiar with using code written by others to put together experiences. As a group, science VR games need object interactivity to be easy to implement and allow for a range of object events based on player interactions, as well as the ability of users to move about the space and view environments from different angles.

VR serious games for science education tend to focus on individual learning of technical concepts instead of collaborative learning. Because of the single-player nature of VR science education in some fields, and the physical simulation precision required to demonstrate scientific principles, a VRVW experience may not be as applicable for VRVW development as other subjects. However, this could be because the difficulty of initial setup in VR provides a barrier to implementing multiplayer interactivity in science education scenarios, a problem that could be solved with an easier development pipeline. VR does provide benefits to science education, as multiple studies noted that while learning outcomes did not drastically differ comparing VR and traditional modes, students indicated a preference for learning with VR.

Language Learning

Cheng et al. (2017) adapted an existing Japanese language learning game to VR to incorporate body movement tracked cultural interactions into the language learning experience. Their game used mouse and keyboard for movement and performing actions in the world, but included a VR feature of tracking when the user put their head down in a “bowing” state. The game involved interacting with non-player characters (NPCs) and collecting words based on overheard conversations to use in dialogue scenarios to complete the game, requiring each player to have an inventory of words that grew over the course of the game. After a word added, players could use those words inside of the environment to complete a task series. Peixoto et al. (2019) created a VR application with NPCs to train listening comprehension skills for English language skills. The experience included dialogue recorded by instructors and motion-captured animations that played in two scenarios.

There are many studies available on the use of VR in language learning, however most of the experiences analyzed involved COTS VR applications instead of experiences developed by the researchers. This indicates that either the researchers do not have the technical expertise to build their own language-learning solutions in VR or that COTS tools provide an adequate degree of functionality to create VR experience that enhance language-learning outcomes.

Compared with science, which focused on individual learning and interacting with objects, language learning VR experiences put more of an emphasis on group learning and interacting with people. This would make language learning applications a better fit for a VRVW environment than science learning games, since there would be more focus on communication and less on precise object movement. In addition, VR provides affordances for non-verbal communication that are more immersive than the clicking of a button on a computer screen. Because language educators may not have the programming background necessary for developing immersive VR experiences, they could benefit more from a toolkit which makes that development process easier for non-technical educators.

Physical Education

Physical education serious games focus on training users in specific skills or encouraging long-term behavioral changes. Research related to long-term behavior changes is not as common as short-term skill training due to the requirement of access to a VR device for the duration of the study, but as HMD VR devices become cheaper, long-term studies may become more common. Petri et al. (2019) developed an application to test improvement in reaction time to karate attacks. Hand positions were calculated with a hand attachment add-on for a HMD. The game tracked the position and timing of the player’s action in relation to the character, and then manual data collection.

History

Bruno et al. (2018) created a VR diving system to create an immersive learning experience for underwater archeological sites. They created an underwater scene where users could navigate using a VIVE controller. The user has the ability to move gradually in a direction and point the controller towards a point of interest to bring up contextual information about the environment.. The user can select to explore on their own or with a guided tour provided by an NPC. Andreoili et al. (2016) created a game focused on exploring a specific historical structure in three different time periods. The players needed to pick up objects in one location in the site and move them to a different location to proceed with the game. The researchers tracked the time it took to perform certain actions in the game, and the player moves around the world with directional movement and does not use grab actions for object pickups.

VR games have the opportunity to use immersion to engage students with historical content they would not otherwise be able to experience. Therefore, history VR experiences focus on accurate portrayal of the environment through models and allowing limited interactivity for the users to not break the quality of their immersion.

Training

Eller et al. (2018) created a multiplayer training simulation for emergency rescue personnel. The simulation was designed to have multiple roles with different responsibilities inside of the environment using VR tracking attachments to physical peripherals like a fire hydrant to increase immersion of participations. The game had a pre-scenario room where participants could decide on how to complete the scenario and manipulate conditions such as starting positions. Xu et al. (2019) created a multiplayer training simulation game focused on training accurate railway accident signaling. Two participants performed different roles in the process, one controlling a crane while the other signaled actions to perform to that crane operator with a second set of controllers. As part of the experiment, they measured the signaler's poses to determine their accuracy. Buttussi and Chittaro (2017) created a simulation of airplane evacuation involving multiple steps to test training correct responses. The game involved walking movement and required the user to perform context-sensitive actions with a controller. The experience is heavily scripted as a single-player experience, with frequent restarts of the experience when the player selects incorrect options. Dean et al. (2019) created a training experience for operating a construction site surveying tool with a goal of evaluating how hand-based controllers could improve the training experience. The training involved grabbing and manipulating elements on the device to ensure it has been prepared properly for the surveying task. Students receive audio and visual cues at each step of the training before completion. Hilfert et al. (2016) created a training simulation for construction safety which tracked the gaze of users to determine their awareness of construction site hazards. They logged data of users and created specific scenarios that could be replayed from intermediary steps to provide additional guidance as part of the training.

For VR serious games designated as training experiences, developers tended to provide more linear scenario-based experiences, rather than open-ended experiences allowing users to explore. The linear nature of training makes them possible within a VW setup, but not ideal. Training is different from education in that measurement of player ability after the training is more important than for education. While many education-based VR experiences provided evidence to show improved engagement with the subject matter made their experience as success, training focuses on testable skills inside the experience.

Subject Area Summary

The below table sums up the key functional capabilities shown in the games selected for evaluation. These games will form the basis for analysis to determine the functionality necessary for an effective general-use VRVW serious game toolkit.

Table 1: Key Functional Elements of VR Serious Games

Subject	Subject Detail	Author	Title	Key Functional Elements
Science Education	Anatomy	Seo et al.	Anatomy Builder VR	Object grab, object position check, object distance check with object, area-based physics system adjustment
Science Education	Anatomy	Stepan et al.	Surgical Theater	Camera movement, hand controller interactivity
Science Education	Astronomy	Madden et al.	Untitled	Object grab and pull, camera movement
Science Education	Chemistry	Isabwe et al.	VR Based Solution	Contextual tooltips, object use, object collision, teleportation locomotion, narration
Science Education	Robotics	Santos et al.	VR Robotics	Position recording and replay, scenario editor, automated data collection, automated data reporting, activity time tracking
Language Learning	English	Peixoto et al.	Untitled	Audio, animated NPCs
Language Learning	Japanese	Cheng et al.	Crystallize	Draggable UI Elements, headset angle tracking, inventory (words to be used in conversation), instruction UI
Physical Education	Martial Arts	Petri et al	Untitled	Animated NPCs, hand visualization, hand position and timing tracking, scoring system
History	Site Exploration	Andreoili et al.	HippocraticaCivitasGame	Directional movement, inventory, time tracking
History	Site Exploration	Bruno et al.	Underwater Cultural Heritage	Animated NPCs, directional movement, contextual UI
Training	Construction	Dean et al.	Theodolite Training Experience	Grabbing and manipulating a static machine, audio prompts
Training	Construction	Hilfert et al.	Untitled	Gaze tracking, data logging, experience recording, intermediary restarts, NPCs, object pick up, time tracking
Training	Emergency Response	Eller et al.	Untitled	Roles system, pre-training setup
Training	Emergency Response	Xu et al.	Untitled	Remote machine control, roles system, time tracking, pose tracking
Training	Evacuation	Buttussi & Chittaro	Untitled	NPCs, directional movement, action selection in area, intermediary restarts

Analysis of Subject Area VR Serious Game Findings

While these different subject areas create games that look very different on the surface, they share common sets of VR functionality that are needed to create basic VR experiences. All of the experiences need a VR framework that will control camera direction based on player gaze, even if the player cannot interact with anything in the environment. Most of the experiences had some form of user movement in the environment and interactivity based on hand controls. For movement, some experiences used the teleport movement style while others used control stick movement. Many experiences had hand interactivity, though others used controllers or mouse and keyboard controls. Hand interactivity included functionality such as grabbing and holding objects, manipulating objects inside of the environment, and static point activation. Most movement and hand interaction functionality is already implemented inside of VRVWs with the exception of automated correctness checking.

For language learning, physical education, history, and some training experiences, the implementation of NPCs was a critical aspect of the experience. The ability to see other human-like avatars in the environment provided the facsimile of an in-person training experience. However, VRVWs tend not to have NPC built into their development pipelines, since users are expected to interact with other human beings online in the VW. While VRVWs create opportunities to reduce reliance on NPCs for training and education scenarios, using avatars as human participants increases the cost of running the experience.

For single-player education and training experience, the facilitator plays a critical role in the experience. In most of these testing scenarios, the facilitator explains the game before they enter the experience, begins the experience, then performs a post-experiment evaluation of the participant. Control of participants in VRVWs can be more challenging than in single-player experiences, since the world is persistent even though learning outcomes of the game may be enhanced through effective facilitation. Most VRVWs have a sense of facilitator or owner of the instance of the virtual world created, but these owners may not have all the tools they need to control the experience for participants.

Training applications nearly all require some form of data collection to ensure that users perform actions correctly based on training in VR. In single-player VR serious games, this usually means creating a file that is stored locally on the computer running the game to track user data. However, the distributed nature of VRVWs means data collection can be challenging to implement, and data collection on participants will need to be implemented through code that exports data from the VRVW in a useable form.

For training simulations which involve multiple users who need to collaborate to achieve a goal, a roles system is critical for restricting users and forcing them to collaborate as they would in the real world. VRVWs tend to treat all users entering a world as the same except for their choice of avatar, so restricting their functionality will need to be implemented through additional code placed inside the world.

Initial Toolkit Functionality

Based on the previous analysis, initial toolkit functionality can be proposed to satisfy the requirements of VR serious game development in a way that educators and trainers can use to create experiences without requiring VR development expertise. This toolkit will provide pre-made functionality that can be placed inside of a VW environment along with training documentation for how to use the toolkit for individuals without development expertise.

Facilitator Controls

In the VR serious game, a user can take on the facilitator role and perform actions such as initializing the experience, ending the experience, and restarting the experience. More research needs to be performed to identify an effective way to identify the facilitator for the game and the type of controls they should have.

Head/Hand Position Checks

A basic element of serious games is determining correctness through the participant going into a specific area. For example, in history serious games, the users are generally expected to navigate to a particular area, at which point an audio clip will play. Implementing these inside of the experience will enable educators to implement basic VR correctness checks based on player position.

Object Placement Check

Users in the VR serious game should be able to pick up an object and place it in a location. If the location is correct, then the users can proceed with the experience.

Roles System

In addition to the facilitator, participant roles may need to be identified. There can exist certain restrictions based on the role a user is provided, such as being able to perform specific interactions.

Data Tracking

VRVWs lack data tracking features that are commonly implemented in VR serious games. Therefore, a key aspect of this toolkit will be allowing educators and trainers to determine what data they would like to track in the experience, including time of completion, percent of correct actions, and other data that allows them to show the learning outcomes of the game.

NPCs

VRVWs do not implement NPCs as part of their standard development pipeline, but NPCs are a common aspect of VR serious games. A basic NPC system is necessary that allows users to interact and be guided through the experience, assuming the facilitator does not take on this role.

Conclusion and Next Steps

The key functional elements identified as both implemented inside of VRVW platforms and the functional elements which need additional development both need to be presented to serious game developers as viable ways to build their serious games for VR. If developers do not feel these platforms provide them the necessary flexibility to create experiences that fit their requirements, they will gravitate towards using solutions they are already familiar with. A VRVW needs to be selected for implementation of the toolkit. This VRVW should allow for functionality to come packaged and easily implementable inside of the game.

To provide the right context to present VRVWs as a viable development platform for serious game developers, a clear training pathway needs to be created for developers to get started with the platform. This can be a resource which includes examples of serious game setups inside the tool, instructional content on how to edit the samples to create new experiences, and references to additional tutorials related to content development. In addition, functionality that is not already covered by the out-of-the-box implementations will need to be created and put in editable samples. The serious games evaluated as part of this research will provide good baseline experiences that could fit in sample VWs easily, and more examples could be added over time to support broader types of VR serious game development.

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