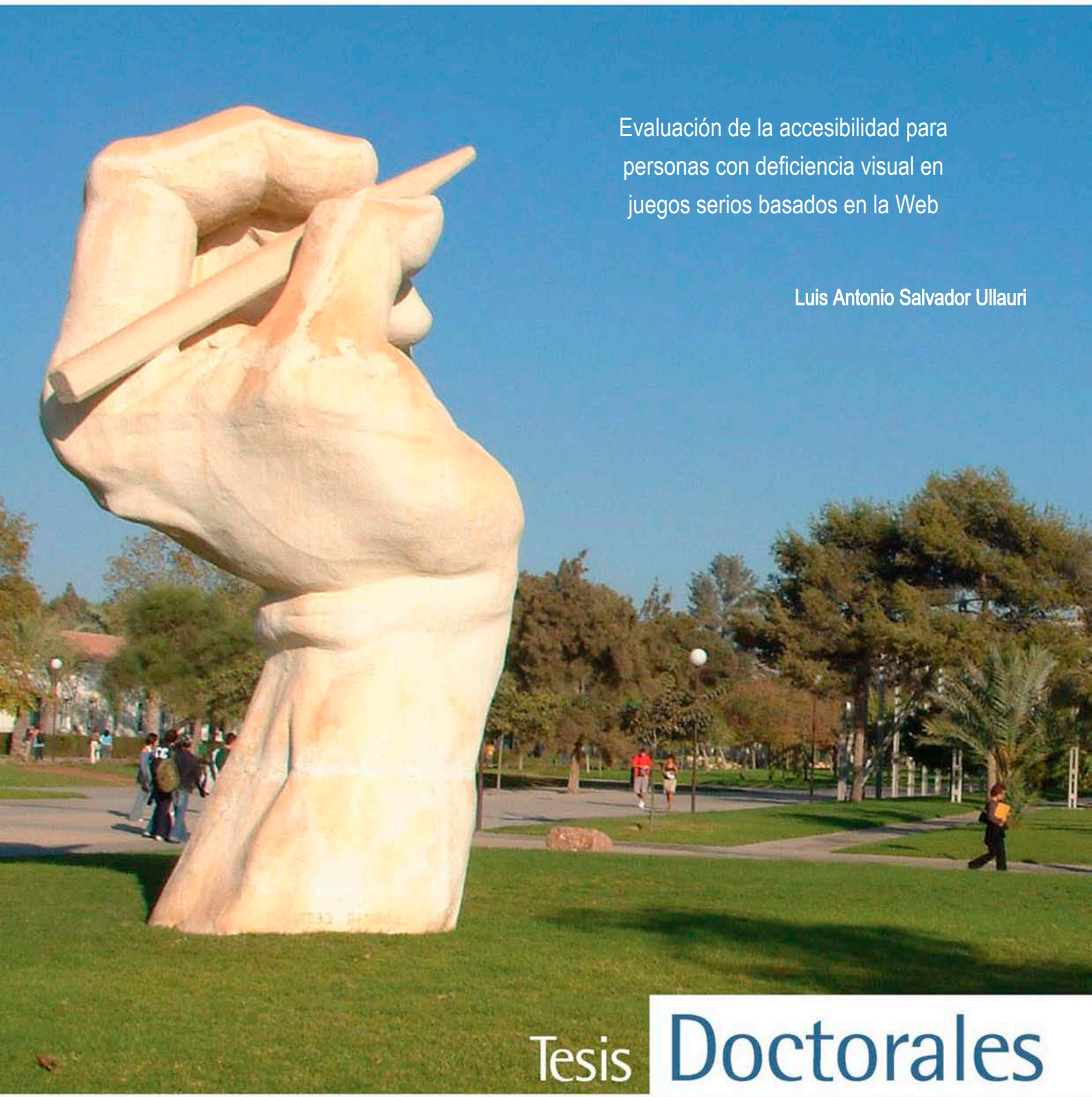
Universitat d'Alacant
Universidad de Alicante



Evaluación de la accesibilidad para personas con deficiencia visual en juegos serios basados en la Web

Luis Antonio Salvador Ullauri

Tesis Doctorales
UNIVERSIDAD de ALICANTE

Unitat de Digitalització UA
Unidad de Digitalización UA

Universitat d'Alacant
Universidad de Alicante

Instituto Universitario de Investigación
Informática

Escuela Politécnica Superior

Evaluación de la accesibilidad para personas con deficiencia visual en juegos serios basados en la Web

Luis Antonio Salvador Ullauri

Tesis presentada para aspirar al grado de

Doctor por la Universidad de Alicante

Doctorado en Informática

Dirigida por:

Dr. Sergio Luján Mora

Marzo 2021

TESIS DOCTORAL EN FORMA DE COMPENDIO DE PUBLICACIONES

Evaluación de la accesibilidad para personas con deficiencia visual en juegos serios basados en la Web

El presente trabajo realizado por Luis Antonio Salvador Ullauri, bajo la dirección del Dr. Sergio Luján Mora, para optar por el grado de Doctor en Informática se presenta en la Universidad de Alicante y se estructura según la normativa establecida para la presentación de tesis. En la primera parte se incluye una síntesis del trabajo elaborado; la segunda parte contiene una reproducción de las publicaciones científicas realizadas en la modalidad de compendio; la tercera parte incluye la visibilidad y los perfiles del doctorando; la cuarta parte contiene las conclusiones, aportaciones y trabajos futuros. Finalmente, se incluye la sección apéndices que contiene varias publicaciones realizadas durante el doctorado, las mismas que no fueron incluidas como parte del compendio para garantizar la unidad temática de los presentados.

Marzo 2021

Dedicatoria

Esta tesis está dedicada a:

Mis padres Bertha y Luis por sus sabios consejos.

María Belén y Luis Antonio, mis amados hijos.

Mi esposa Patricia por ser mi amiga y compañera de vida, por el apoyo y motivación en el desarrollo de este trabajo.

Mis amigos y compañeros que me motivaron a cumplir con este reto.

Agradecimientos

Mi gratitud a:

Sergio Luján Mora, por brindarme la oportunidad de recurrir a su experiencia científica y consejos.

La Universidad de Alicante que me apoyó a perseguir este gran reto.

Patricia Acosta y Mario González por compartir sus conocimientos en otras áreas de investigación.

Todas las personas y amigos que colaboraron de múltiples maneras en la realización de la presente tesis doctoral.

Quito, 1 de Enero de 2021
Luis Salvador Ullauri

Resumen

We need to make every
single thing accessible
to every single person with
a disability.
Stevie Wonder (Lewis, Chamel, Mohsenin, Ots, y White, 2018, pag. 275)

Los juegos serios, incluyendo las simulaciones interactivas, son un poderoso medio de apoyo al aprendizaje de los estudiantes universitarios (Martin y Betrus, 2019). Entre los principales beneficios de las simulaciones está el de aclarar conceptos y mejorar la comprensión de los diferentes temas que se imparten en las instituciones de enseñanza superior. Varios autores están de acuerdo en que los juegos serios mejoran la capacidad de comprensión de los estudiantes a medida que aprenden (Cheng, Chen, Chu, y Chen, 2015).

La Organización de las Naciones Unidas considera que la Educación para Todos (EPT) involucra el acceso a la educación para todas las personas incluidas a las personas con discapacidad. De igual forma, la Organización Mundial de la Salud (OMS) en su reporte sobre la discapacidad (World Health Organization [WHO], 2017) revela que más de mil millones de individuos sobrellevan algún tipo de discapacidad, este valor representa el 15 % de la población mundial.

Asimismo, existen millones de juegos serios basados en la Web, de diferentes temáticas. Este estudio se centra en los juegos serios educativos; no todos los existentes son accesibles, la accesibilidad se asume como la finalidad de lograr que los juegos serios puedan ser utilizados por el mayor número de personas, independientemente de las capacidades, conocimientos, y características de los dispositivos tecnológicos que se utilicen para interactuar con las aplicaciones.

En este contexto, el compromiso con este tema de gran interés educativo y social surge desde el año 2015 bajo la dirección del Dr. Sergio Luján Mora en calidad de director de esta tesis.

Por supuesto, el uso de juegos serios puede ser una alternativa a las herramientas didácticas actuales (Kazimoglu, Kiernan, Bacon, y Mackinnon, 2012), pero estos recursos

deben ser cuidadosamente diseñados para que su utilidad sea valorada. Aunque el uso de los videojuegos ha aumentado en los Estados Unidos y en varios países europeos, es necesario evaluar su eficacia, que puede estar sujeta, como ocurre con otros medios, a un diseño didáctico adecuado, su correcta aplicación, así como a la accesibilidad.

La evaluación de la accesibilidad de los videojuegos es un factor crucial para promover la evaluación de su contenido educativo. Entre los principales beneficios de un videojuego accesible, se pueden enumerar los siguientes: 1) permite la inclusión de todo tipo de usuarios; 2) mejora el acceso al contenido educativo; 3) ayuda a lograr mejores resultados de aprendizaje; 4) permite la reutilización del contenido en múltiples dispositivos; y 5) permite a los usuarios con una discapacidad permanente o temporal recibir y comprender su contenido educativo, así como poder utilizarlo correctamente.

Por lo tanto, la accesibilidad es esencial para proporcionar una mejor interacción entre los usuarios y los juegos serios. Sin duda, la razón principal para diseñar juegos serios accesibles es proporcionar acceso a un número más significativo de usuarios, incluidas a las personas con algún tipo de discapacidad.

Por consiguiente, para lograr que los juegos serios basados en la Web sean accesibles e inclusivos se sugiere aplicar las normas que establece el World Wide Web Consortium [W3C] (1997). Este estudio se centra en las Web Content Accessibility Guidelines (WCAG) 2.1 (World Wide Web Consortium [W3C], 2018), aplicadas a la Web pero que se adaptan a los juegos serios para reducir las barreras de acceso.

Esta investigación se orienta en estudiar la accesibilidad en los juegos serios basados en la Web aplicados al área educativa, además, este estudio se enfoca a las personas interesadas en conocer el estado de la cuestión relacionado con la accesibilidad y los estándares de las WCAG 2.0 y 2.1 en los juegos serios y la importancia de utilizar estas normas.

En esta investigación se propone aplicar un método combinado para evaluar la accesibilidad en los juegos serios, teniendo en cuenta las WCAG 2.1. Se evaluó la accesibilidad de 82 juegos serios, tomados de forma aleatoria, desarrollados en HTML5 por Physical Education Technology (PhET) Interactive Simulations de la Universidad de Colorado (Martin y Betrus, 2019).

PhET ofrece simulaciones divertidas, gratuitas e interactivas en Matemáticas, Biología, Química, Ciencias de la Tierra y Física (Cheng y otros, 2015) que se basan en la investigación. Tiene un total de 83 simulaciones desarrolladas en HTML5, 57 aplicaciones en Java vía CheerpJ, 63 simulaciones desarrolladas en Java, y 12 aplicaciones en Flash. Las aplicaciones pueden ser ejecutadas en línea o descargadas a un ordenador. Todas las simulaciones incluyen el código fuente HTML5 y Javascript de PhET, que se encuentra en la página GitHub de PhET.

Esta investigación puede servir como guía para que los diseñadores y desarrolladores de juegos serios apliquen las WCAG 2.1 con un nivel aceptable de accesibilidad; además, este estudio puede aportar referencias para futuros trabajos relacionados con la accesibilidad en los juegos serios basados en la Web.

En la primera fase se realizó una revisión de la literatura (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020) que permitió identificar el estado actual de los juegos serios basados en la Web y la accesibilidad, esto posibilitó identificar los estudios que aplican las WCAG 2.1 y los estudios de juegos serios relacionados con las discapacidades

sensoriales, motoras y cognitivas.

En la segunda fase, en la evaluación de la accesibilidad de los juegos serios, se aplicó un método combinado de accesibilidad que permitió comprobar los estándares de la WCAG 2.1 (W3C, 2018). El método combinado (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020a) fue aplicado a un caso de estudio para probar que se puede replicar a cualquier juego serio basado en la Web, en esta fase, se contó con el aporte de dos expertos en accesibilidad Web. Finalmente, en la tercera fase se implementó la evaluación heurística (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020b) de accesibilidad para juegos serios; en la cual se aplicó tres modificaciones al método de Barrier Walkthrough (BW) propuesto por Brajnik y Lomuscio (2007).

Los resultados de la presente investigación fueron publicados durante los años 2016 y 2020, después de pasar por procesos de revisión ciega por pares, en revistas y congresos indexados en Web of Science (WOS) y Scopus. Se han realizado un total de siete publicaciones principales: tres artículos en revistas de alto impacto con cuartil Q2 con índice de impacto en Journal Citation Reports (JCR), tres artículos de congreso y un capítulo de libro. Los artículos publicados se presentan en orden cronológico:

1. Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM. Capítulo de libro. Octaedro. 2016.

2. Juego serio móvil de cálculo binario para personas con discapacidad visual. Conferencia ATICA. 2017.

3. A Serious Game Accessible to People with Visual Impairments. Conferencia ACM. Indexada en Scopus. 2017.

4. Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. Conferencia IHSI. Indexada en Scopus. SJR Q3. 2020.

5. Combined Method for Evaluating Accessibility in Serious Games. Revista Applied Sciences. JCR IF= 2.474. Q2. SJR Q1. 2020.

6. Web-Based Serious Games and Accessibility: A Systematic Literature Review. Revista Applied Sciences. JCR IF= 2.474. Q2. SJR Q1. 2020.

7. A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision. Revista Applied Sciences. JCR IF= 2.474. Q2. SJR Q1. 2020.

Los artículos uno, dos, tres y cuatro fueron trabajos previos en los que se estudió el desarrollo de juegos serios y sus problemas de accesibilidad, para las personas con problemas de visión y problemas cognitivos.

En paralelo, se trabajó en el análisis de la literatura; nunca se paró de revisar la literatura existente, que se plasmó en el trabajo seis, que fue publicado después del artículo cinco.

Se propuso el método combinado en el trabajo cinco; y posterior a este, un método heurístico para evaluar la accesibilidad de las personas con baja visión que se plasma en el siete.

La comprobación de la accesibilidad de un juego serio basado en la Web es un reto esencial para los expertos y no expertos en accesibilidad. Los usuarios que sufren cambios relacionados con la edad, como la baja visión, mala audición y disminución de la motricidad, entre otros, presentan barreras para acceder a los juegos serios.

Los principales resultados que se han obtenido de este trabajo son: 1) caracterizar la accesibilidad de los juegos serios educativos considerando las discapacidades sensoriales, motrices y cognitivas; 2) proponer un método combinado para la evaluación de la accesibilidad aplicando las WCAG 2.1; 3) probar un método heurístico para evaluar la accesibilidad en juegos serios, caso específico usuarios con baja visión; 4) compartir los datos de los experimentos en repositorios abiertos para la réplica y difusión de la investigación en accesibilidad en juegos serios.

En este estudio se encontró que varios de los juegos serios evaluados no cumplen los requisitos de accesibilidad establecidos en las WCAG 2.1. El mayor número de los problemas identificados con relación a la accesibilidad de los juegos serios indican que es esencial robustecer las políticas de accesibilidad en cada país y difundir los lineamientos para que los juegos serios sean más accesibles e inclusivos.

Los futuros trabajos deberían seguir analizando la evolución de la accesibilidad de los juegos serios, al compartir datos abiertos que permitan identificar el mayor número de barreras de accesibilidad de tal forma que se apliquen los correctivos del caso. Se recomienda analizar los errores más frecuentes y aplicar las mejores prácticas para lograr juegos serios más inclusivos que cumplan con las WCAG 2.1.

Durante el proceso de revisión de literatura en un filtrado de cuatro fases con el método PRISMA se encontró que no existen herramientas automáticas para la revisión de la accesibilidad en juegos serios. Tampoco se encontraron métodos de evaluación de la accesibilidad para los juegos serios basados en la Web. También se identificaron que varias soluciones de accesibilidad se logran con la aplicación de tecnologías de asistencia o rampas digitales especialmente para la discapacidad motora.

Esta investigación presenta como propuesta un método combinado y un método heurístico para ayudar en la evaluación de la accesibilidad de cualquier juego serio basado en la Web. La propuesta incluye una nueva heurística con rangos de persistencia que ayudan a los evaluadores a tener una aproximación más realista de la severidad de una barrera o impedimento de accesibilidad entre el juego serio y los usuarios. Se sugiere replicar estos métodos propuestos para diversos tipos de usuarios considerando las respectivas barreras de discapacidad.

Como resultado de la investigación se encontró que ninguno de los juegos seleccionados en la muestra alcanzó un nivel aceptable de accesibilidad. Por lo tanto, los desarrolladores de los juegos serios y las empresas que están a la vanguardia de aplicaciones de juegos serios deben realizar esfuerzos significativos para perfeccionar la accesibilidad en los juegos serios.

Por último, se anima a los diseñadores y programadores de juegos serios a aplicar y difundir los lineamientos establecidos en las WCAG 2.0 y 2.1 como punto de partida a la hora de construir aplicaciones inclusivas y accesibles.

Abstract

Serious games, including interactive simulations, are a powerful means of supporting college student learning (Martin y Betrus, 2019). Among the simulations' primary benefits is to clarify concepts and improve the understanding of the different topics taught in higher education institutions. Several authors agree that serious games improve students' comprehension capacity as they learn (Cheng y otros, 2015).

On the other hand, the United Nations Organization considers that Education for All (EFA) involves access to education for all people, including people with disabilities. Similarly, the World Health Organization (WHO) in the report on disability (WHO, 2017) reveals that more than one billion individuals live with some disability, representing 15 % of the world's population.

Likewise, there are millions of serious games based on the Web, of different themes; in this study, we focus on the educational serious games; not all the existing ones are accessible, the accessibility is assumed as the purpose to achieve that the serious games can be used by the most significant number of people, independently of the capacities, knowledge, and characteristics of the technological devices that are used to interact with the applications.

In this context, the commitment to this topic of great educational and social interest has arisen since 2015 under the direction of Dr. Sergio Lujan Mora as director of this thesis. Of course, the use of serious games can be an alternative to the current didactic tools (Kazimoglu y otros, 2012), but these resources must be carefully designed so that their usefulness is valued. Although the use of video games has increased in the United States and several European countries, it is necessary to evaluate their effectiveness, which may be subject, as with other media, to an appropriate didactic design, as well as to accessibility. The evaluation of the accessibility of video games is a crucial factor in promoting the evaluation of their educational content. Among the main benefits of an accessible video game, we can list the following: 1) it allows the inclusion of all types of users; 2) it improves access to educational content; 3) it helps to achieve better learning results; 4) it allows the reuse of the content in multiple devices; and 5) it allows users with a permanent or temporary disability to receive and understand its educational content, as well as to be able to use it correctly.

Therefore, accessibility is essential to provide better interaction between users and in serious games. Without a doubt, the main reason for designing accessible serious games is to provide access to a more significant number of users, including people with disabilities. Therefore, to make Web-based serious games accessible and inclusive, we suggest applying the standards set by the W3C (1997); in our study, we will focus on the Web Content Accessibility Guidelines (WCAG) 2.1; (W3C, 2018), applied to the Web but adapted to serious games to reduce access barriers.

This research is oriented to study the accessibility in the serious games based on the Web applied to the educational area; besides, this study is focused on the people interested in knowing the state of the matter related to the accessibility and the standards of the WCAG 2.0 and 2.1 in the serious games and the importance of using these standards. In this research, we propose to apply a combined method to evaluate accessibility in serious games, taking into account WCAG 2.1. We evaluated the accessibility of 82 serious games, taken at random, developed in HTML5 by Physical Education Technology (PhET) Interactive Simulations of the University of Colorado (Martin y Betrus, 2019). PhET offers fun, free, interactive simulations in Mathematics, Biology, Chemistry, Earth Science, and Physics (Cheng y otros, 2015) that are based on research. It has 83 simulations developed in HTML5, 57 applications in Java via CheerpJ, 63 simulations developed in Java, and 12 applications in Flash. The applications can be executed online or downloaded to a computer. All simulations include the HTML5 source code and PhET's Javascript, which can be found on PhET's GitHub page.

This research can guide serious game designers and developers to apply WCAG 2.1 with an acceptable level of accessibility; furthermore, this study can reference future work related to accessibility in serious Web-based games.

In the first phase, we performed a literature review (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020), which allowed us to identify the current status of Web-based serious games and accessibility to identify studies applying WCAG 2.1 and studies of serious games related to sensory, motor, and cognitive disabilities.

In the second phase, in evaluating the accessibility of serious games, we applied a combined accessibility method to check the WCAG 2.1 standards (W3C, 2018). The combined method (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020a) was applied to a case study to prove that the method can be replicated to any serious Web-based game; in this phase, we have the contribution of two experts in Web accessibility. Finally, in the third phase, we implemented the heuristic evaluation (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020b) of accessibility for serious games; in which three modifications were applied to the Barrier Walkthrough (BW) method proposed by Brajnik y Lomuscio (2007).

The results of this research were published during 2016 and 2020, after going through blind peer review processes, in journals and congresses indexed in Web of Science (WOS) and Scopus. A total of seven main publications have been made: three articles in high-impact journals with Q2 quartile with impact index in Journal Citation Reports (JCR), three conference articles and a book chapter. The published articles are presented in chronological order:

1. Production of video games oriented to teaching through block programming lan-

guages applicable to virtual classrooms through SCORM. Book chapter. Octahedron. 2016.

2. Serious mobile game of binary calculus for visually impaired people. ATICA Conference. 2017.

3. A Serious Game Accessible to People with Visual Impairments. Indexed in Scopus. 2017.

4. Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. Indexed in Scopus. SJR Q3. 2020.

5. Combined Method for Evaluating Accessibility in Serious Games. Applied Sciences Journal. JCR IF= 2.474. Q2. SJR Q1. 2020.

6. Web-Based Serious Games and Accessibility: A Systematic Literature Review. Applied Sciences Magazine. JCR IF= 2.474. Q2. SJR Q1. 2020.

7. A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision. Applied Sciences Magazine. JCR IF= 2,474. Q2. SJR Q1. 2020.

Articles one, two, three, and four were previous works in which the development of serious games and their accessibility problems for people with vision and cognitive problems were studied.

At the same time, work was done on the literature analysis; it never stopped reviewing the existing literature; this was reflected in work six, which was published after article five.

The combined method was proposed in paper five. Furthermore, following this is a heuristic method for accessibility for people with low vision embodied in seven.

Testing the accessibility of a serious Web-based game is an essential challenge for accessibility experts and non-experts alike. Users who suffer age-related changes, such as low vision, poor hearing, and decreased motor skills, among others, present barriers to accessing serious games.

The main results obtained from this work are: 1) to characterize the accessibility of educational serious games considering the sensory, motor, and cognitive disabilities; 2) to propose a combined method for the evaluation of accessibility applying the WCAG 2.1; 3) to test a heuristic method to evaluate the accessibility in serious games specific case users with low vision; 4) to share the data of the experiments in open repositories for the replication and diffusion of the research in accessibility in serious games.

In this study, we found that several serious games evaluated violate the accessibility requirements set out in WCAG 2.1. The more significant number of issues identified regarding the accessibility of serious games indicate that it is essential to strengthen accessibility policies in each country and disseminate guidelines to make serious games more accessible and inclusive.

Future work should continue to analyze the evolution of accessibility of serious games by sharing open data to identify the most significant accessibility barriers so that appropriate corrections can be applied. We recommend analyzing the most frequent

errors and applying best practices to achieve more inclusive serious games that comply with WCAG 2.1.

During the literature review process in four-stage filtering with the PRISMA method, we found no automatic tools for accessibility review in serious games. We also found no accessibility evaluation methods for Web-based serious games.

We also identified that several accessibility solutions are achieved using assistive technologies or digital ramps, especially for motor disabilities. Our proposal presents a combined method and a heuristic method to assist in the accessibility evaluation of any serious Web-based game. Our proposal includes a new heuristic with persistence ranges that help evaluators have a more realistic approach to the severity of an accessibility barrier or impairment between the serious game and the users. We suggest replicating these proposed methods for various types of users considering the respective disability barriers.

As a result of our research, we found that none of the games selected in the sample reached an acceptable level of accessibility. Therefore, serious game developers and companies at the forefront of serious game applications should make significant efforts to improve accessibility in serious games. Finally, we encourage designers and programmers of serious games applications to apply and disseminate the guidelines established in WCAG 2.0 and 2.1 as a starting point when building inclusive and accessible serious games.

Índice general

Índice de figuras

Índice de tablas

Parte I

SÍNTESIS

1 Introducción

1.1. Motivación

La Web ha cambiado la forma en que la gente se comunica y se relaciona con los demás. La tecnología ha generado un impacto continuo en la sociedad y el comportamiento de los individuos. El creciente acceso a la Web y la variedad de dispositivos que nos permiten interactuar con ella han hecho posible que los estudiantes elijan las herramientas y servicios que mejor se adaptan a sus necesidades, y así personalizar la experiencia de aprendizaje (Kompen, Edirisingha, Canaleta, Alsina, y Monguet, 2019).

Los juegos serios son "juegos que no tienen como objetivo principal el entretenimiento, o la diversión" (Michael y Chen, 2005, pág. 21). Los principales objetivos de los juegos serios pueden ser, entre otros, la educación, la formación, la gestión de los recursos humanos y la mejora de la salud (Lau, Smit, Fleming, y Riper, 2017). Los juegos serios basados en la Web constituyen un área en crecimiento gracias a la mejora de los navegadores y las tecnologías utilizadas en la Web (de Castro Lozano, 2015), que han reducido la brecha entre las aplicaciones de escritorio y las de la Web. Según Statista (2020), se espera que el mercado de los juegos serios crezca de 3,500 a 24,000 millones para el año 2024. La tendencia de los juegos serios basados en la Web presenta varios beneficios:

1. Reforzar el aprendizaje en los procesos educativos de forma virtual y a distancia (Kompen y otros, 2019).

2. Usar las aplicaciones sin necesidad de descargar, instalar y configurar.

3. Interactuar con las aplicaciones en cualquier momento y espacio.

4. Actualizar la aplicación automáticamente con la última versión.

5. Usar las aplicaciones con menos problemas técnicos debido a conflictos de software o hardware con otras aplicaciones.

Hoy en día, hay muchos juegos serios basados en la Web, pero los desarrolladores no suelen preocuparse por su accesibilidad. La accesibilidad (World Wide Web Consortium [W3C], 2008) tiene como objetivo garantizar que las aplicaciones puedan ser utilizadas por el máximo número de personas, independientemente de sus capacidades y de las características técnicas del equipo utilizado para acceder a la aplicación. De acuerdo con las Web Content Accesibility Guidelines (WCAG) 2.1, algunas pautas ayudan a validar las páginas Web y las aplicaciones, incluyendo los juegos serios, haciéndolas más accesibles para todas las personas. En este estudio se identifican y comparan los artículos relacionados con la accesibilidad en los juegos serios basados en la Web. Se presenta una revisión sistemática de la literatura (RSL) (Kitchenham, 2004; Petersen, Feldt, Mujtaba, y Mattsson, 2008) que permite examinar la accesibilidad de los juegos serios. La pregunta de investigación considerada es: ¿Qué estándares de evaluación de la accesibilidad han sido utilizados por los desarrolladores para crear juegos serios basados en la Web? Este estudio define las cadenas de consulta que permiten encontrar la investigación más significativa relacionada con la accesibilidad en los juegos serios (Aguado-Delgado, Gutiérrez-Martínez, Hilera, De-Marcos, y Otón, 2020). Para determinar la cadena de consulta, se aplicó la estructura en términos de población, intervención, comparación y resultado (PICO) (Eriksen y Frandsen, 2018). Esta RSL permitió: 1) esbozar los problemas relevantes para los juegos serios basados en la Web y los estudios de accesibilidad; 2) identificar cómo la accesibilidad está implicada en los juegos serios; 3) determinar las pautas de accesibilidad basadas en las WCAG, y 4) identificar las tecnologías y dispositivos de asistencia utilizados para lograr la accesibilidad en los juegos serios según la discapacidad. Después de un proceso de extracción de 476 estudios, se seleccionó una colección de 47 estudios primarios utilizando los Elementos de Información Preferidos para Revisiones Sistemáticas conocidos como *Preferred Reporting Items for Systematic Reviews and Meta-analysis* (PRISMA) (García-Holgado y García-Peñalvo, 2018; Prisma-Statement, 2015), y el diagrama de flujo en el proceso de selección. La propuesta presenta, además, un método combinado que ayuda a los expertos en accesibilidad a evaluar los juegos serios. En esta investigación se parte de la siguiente pregunta de investigación: ¿Qué métodos de evaluación de la accesibilidad en juegos serios han utilizado los investigadores para evaluar los serious games? Previamente para identificar el estado de la cuestión para este tema se definieron las cadenas de búsqueda que permitieron encontrar el mayor número de tópicos relacionados con la accesibilidad en juegos serios considerando la discapacidad visual. Se sugiere replicar este método para usuarios con otros tipos de discapacidad, teniendo en cuenta las diferentes barreras identificadas. La entidad encargada de regular los estándares de Internet es el World Wide Web Consortium (Song y otros, 2017; World Wide Web Consortium [W3C], 2015) que se basa en la Web Accessibility Initiative (WAI) (World Wide Web Consortium [W3C], 2016), y sirve de base para aplicar la evaluación de la accesibilidad de los juegos serios.

La Figura 1.1 muestra la búsqueda de Google Trends[1] relacionada con las aplicaciones Web, los juegos serios y las aplicaciones móviles realizadas en la Web en los últimos cinco años. Se encontró que los términos "juegos serios" y "aplicaciones Web" comenzaron a intensificarse a partir de 2019.

[1] https://trends.google.es/trends/

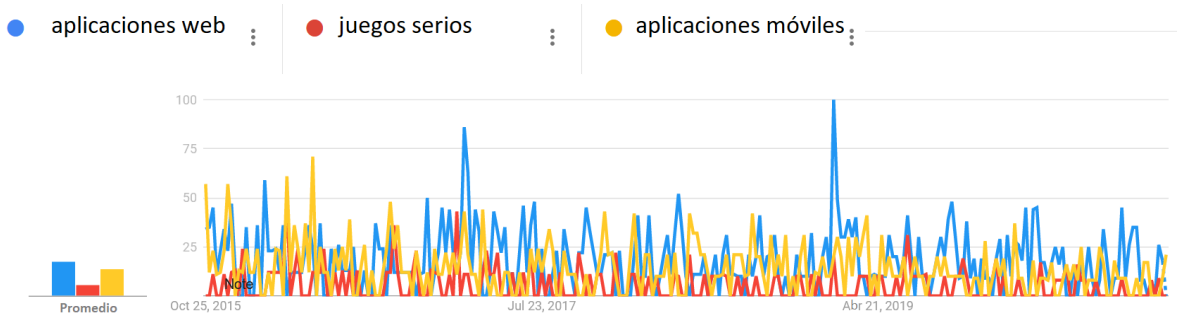


Figura 1.1: Tendencia de los juegos serios basados en la Web en Google Trends

La accesibilidad en los juegos serios (Jaramillo-Alcázar y Luján-Mora, 2017) tiene por objeto garantizar que los juegos serios puedan ser utilizados por el máximo número de personas para acceder a ellos. Los autores sugieren aplicar los cuatro principios de las WCAG 2.1. Varios estudios (Aguado-Delgado y otros, 2020; Jaramillo-Alcázar y Luján-Mora, 2017) muestran una falta de compromiso por parte de los diseñadores para implementar la accesibilidad. Por esta razón, hay un bajo porcentaje de juegos serios accesibles. Actualmente, los juegos serios se han incorporado a los procesos de enseñanza-aprendizaje. Por lo tanto, es esencial garantizar la accesibilidad (López, Medina, y de Lope, 2016) para que el mayor número de personas pueda usarlos.

Los autores Jaramillo-Alcázar, Luján-Mora, y Salvador-Ullauri (2017) presentan un análisis de las pautas de accesibilidad para el desarrollo de videojuegos orientados a las personas que presentan discapacidades cognitivas. Los autores proponen una herramienta de evaluación para el desarrollo de juegos serios para dispositivos móviles.

Finalmente, los autores Salvador-Ullauri, Luján-Mora, y Acosta-Vargas (2016a) indican que es un gran desafío implementar juegos serios para apoyar los procesos de aprendizaje de las personas con discapacidades cognitivas. Los autores evaluaron diez videojuegos serios utilizando los principios de diseño establecidos por las WCAG 2.0 (W3C, 2008). Los resultados revelaron que las aplicaciones no alcanzan un nivel de accesibilidad adecuado para ser utilizadas por personas con problemas cognitivos. Sin embargo, sí cumplen con algunos de los requisitos de accesibilidad.

1.2. Objetivos

El objetivo principal de esta tesis es desarrollar un proceso para evaluar la accesibilidad en los juegos serios basados en la Web y aplicar un método manual, debido a que no se cuenta con herramientas de evaluación automática, así como con algún método que ayude en el proceso de evaluación manual. Los objetivos específicos fueron:

Objetivo 1 Caracterizar los problemas más relevantes sobre juegos serios basados en la Web y la accesibilidad.

Objetivo 2 Identificar las pautas de accesibilidad que se aplican a los juegos serios basados en la Web.

Objetivo 3 Detectar los diferentes enfoques de los juegos serios basados en la Web para las discapacidades cognitivas, motoras y sensoriales.

Objetivo 4 Identificar las pautas de accesibilidad basadas en las WCAG que se aplican a los juegos serios para determinar las tendencias y las lagunas en el desarrollo de los juegos serios.

Objetivo 5 Proponer un método manual para evaluar los juegos serios para usuarios con baja visión.

1.3. Método de trabajo

Para cumplir con los objetivos 1 y 2 se aplicó una evaluación manual y automática de accesibilidad sobre un grupo de videojuegos educativos basados en la Web. Para el objetivo 3 y 4 se aplicó una combinación de las metodologías Kitchenham (Kitchenham, 2004; Kitchenham y otros, 2009) y PRISMA (Moher, Liberati, Tetzlaff, y Altman, 2009; Urrútia y Bonfill, 2010) y con lo cual se realizó una revisión sistemática de literatura para la propuesta del método heurístico de accesibilidad en juegos serios.

Finalmente, para el desarrollo del objetivo 5 se utilizó un método manual combinado y se aplicó una modificación a la metodología Website Accessibility Conformance Evaluation Methodology (WCAG-EM) 1.0 aplicado a juegos serios (World Wide Web Consortium [W3C], 2014).

1.4. Estructura de la tesis

Esta tesis contiene cuatro partes principales: 1) Síntesis, 2) Trabajos publicados, y 3) Conclusiones. La primera sección contiene el resumen del trabajo realizado e incluye los siguientes capítulos:

Capítulo 1 Introducción, contiene: objetivos, método de trabajo, estructura de la tesis y convenciones de escritura.

Capítulo 2 Publicaciones, contiene: un breve descripción de las publicaciones realizadas en revistas de alto impacto y algunos congresos que sirvieron de apoyo en esta investigación.

Capítulo 3 Visibilidad, contiene: perfiles académicos, página personal, sitio Web y reconocimiento.

Capítulo 4 Descripción del trabajo realizado, contiene: la caracterización del problema de los juegos serios para el área educativa, el estado de la cuestión mediante la revisión de literatura con el método PRISMA y la evaluación de la accesibilidad en juegos serios educativos basados en la Web.

La segunda parte contiene los trabajos completos publicados con el propósito de cumplir con los objetivos de la presentación de la tesis doctoral por compendio de artículos y abarca los siguientes capítulos:

Capítulo 5 Lista de publicaciones, contiene: una breve descripción temporal de las publicaciones realizadas en esta investigación.

Capítulo 6 Artículo "Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM" publicado en el libro Octaedro, incluye la referencia, aporte y el texto completo.

Capítulo 7 Artículo "Juego serio móvil de cálculo binario para personas con discapacidad visual" publicado en el Congreso Internacional sobre Aplicación de Tecnologías de la Información y Comunicaciones Avanzadas (ATICA), incluye la referencia, aporte y el texto completo.

Capítulo 8 Artículo "A Serious Game Accessible to People with Visual Impairments" publicado en la Novena Conferencia Internacional sobre Educación Tecnología y Computadoras, incluye la referencia, aporte y el texto completo.

Capítulo 9 Artículo "Accessibility Evaluation of Video Games for Users with Cognitive Disabilities" publicado en la Novena Conferencia Anual Internacional de Educación, Investigación e Innovación, incluye la referencia, aporte y el texto completo.

Capítulo 10 Artículo "Combined Method for Evaluating Accessibility in Serious Games" publicado en la revista Applied Sciences, incluye la referencia, aporte y el texto completo.

Capítulo 11 Artículo de revisión "Web-based Serious Games and Accessibility: A Systematic Literature Review" publicado en la revista Applied Sciences, incluye la referencia, aporte y el texto completo.

Capítulo 12 Artículo "A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision" publicado en la revista Applied Sciences, incluye la referencia, aporte y el texto completo.

La tercera parte contiene dos capítulos:

Capítulo 13 Conclusiones y Contribuciones, contiene: las conclusiones obtenidas y las contribuciones de esta investigación.

Capítulo 14 Trabajos futuros y recomendaciones, contiene: los trabajos que pueden realizarse a futuro y las recomendaciones para el éxito de dichos trabajos.

Capítulo A Apéndice, contiene: varios artículos relacionados que dan soporte a este trabajo de investigación.

1.5. Convenciones de escritura

En esta tesis se utiliza el acrónimo WCAG 2.0 y 2.1 para hacer referencia a los estándares de la *Web Content Accessibility Guidelines*, además, se utiliza WCAG-EM

1.0 para *Website Accessibility Conformance Evaluation Methodology.*Al hacer referencia al método heurístico de recorrido de la barrera se usa BW que significa *Barrier Walkthrough.*

Los acrónimos se construyen con las primeras letras del texto y se acompañan de la definición entre paréntesis en la primera vez que aparecen en el texto. Por ejemplo, BW (*Barrier Walkthrough*).

Las citas se transcriben en el idioma original de la referencia de donde proceden.

Algunas de las figuras que se incluyen provienen de las publicaciones que conforman el compendio, las mismas que han sido traducidas al idioma español.

Las palabras de un idioma diferente al castellano que se utilizan en algunos párrafos de texto se representan en letra cursiva. Por ejemplo, *Journal Citation Report.*

Debido al origen del autor, cuando existen sinónimos se representan en los términos más utilizados en Sudamérica (Ecuador). Por ejemplo, computador por ordenador.

Para las cifras numéricas como separador de miles se utiliza la coma y para los decimales el punto. Por ejemplo; 5,343.58 se lee cinco mil trescientos cuarenta y tres con cincuenta y ocho.

2 Publicaciones

A lo largo del desarrollo de la presente tesis doctoral, y en relación con los aportes, se han realizado las siguientes publicaciones científicas:

Revistas Tres (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020a; Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020; Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020b)

Congresos Tres (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020; Salvador-Ullauri, Jaramillo-Alcázar, y Luján-Mora, 2017; Salvador-Ullauri, Jaramillo-Alcázar, y Luján-Mora, 2017)

Capítulos de libro Uno (Salvador-Ullauri, Luján-Mora, y Acosta-Vargas, 2016c)

2.1. Revistas

Las revistas científicas donde se han publicado artículos se detallan en la Tabla 2.1, incluyendo identificador único, nombre, ISSN, país, factor de impacto JCR IF *(Journal Citation Report Impact Factor)*, ranking en la categoría de JCR y factor de impacto SJR *(SCImago Journal Rank)*. Todos los artículos publicados en revistas que fueron sometidos a procesos de revisión ciega por pares, corresponden a:

1. "Combined Method for Evaluating Accessibility in Serious Games" (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020a). Este artículo fue publicado en la revista Applied Sciences. En el capítulo 10 se detalla el contenido del artículo.

2. "Web-based Serious Games and Accessibility: A Systematic Literature Review" (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020). Este artículo fue publicado en la revista Applied Sciences. En el capítulo 11 se detalla el contenido del artículo.

Id.	Revista	JCR IF	SJR
J1	Multidisciplinary Digital Publishing Institute, Applied Sciences, ISSN: 2076-3417. United States. Special Issue Human Factors in the Digital Society. Vol: 10. Num: 18.	2.474 - Q2	0.42 - Q1
J2	Multidisciplinary Digital Publishing Institute, Applied Sciences, ISSN: 2076-3417. United States. Special Issue Human Factors in the Digital Society. Vol: 10. Num: 21.	2.474 - Q2	0.42 - Q1
J3	Multidisciplinary Digital Publishing Institute, Applied Sciences, ISSN: 2076-3417. United States. Special Issue Human-Computer Interaction. Vol: 10. Num: 24.	2.474 - Q2	0.42 - Q1

Tabla 2.1: Descripción de las revistas

3. "A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision" (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020b). Este artículo se publicó en la revista Applied Sciences. En el capítulo 12 se detalla su contenido.

2.2. Congresos

En las memorias de los congresos se publicaron los artículos que se detallan en la Tabla 2.2. Se incluye el identificador único, nombre, indexación en Scopus o Web of Science, país, ciudad y fecha de realización del congreso. Todos los congresos fueron sometidos a procesos de revisión ciega por pares. Los artículos publicados en memorias en orden cronológico de publicación corresponden a:

1. "Accessibility Evaluation of Video Games for Users with Cognitive Disabilities" (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020). Este artículo fue publicado en el congreso C1.

2. "A Serious Game Accessible to People with Visual Impairments" (Salvador-Ullauri y otros, 2017). Este artículo fue publicado en el congreso C2.

3. "Juego serio móvil de cálculo binario para personas con discapacidad visual" (Salvador-Ullauri y otros, 2017). Este artículo fue publicado en el congreso C3.

2.3. Capítulos de libros

En esta sección se lista un capítulo de libro relacionado con la temática en estudio, publicado por la editorial Octaedro que se encuentra en el puesto número 48 de entre

ID	Congreso	País/Ciudad	Fechas
C1	3rd International Conference on Intelligent Human Systems Integration (IHSI 2020). Indexado en EI-Compendex, Scopus y publicado en ACM Digital Library.	Italia/ Módena	Febrero 19 - 21, 2020
C2	9th International Conference on Education Technology and Computers (ICETC 2017). Indexado en EI-Compendex, Scopus y publicado en ACM Digital Library.	España/ Barcelona	Diciembre 20 - 22, 2017
C3	8th International Congress on Application of Advanced Information and Communications Technologies (ATICA 2017). Publicado en el libro de actas del congreso.	Colombia/ Medellín	Octubre 25 - 27, 2017

Tabla 2.2: Descripción de los congresos

272 editoriales a nivel general de acuerdo con el ranking *Scholarly Publishers Indicators* (SPI).

1. "Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM" (Salvador-Ullauri y otros, 2016c).

3 Visibilidad

Durante la formación del doctorado, se impartieron cursos y talleres de actualización continua para fomentar la visibilidad de la producción científica que permitieron incrementar el impacto de los resultados en la comunidad científica. Por lo cual fue esencial la selección de revistas y congresos para la presentación y divulgación de los trabajos realizados, los repositorios científicos y los lugares de indexación, se detallan en la Tabla 3.1. Los artículos publicados están disponibles en varias bases de datos científicas entre ellas:

- Scopus muestra 30 artículos como se presenta en la Figura 3.1.
- WOS muestra 18 artículos como se presenta en la Figura 3.2.
- DBLP muestra 8 artículos como se presenta en la Figura 3.3.

A noviembre de 2020, se tiene una estadística de un total de 90 citas fuertes. En resumen, se cuentan con 90 citas en Scopus, 35 en WOS y 184 citas en Google Scholar.

3.1. Perfiles académicos

Se han creado los perfiles académicos que se detallan en la Tabla 3.2.

3.2. Página personal

La Figura 3.4 presenta una captura de la página personal [1] que se ha actualizado de forma permanente con la información de la producción científica en orden cronológico.

[1] http://saccec.com/LuisSalvador/HojaDeVida/Trabajos.html

ID	Repositorio científico	Publicaciones principales	Otras publicaciones
RC1	ACM	2	
RC2	IEEE Xplore	4	2
RC3	Springer	3	17
RC4	Revistas científicas online	3	
RC5	Editoriales de libros	1	
RC6	Otros repositorios digitales-Mendeley	3	9
	Total	16	28

Tabla 3.1: Repositorios científicos

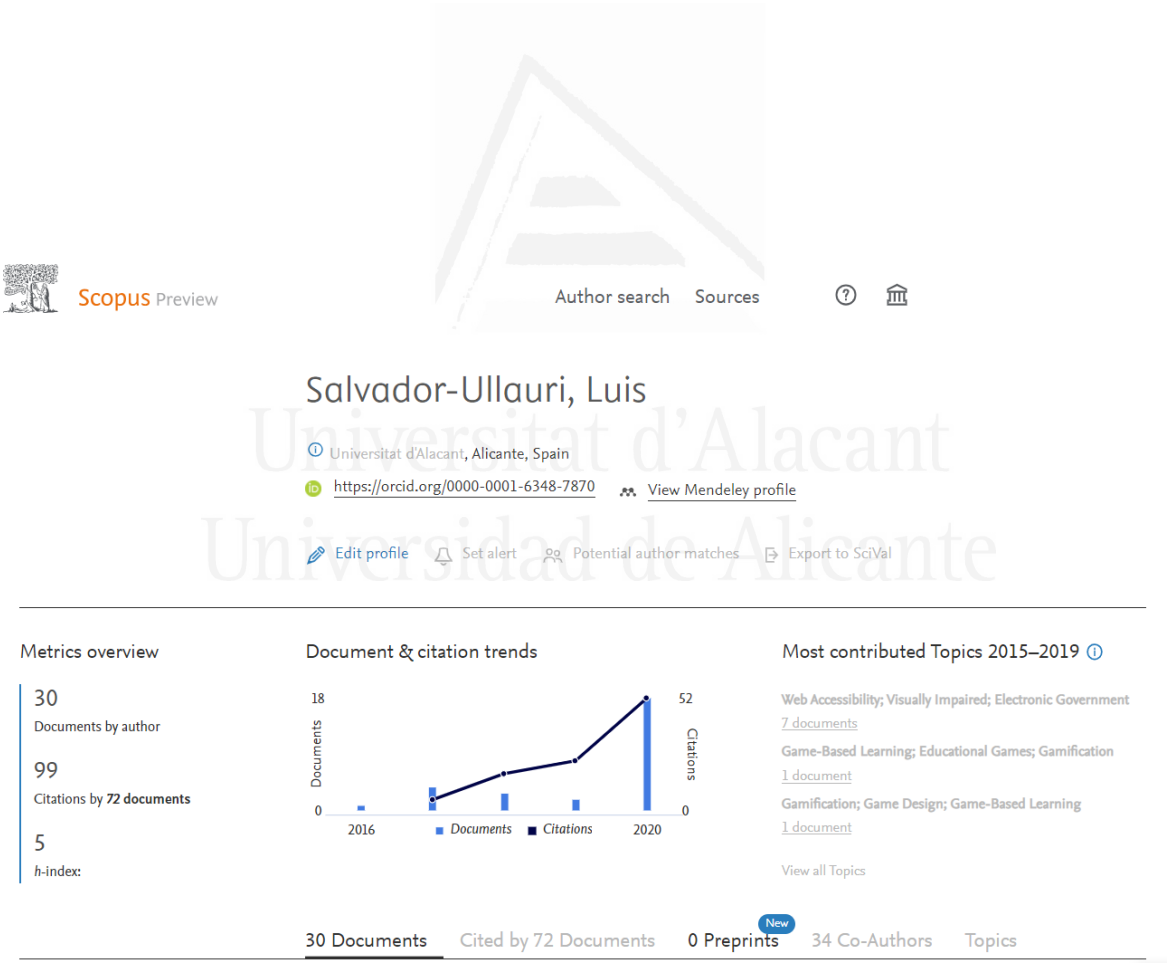


Figura 3.1: Artículos en Scopus

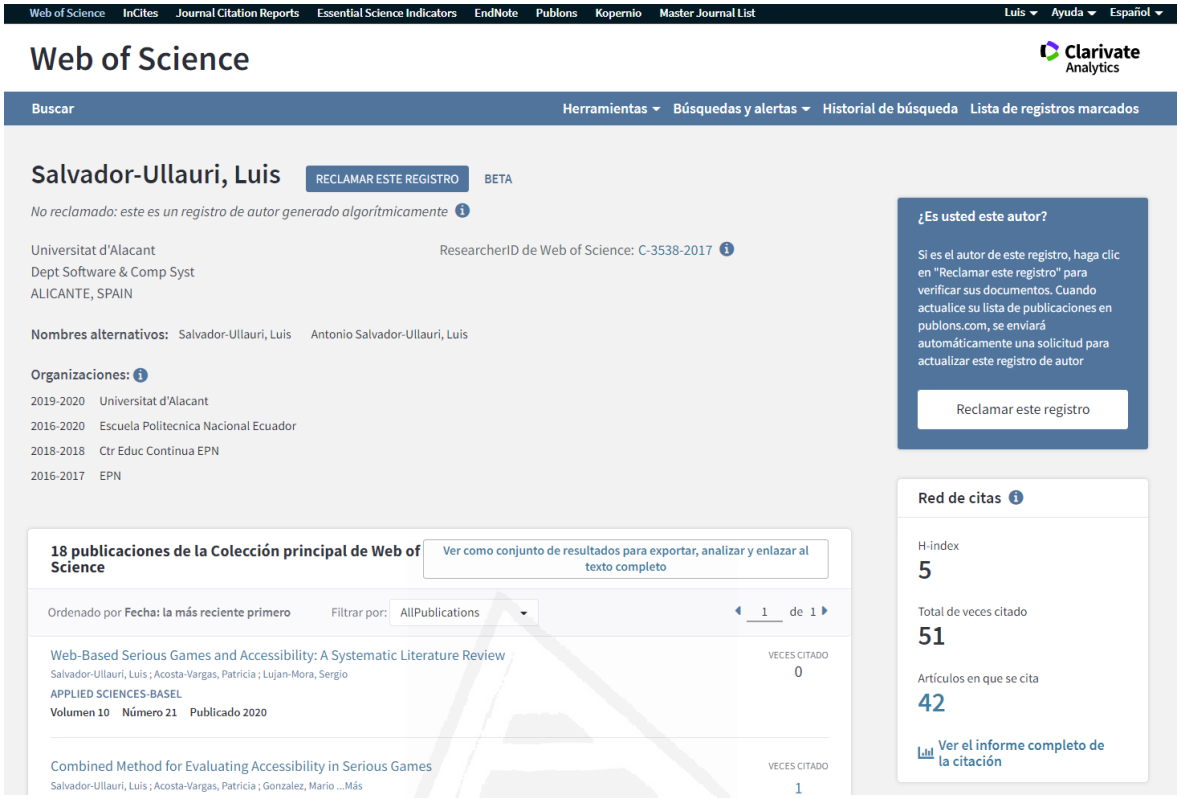
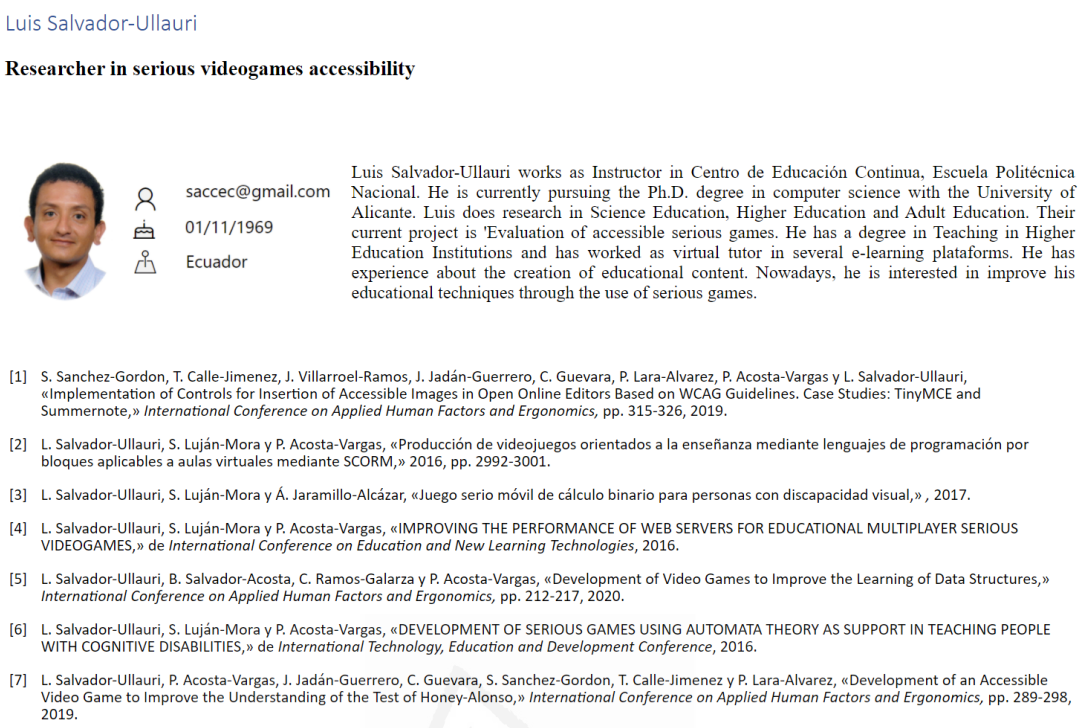


Figura 3.2: Artículos en Web of Science

ID	Perfil académico	URL
P1	ORCID	https://orcid.org/0000-0001-6348-7870
P2	Researcher ID	https://publons.com/researcher/2153760/luis-salvador-ullauri/
P3	Scopus	https://www.scopus.com/authid/detail.uri?authorId=57192689183
P4	Microsoft Academic	https://academic.microsoft.com/author/2477113688/
P5	ResearchGate	https://www.researchgate.net/profile/Luis_Salvador-Ullauri
P6	Google Scholar	https://scholar.google.com/citations?hl=es&user=NMvfwlEAAAAJ

Tabla 3.2: Perfiles académicos

Figura 3.3: Artículos en DBLP



Luis Salvador-Ullauri

Researcher in serious videogames accessibility

saccec@gmail.com

01/11/1969

Ecuador

Luis Salvador-Ullauri works as Instructor in Centro de Educación Continua, Escuela Politécnica Nacional. He is currently pursuing the Ph.D. degree in computer science with the University of Alicante. Luis does research in Science Education, Higher Education and Adult Education. Their current project is 'Evaluation of accessible serious games. He has a degree in Teaching in Higher Education Institutions and has worked as virtual tutor in several e-learning plataforms. He has experience about the creation of educational content. Nowadays, he is interested in improve his educational techniques through the use of serious games.

[1] S. Sanchez-Gordon, T. Calle-Jimenez, J. Villarroel-Ramos, J. Jadán-Guerrero, C. Guevara, P. Lara-Alvarez, P. Acosta-Vargas y L. Salvador-Ullauri, «Implementation of Controls for Insertion of Accessible Images in Open Online Editors Based on WCAG Guidelines. Case Studies: TinyMCE and Summernote,» *International Conference on Applied Human Factors and Ergonomics,* pp. 315-326, 2019.

[2] L. Salvador-Ullauri, S. Luján-Mora y P. Acosta-Vargas, «Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM,» 2016, pp. 2992-3001.

[3] L. Salvador-Ullauri, S. Luján-Mora y Á. Jaramillo-Alcázar, «Juego serio móvil de cálculo binario para personas con discapacidad visual,» , 2017.

[4] L. Salvador-Ullauri, S. Luján-Mora y P. Acosta-Vargas, «IMPROVING THE PERFORMANCE OF WEB SERVERS FOR EDUCATIONAL MULTIPLAYER SERIOUS VIDEOGAMES,» de *International Conference on Education and New Learning Technologies*, 2016.

[5] L. Salvador-Ullauri, B. Salvador-Acosta, C. Ramos-Galarza y P. Acosta-Vargas, «Development of Video Games to Improve the Learning of Data Structures,» *International Conference on Applied Human Factors and Ergonomics,* pp. 212-217, 2020.

[6] L. Salvador-Ullauri, S. Luján-Mora y P. Acosta-Vargas, «DEVELOPMENT OF SERIOUS GAMES USING AUTOMATA THEORY AS SUPPORT IN TEACHING PEOPLE WITH COGNITIVE DISABILITIES,» de *International Technology, Education and Development Conference*, 2016.

[7] L. Salvador-Ullauri, P. Acosta-Vargas, J. Jadán-Guerrero, C. Guevara, S. Sanchez-Gordon, T. Calle-Jimenez y P. Lara-Alvarez, «Development of an Accessible Video Game to Improve the Understanding of the Test of Honey-Alonso,» *International Conference on Applied Human Factors and Ergonomics,* pp. 289-298, 2019.

Figura 3.4: Página personal

3.3. Perfil en Google Académico

La Figura 3.5 presenta una captura de la página de Google Académico en donde se presenta el número de las citas alcanzadas y los respectivos índices.

3.4. Perfil en Researchgate

La Figura 3.6 presenta una captura del perfil en Researchgate.

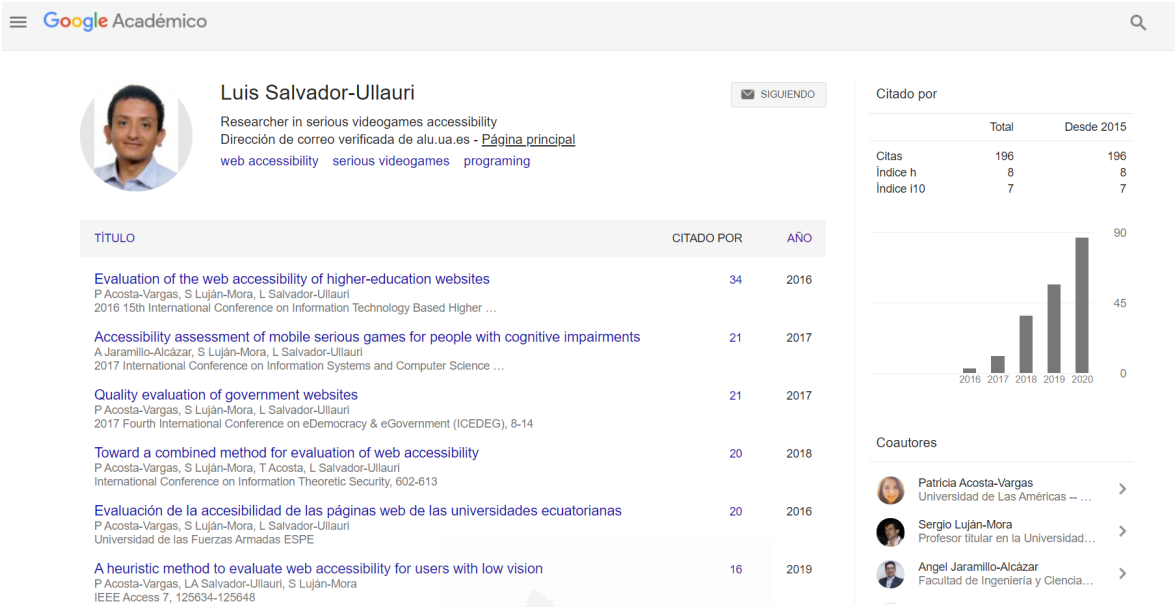


Figura 3.5: Perfil en Google Académico

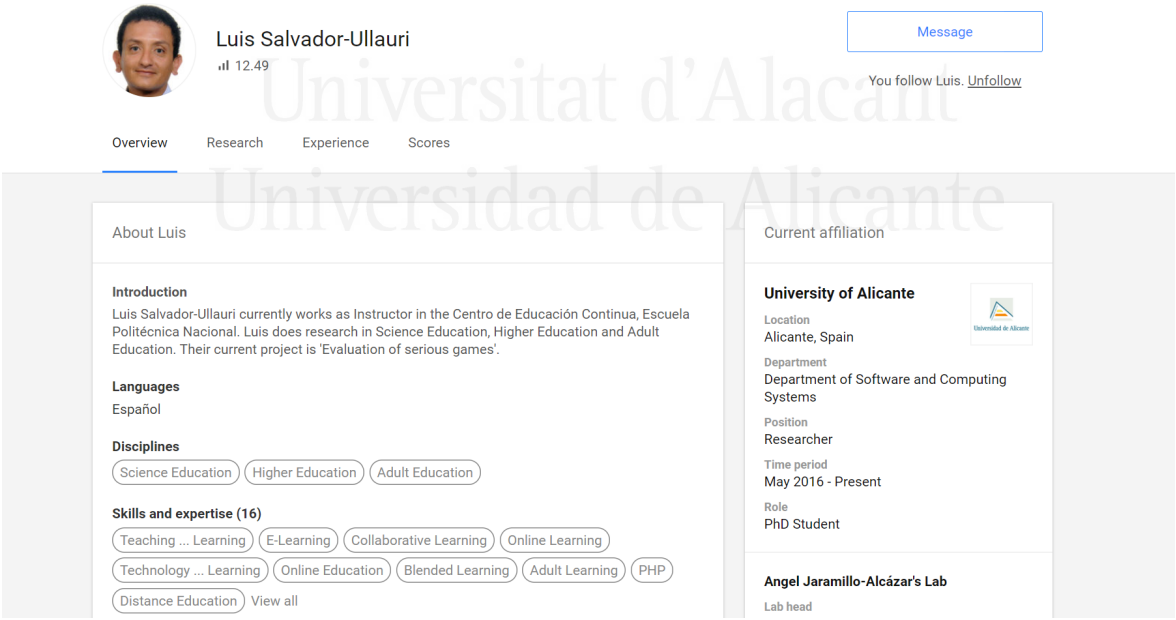


Figura 3.6: Perfil en Researchgate

4 Descripción del trabajo realizado

I wish for a world that views disability,
mental or physical, not as a hindrance but as unique
attributes that can be seen as powerful
assets if given the right opportunities.
Oliver Sacks (Western Washington University, 2019)

4.1. Caracterización del problema

La accesibilidad en los juegos serios (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020) tiene por objeto garantizar que este tipo de juegos puedan ser utilizados por diversidad de personas. En esta investigación sugerimos aplicar los cuatro principios de las WCAG 2.1. Varios estudios (Aguado-Delgado y otros, 2020; Jaramillo-Alcázar y Luján-Mora, 2017) muestran una falta de compromiso por parte de los diseñadores de aplicaciones destinadas a la educación para implementar la métodos de accesibilidad. Por esta razón, existe un bajo porcentaje de juegos serios accesibles. Actualmente, los juegos serios se han incorporado a los procesos de enseñanza-aprendizaje. Por lo tanto, es esencial garantizar la accesibilidad (López y otros, 2016) para que el mayor número de personas puedan usarlos. Los autores Jaramillo-Alcázar y otros (2017) presentan un análisis de las pautas de accesibilidad para el desarrollo de videojuegos; este estudio está orientado a las discapacidades cognitivas. También proponen categorizar las pautas que deben utilizarse para analizar la accesibilidad de los videojuegos, especialmente de los juegos serios. Los autores presentan una herramienta de evaluación para el desarrollo de juegos serios destinados a dispositivos móviles.

Tras el artículo, los autores (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020) indican que es un gran desafío implementar juegos serios para apoyar los procesos de aprendizaje de las personas con discapacidades cognitivas. Los autores evaluaron diez videojuegos serios utilizando los principios de diseño establecidos por las WCAG 2.0 (W3C, 2008). Los resultados revelaron que las aplicaciones no alcanzan un nivel de accesibilidad adecuado para ser utilizadas por personas con problemas cognitivos. Sin

embargo, sí cumplen algunos de los requisitos de accesibilidad.

4.2. Recopilación del estado de la cuestión

Las WCAG 2.1 (W3C, 2018) definen cómo hacer que el contenido del sitio Web sea más accesible para las personas con discapacidades. La accesibilidad incluye discapacidades visuales, auditivas, físicas, del habla, cognitivas, del lenguaje, del aprendizaje y neurológicas. Estas directrices también ayudan a facilitar el acceso a los juegos serios basados en la Web para los adultos mayores con capacidades cambiantes debidas al envejecimiento y, a menudo, facilitan la interacción con los juegos serios y los usuarios.

4.3. Accesibilidad en juegos serios basados en la Web

Según Park y Kim (2013), la accesibilidad en los juegos serios permite garantizar que cualquier usuario, bajo cualquier circunstancia técnica, pueda acceder al contenido mostrado por la aplicación; por esta razón, en esta investigación se aplican los criterios de la WCAG 2.1 (W3C, 2018), específicamente la versión oficial del 5 de junio de 2018, que proporciona recomendaciones para hacer el contenido más accesible. La WCAG 2.1 consiste en 4 principios, 13 directrices y 78 criterios de cumplimiento, e incluye un número indeterminado de técnicas y consejos suficientes. Los cuatro principios son los mismos que los presentados en WCAG 2.0 (W3C, 2008):

- **Principio 1: Perceptible**. Todos los usuarios deben ser capaces de percibir el contenido de forma visual, sonora o táctil.
- **Principio 2: Operable**. Todos los usuarios deben ser capaces de utilizar y navegar por los componentes de la interfaz.
- **Principio 3: Comprensible**. Tanto el contenido como los controles de la interfaz para su gestión deben ser comprensibles para el usuario.
- **Principio 4: Robusto**. Todo el contenido debe ser robusto para ser interpretado de manera fiable por el número más significativo de usuarios con tecnologías actuales y futuras.

Las directrices de la WCAG 2.1 (W3C, 2018) proponen criterios de éxito asociados a uno de los siguientes niveles de cumplimiento: Nivel “A”: Nivel mínimo de accesibilidad, cuando no se alcanza, los usuarios no pueden acceder al contenido de la Web; Nivel “AA”: Nivel intermedio, implica que es difícil para los usuarios acceder al contenido; Nivel “AAA”: Nivel máximo, cuando los usuarios pueden acceder al contenido sin dificultad.

Los autores encontraron varios estudios de accesibilidad en simulaciones interactivas como parte de los juegos serios, que contribuyen a esta investigación. Todos estos trabajos fueron seleccionados teniendo en cuenta el interés de la comunidad científica

de integrar a las personas con discapacidades, en el mundo académico, utilizando las nuevas tecnologías.

Araújo y otros (2017) sostienen que los videojuegos son cada vez más populares pero no son accesibles, lo que representa un desafío importante para los expertos en accesibilidad y los diseñadores de juegos. Los autores presentan un estudio sobre las directrices y recomendaciones existentes en materia de accesibilidad en los videojuegos y proponen 10 recomendaciones de diseño para las personas con discapacidad visual.

Cairns, Power, Barlet, y Haynes (2019) indican que los videojuegos proporcionan una salida cultural en la que se puede incluir a más jugadores e interactuar para realizar actividades de forma equilibrada entre los diferentes usuarios. Este evento es posible si creamos entornos de diseño que ofrezcan oportunidades de inclusión.

Los autores sugieren incluir las pautas con un lenguaje de accesibilidad del juego; proponen 1) incluir una estructura para el vocabulario del juego, 2) capacitar para enfrentar los desafíos del juego, y 3) mejorar la experiencia del jugador. Además, muestran cómo la incorporación de las pautas en el desarrollo de los videojuegos proporciona experiencias accesibles a un número más significativo de usuarios.

Park y Kim (2013) argumentan que la legislación de las pautas de accesibilidad podría garantizar el fácil acceso al contenido de la Web, pero no al contenido de los videojuegos, ya que los contenidos de la Web o de una aplicación móvil consisten en información razonablemente sencilla en comparación con los contenidos de los videojuegos. El contenido del videojuego incluye un número más significativo de 1) personajes, 2) jugadores, 3) conflictos entre ellos, y 4) actualización de un personaje al completar una misión. Por lo tanto, explican que es necesario analizar y clasificar las pautas de accesibilidad para evaluar cada videojuego.

Waki, Fujiyoshi, y Almeida (2015) afirman que, actualmente, la falta de accesibilidad en los juegos digitales impone barreras a las personas con discapacidades. Los autores proponen un proceso para evaluar un conjunto de pautas integradas. Los resultados revelaron que el conjunto de pautas integradas permite determinar la accesibilidad de los juegos digitales y perfeccionar estas pautas.

Westin, Ku, Dupire, y Hamilton (2018) formularon que la accesibilidad en los videojuegos consiste en eliminar las posibles barreras que impiden a las personas con discapacidad acceder a los videojuegos. Los autores comparan los criterios de la WCAG 2.1 con un conjunto de pautas de accesibilidad para los juegos digitales. Comparan 107 directrices para juegos accesibles.

Wilson y Crabb (2018) indican que los videojuegos, en particular los juegos en dispositivos móviles, han evolucionado rápidamente en todo el mundo. Uno de los problemas identificados en este tema es la accesibilidad a la que se enfrentan los usuarios, especialmente si tienen algún tipo de discapacidad. En conclusión, los autores pudieron determinar el conocimiento que tenían los participantes de las pautas de accesibilidad e identificar opiniones sobre la importancia de aplicar las pautas de accesibilidad al crear contenidos para los juegos móviles.

Spyridonis y Daylamani-Zad (2020) argumentan la falta de compromiso de los diseñadores en la aplicación de los criterios de accesibilidad de la WCAG sobre el diseño de juegos serios. Proponen: 1) centrarse en el diseño orientado al usuario, 2) identificar los tipos de usuarios, 3) aplicar los criterios de la WCAG a la mecánica de los juegos

serios, 4) medir la satisfacción del usuario y 5) aplicar métodos mixtos. Los resultados revelan que al aplicar el WCAG, los juegos serios presentaban una solución innovadora y atractiva.

4.4. Método PRISMA utilizado para la revisión sistemática de la literatura

Una RSL es un medio para identificar, analizar, evaluar e interpretar cualquier investigación que sea relevante para una pregunta de investigación, un área o un fenómeno de interés (Kitchenham, 2004). En esta investigación se comparan los artículos relacionados con la accesibilidad en los juegos serios de la Web. Se presenta una RSL (Kitchenham, 2004; Petersen y otros, 2008) que permite examinar la accesibilidad de los juegos serios. Se parte de la siguiente pregunta de investigación: ¿Qué estándares de evaluación de la accesibilidad han sido utilizados por los desarrolladores para crear juegos serios basados en la Web? Este estudio define las cadenas de consulta que permiten encontrar la investigación más significativa relacionada con la accesibilidad en los juegos serios (Aguado-Delgado y otros, 2020). Para determinar la cadena de consulta, se aplica la estructura en términos de población, intervención, comparación y resultado (PICO) (Eriksen y Frandsen, 2018).

Esta RSL permitió: 1) esbozar los problemas relevantes para los juegos serios basados en la Web y los estudios de accesibilidad; 2) identificar cómo la accesibilidad está implicada en los juegos serios; 3) determinar las pautas de accesibilidad basadas en las WCAG, y 4) identificar las tecnologías y dispositivos de asistencia utilizados para lograr la accesibilidad en los juegos serios según la discapacidad. Después de un proceso de extracción de 476 estudios, se seleccionó una colección de 47 estudios primarios utilizando los Elementos de Información Preferidos para Revisiones Sistemáticas (PRISMA) (García-Holgado y García-Peñalvo, 2018; Prisma-Statement, 2015) siguiendo el correspondiente diagrama de flujo en el proceso de selección.

Esta RSL (Kitchenham, 2004; Petersen y otros, 2008) define un protocolo de revisión, la pregunta de investigación y los métodos. Se aplica la declaración de PRISMA, que consiste en una lista de 27 elementos y un diagrama de flujo de cuatro fases. El método PRISMA se utiliza con frecuencia en cuestiones de salud (Moher, Liberati, Tetzlaff, Altman, y Prisma Group, 2009); este método se adapta para identificar estudios relacionados con la accesibilidad y los juegos serios. Se Adjunta una lista de verificación (Apéndice A); en la lista de verificación de PRISMA, se registra el número de página o páginas en las que se puede evidenciar el cumplimiento o incumplimiento de los 27 elementos detallados en las siete secciones: 1) Título, 2) Resumen, 3) Introducción, 4) Métodos, 5) Resultados, 6) Discusión, y 7) Financiación.

El proceso de revisión consta de cinco fases: 1) definición de las preguntas de investigación para revisar el alcance; 2) estrategia de búsqueda para obtener todos los documentos; 3) selección y extracción de los documentos más relevantes; 4) redacción

clave utilizando resúmenes para el esquema de clasificación, y 5) proceso de extracción de datos y revisión para obtener los resultados.

4.4.1. Objetivos y preguntas de la investigación

El primer objetivo de este estudio es presentar información sobre las investigaciones más relevantes sobre los juegos serios publicados en la Web y la accesibilidad. Esta RSL contiene una serie de artículos de las bibliotecas digitales y detalla los autores, el año de publicación y el factor de impacto del Scimago Journal Rank (SJR).

El segundo objetivo es detectar las diferentes aproximaciones a los juegos serios basados en la Web para discapacidades cognitivas, motoras y sensoriales.

El tercer objetivo es identificar las pautas de accesibilidad basadas en WCAG aplicadas a los juegos serios para determinar las tendencias y las lagunas en el desarrollo de los juegos serios.

Las preguntas de investigación se plantean porque los juegos serios han sido ampliamente incorporados en los procesos de enseñanza-aprendizaje (Fuster-Guilló y otros, 2019; Hersh y Leporini, 2018). Debido al aumento de su uso, surge la necesidad de garantizar plenamente su accesibilidad a las personas con discapacidades en los entornos educativos. Este estudio examina los resultados de los trabajos primarios existentes publicados sobre la accesibilidad y los juegos serios, para identificar las tendencias actuales y las cuestiones abiertas en el dominio: las preguntas de investigación y el propósito de cada pregunta.

- **RQ1. ¿Son accesibles los juegos serios basados en la Web que se están desarrollando hoy en día?**-Investigar la accesibilidad de los juegos serios basados en la Web que se han desarrollado desde el año 2000 hasta el presente.
- **RQ2. ¿Cuáles son las propuestas para incrementar la accesibilidad por discapacidad en los juegos serios basados en la Web?**-Identificar las propuestas de accesibilidad por discapacidad que se aplican en los juegos serios basados en la Web.
- **RQ3. ¿Cuáles son las soluciones de accesibilidad por discapacidad para los juegos serios basados en la Web?**- Identificar las soluciones existentes por la discapacidad que se utilizan para lograr la accesibilidad en los juegos serios basados en la Web.
- **RQ4. ¿Qué métodos se aplican en el diseño de juegos serios basados en la Web?**- Clasificar los métodos aplicados en el diseño de juegos serios basados en la Web por discapacidad.
- **RQ5. ¿Qué tipos de investigación y contribuciones se utilizan en los juegos serios basados en la Web y la accesibilidad?**-Identificar los tipos de investigación y contribución utilizados en los juegos serios basados en la Web y la accesibilidad teniendo en cuenta la discapacidad.

4.4.2. Estrategia de búsqueda

Los estudios primarios se identifican mediante una cadena de preguntas derivadas de las preguntas de investigación. Sobre la base de las preguntas de investigación, la PICO (Eriksen y Frandsen, 2018) se aplicó de la siguiente manera:

- Población: estudios publicados.
- Intervención: accesibilidad, juegos serios basados en la Web.
- Comparación: estudios seleccionados por discapacidad, accesibilidad basada en estándares, tipo de investigación, tecnologías de asistencia y uso de dispositivos externos.
- Resultado: estudios sobre accesibilidad y juegos serios basados en la Web.

Establecida la PICO, se creó la cadena de consulta, como se presenta en la Tabla 4.1. La búsqueda se realizó el 6 de junio de 2020, y se seleccionaron cuatro bases de datos de investigación académica utilizadas en ingeniería para recuperar información primaria: 1) ACM Digital Library; 2) IEEE Xplore; 3) Scopus, y 4) Web of Science (WOS).

Las cadenas de consulta para cada fuente elegida se definieron a partir de los términos de búsqueda conectados por los operadores booleanos AND/OR. Además, se utilizó el asterisco (*) como comodín para incluir tanto la forma singular como la plural de cada término. La Tabla 4.1 muestra la base de datos seleccionada, la cadena de consulta y el número de estudios extraídos. La cadena de consulta se aplicó al título de la publicación con las palabras clave: “serious”, “game*” y “accesi*”. Se aplicó una sintaxis de búsqueda similar en las cuatro fuentes seleccionadas para mayor coherencia; el período examinado incluyó estudios publicados entre 2000 y 2020. Se utilizaron cadenas equivalentes para localizar los mismos artículos, pero cada base de datos tiene su sintaxis específica.

4.4.3. Revisión de los documentos

Basándose en las directrices de la revisión de la literatura (Petersen y otros, 2008), la aplicación de los criterios de inclusión y exclusión es esencial para filtrar los resultados. Los criterios de inclusión y exclusión tienen como objetivo obtener estudios primarios relevantes para responder a las preguntas de investigación definidas. Las discrepancias en la selección se resuelven por consenso entre los autores.

- **Criterios de inclusión:** El estudio primario debe estar relacionado con: 1) el tipo de publicación en revistas, conferencias, libros y capítulos de libros, que tratan sobre la accesibilidad en los juegos serios basados en la Web publicados de 2000 a 2020; 2) estudios primarios revisados por pares; 3) escritos en idioma inglés.
- **Criterios de exclusión:** El estudio primario: 1) resume un discurso de apertura, una introducción a un taller o sólo un resumen; 2) duplica artículos del mismo estudio de diferentes fuentes.

Base de datos	Cadena de búsqueda	Estudios
ACM Digital Library	[Publication Title: accessi*] AND [Publication Title: serious] AND [Publication Date: (01/01/2000 TO 05/31/2020)]	92
	[Publication Title: accessi*] AND [Publication Title: game*] AND [Publication Date: (01/01/2000 TO 05/31/2020)]	
IEEE Xplore	(("Document Title":accessi* serious) OR "Document Title":accessi* game*)	25
Scopus	TITLE(accessi*) AND (TITLE(serious) OR TITLE(game*))	190
Web of Science	TI= (accessi* serious) OR TI= (accessi* game*)	169
Total de estudios		**476**

Tabla 4.1: Bases de datos de búsqueda

En esta fase, para describir el proceso, se aplica PRISMA (García-Holgado y García-Peñalvo, 2018; Prisma-Statement, 2015), PRISMA se aplica a todo tipo de revisiones sistemáticas y no se limita a los ensayos clínicos. PRISMA ha sido concebido como una herramienta para ayudar a mejorar la claridad y la transparencia en las revisiones sistemáticas.

El proceso de búsqueda y selección se coloca en un diagrama de flujo; las fases del proceso sirven como guía para el revisor de la literatura. Este proceso incluye: 1) las bases de datos consultadas, indicando el número de documentos obtenidos de cada una de ellas; 2) el número de documentos que están duplicados; 3) el número de documentos eliminados en cada fase del proceso y las razones de la eliminación, y 4) el número de documentos incluidos en el estudio. En la Figura 4.1 se muestra el diagrama de flujo de PRISMA con las cuatro fases del proceso de selección de los artículos, que se describen a continuación:

Fase 1: Identificación. Se incluyen los registros obtenidos de las búsquedas en las bases de datos: ACM con 92 documentos, IEEE Xplore con 25 artículos, Scopus con 190 artículos, y WOS con 169. Se extrajeron un total de 476 artículos.

Fase 2: Revisión. Se aplican los criterios de inclusión y exclusión. De los 476 artículos, 201 artículos fueron excluidos porque estaban duplicados en diferentes bases de datos y 275 artículos fueron incluidos. En el siguiente filtro, se excluyen los estudios escritos en un idioma distinto al inglés, estudios de revisión, resúmenes, talleres y estudios sobre temas distintos a la accesibilidad en los juegos serios; se excluyeron un total de 228 estudios. Finalmente, un total de 47 revisiones pasaron a la siguiente fase.

Fase 3: Elegibilidad. Tres autores se encargaron de realizar una revisión a profundidad del texto completo de los 47 artículos que se centraban explícitamente en estudios primarios sobre accesibilidad y juegos serios basados en la Web; no se exclu-

N°	Preguntas de evaluación de la calidad	Respuesta
QA1	¿Se detalla la accesibilidad de los juegos serios en el artículo?	(+1) Sí/(+0) No
QA2	¿Se especifica en el documento el método de evaluación de la accesibilidad de los juegos serios?	(+1) Sí/(+0) No
QA3	¿Discute el documento algún hallazgo de la evaluación de la accesibilidad de los juegos serios?	(+1) Sí/(+0) No
QA4	¿Están descritos los errores estándar de accesibilidad de los juegos serios dentro de los resultados?	(+1) Sí/(+0) No
QA5	¿La revista o la conferencia en la que se publicó el artículo está indexada en SJR?	(+1) si está clasificado Q1, (+0.75) si está clasificado Q2, (+0.50) si está clasificado Q3, (+0.25) si está clasificado Q4, (+0.0) si no está indexado.

Tabla 4.2: Lista de verificación de la evaluación de la calidad de los artículos

yó ningún artículo de texto completo. Además, se evaluó la calidad de los artículos de investigación que responden a la accesibilidad en los juegos serios; aplicando una "evaluación de calidad" de los artículos seleccionados.

El propósito de esta evaluación de calidad es sopesar la importancia de cada uno de los artículos seleccionados, cuando se discuten los resultados, y orientar la interpretación de las conclusiones (Kitchenham, 2004).

Cada evaluación obtiene una puntuación de uno por el cumplimiento de cada cláusula: 1) ¿Se detalla en el documento la accesibilidad a los juegos serios basados en la Web? 2) ¿Se especifica en el artículo el método de evaluación de la accesibilidad de los juegos basados en la Web? 3) ¿Discute el artículo los resultados de la evaluación de la accesibilidad en los juegos serios basados en la Web? 4) ¿Se describen los problemas de accesibilidad de los juegos serios basados en la Web? 5) ¿Está la revista en la que se publicó el artículo indexada en el SCImago Journal Rank (SJR)? La Tabla 4.2 presenta la lista de control de la evaluación de la calidad.

Fase 4: Incluida. Se registraron 47 artículos en texto completo en la síntesis cuantitativa. La Figura 4.1 muestra que no se ha añadido ningún registro adicional.

4.4.4. Palabras claves y clasificación

Para las palabras clave y la clasificación, se aplicaron los conceptos: 1) Esquema de clasificación, que consiste en un proceso de lectura de resúmenes, búsqueda de palabras clave y conceptos que reflejen la contribución del estudio primario para asegurar que los resultados deseados sean cubiertos en la revisión de la literatura, proporcionando en

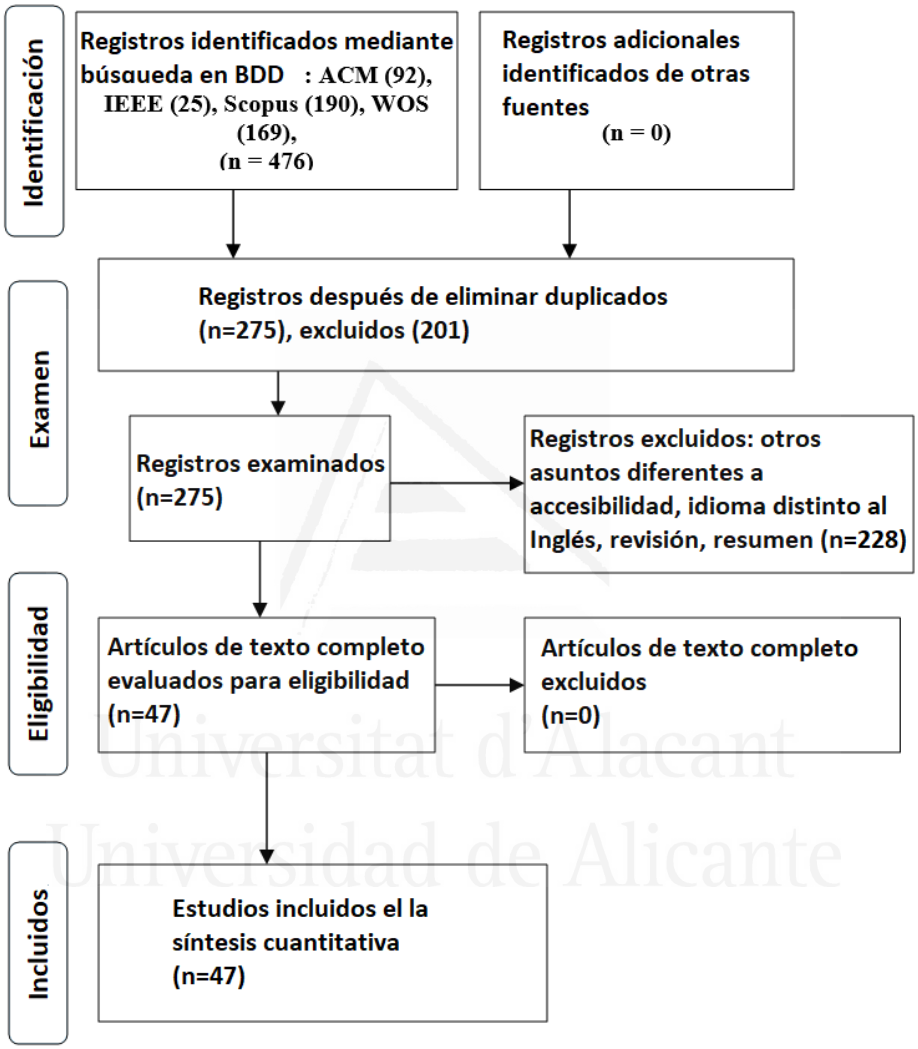


Figura 4.1: Diagrama de flujo PRISMA

la introducción un conjunto de categorías representativas de la población de estudio.

2) Palabras clave que se utilizan para aplicar el esquema de clasificación en el sistema de revisión de la literatura. Se considera la lectura de resúmenes, la búsqueda de palabras clave y el objetivo del estudio relacionado con el contexto.

3) La técnica que permite la clasificación de artículos relevantes para la extracción de datos reales. En esta fase, se utilizan las palabras clave para agrupar y formar categorías. Se revisan todos los documentos seleccionados. Se leen los documentos, se actualizan las categorías, se crea una nueva categoría si el documento revela algo nuevo.

Las palabras clave agrupadas por categorías, y sus frecuencias son:

- Clave1 = Accesibilidad, Evaluación de accesibilidad, Diseño; con 37 de frecuencia.
- Clave2 = Tecnología de asistencia; con 3.
- Clave3 = Computadora, asistida, instrucción; con 10.
- Clave4 = Discapacidad; con 5.
- Clave5 = Juegos, Juego, juegos serios, videojuegos; con 44.
- Clave6 = Pautas, pautas de accesibilidad; con 14.
- Clave7 = Factores humanos, Interacción de los sistemas; con 5.
- Clave8 = Discapacidades de las personas; con 25.
- Clave9 = Discapacidades visuales; con 13.
- Clave10 = Web; con una frecuencia de 6.

4.4.5. Extracción de datos

La extracción de datos iterativa se dividió en varias etapas en las que se llevaron a cabo diferentes actividades. Para extraer la información de la Biblioteca Digital ACM, se exportó al formato BibTeX (BIB). En cambio, la información de IEEE Xplore, Scopus y WOS se exportó en formato Research Information Systems (RIS).

Se importaron los datos de los cuatro archivos a la herramienta StartLapes versión 2.3.4.2 (Budgen, Turner, Brereton, y Kitchenham, 2008), que elimina automáticamente los estudios duplicados. Se aplicó el proceso detallado en el diagrama de flujo de PRISMA. Finalmente, se importaron los datos a una hoja de cálculo de Microsoft Excel para continuar el análisis. La Tabla 4.3 presenta los 47 estudios primarios seleccionados y ordenados por el año de publicación más reciente;contiene el número de artículo, el indicador asignado (se creó con las primeras letras de los apellidos de los dos primeros autores y el año de publicación), el título del artículo, el primer autor con el número de referencia y el año de publicación.

En esta fase, aplicamos la evaluación de calidad a los trabajos seleccionados. La Tabla 4.4 presenta una lista de los trabajos seleccionados, junto con los resultados del control de calidad. Además, se ha creado una columna de normalización para utilizar una escala estándar de 0 a 1.

#	ID	Título	Autores	Año
1	RS20	Be Active! Participatory Design of Accessible Movement-Based Games	Regal G [26]	2020
2	SD20	A Serious Game to Improve Engagement with Web Accessibility Guidelines	Spyridonis F [27]	2020
3	SA20a	Development of an Accessible Video Game to Improve the Understanding of the Test of Honey-Alonso	Salvador-Ullauri L [28]	2020
4	KO20	Game Accessibility and Advocacy for Participation of the Japanese Disability Community	Kaigo M [29]	2020
5	SA20b	Accessibility Evaluation of Video Games for Users with Cognitive Disabilities	Salvador-Ullauri L [20]	2020
6	KT19	A Study on Accessibility in Games for the Visually	Impaired Khaliq I [30]	2019
7	DF19	Startup Workplace, Mobile Games, and Older Adults: A Practical Guide on UX, Usability, and Accessibility Evaluation	De Lima Salgado A [31]	2019
8	OZ19	Accessibility Requirements in Serious Games for Low Vision Children	Othman N [32]	2019
9	CP19a	Future Design of Accessibility in Games: A Design Vocabulary	Cairns P [15]	2019
10	CM19	A Guide for Making Video Games Accessible to Users with Cerebral Palsy	Compañ-Rosique P [33]	2019
11	SD19	A Serious Game for Raising Designer Awareness of Web Accessibility Guidelines	Spyridonis F [34]	2019
12	CP19b	Enabled Players: The Value of Accessible Digital Games	Cairns P [35]	2019
13	MD19	Problem-Based Learning Applied to the Development of Accessible Serious Games	Martins V [36]	2019
14	JG18	Towards an Accessible Mobile Serious Game for Electronic Engineering Students with Hearing Impairments	Jaramillo-Alcázar A [37]	2018
15	KK18	Bonk: Accessible Programming for Accessible Audio Games	Kane S [38]	2018
16	JL18a	Accessibility Assessment of Serious Mobile Games for People with Cognitive Impairments	Jaramillo-Alcázar A [19]	2018
17	JL18b	An Approach to Mobile Serious Games Accessibility Assessment for People with Hearing Impairments	Jaramillo-Alcázar A [39]	2018
18	YC18	Design of a Game Community Based Support System for Cognitive Game Accessibility	Yildiz S [40]	2018
19	WK18	Game Accessibility Guidelines and WCAG 2.0-A Gap Analysis	Westin T [41]	2018
20	WC18	W3C Accessibility Guidelines for Mobile Games	Wilson A [42]	2018

#	ID	Título	Autores	Año
21	LP17a	A Mobile Educational Game Accessible to All, Including Screen Reading Users on a Touch-Screen Device	Leporini B [43]	2017
22	SJ17	A Serious Game Accessible to People with Visual Impairments	Salvador-Ullauri L [44]	2017
23	JL17	Mobile Serious Games: An Accessibility Assessment for People with Visual Impairments	Jaramillo-Alcázar A [17]	2017
24	LP17b	An Inclusive Educational Game Usable via Screen Reader on a Touch-Screen	Leporini B [45]	2017
25	PC17	Game Accessibility Guidelines for People with Sequelae from Macular Chorioretinitis	Pereira A [46]	2017
26	AF17	Mobile Audio Games Accessibility Evaluation for Users Who Are Blind	Araújo M [47]	2017
27	LM16	Interaction in Video Games for People with Impaired Visual Function: Improving Accessibility	López J [18]	2016
28	HS16	Using Video Game Patterns to Raise the Intrinsic Motivation to Conduct Accessibility Evaluations	Henka A [48]	2016
29	DZ15	Accessible Games for Blind Children, Empowered by Binaural Sound	Drossos K [49]	2015
30	WF15	Games Accessibility for Deaf People: Evaluating Integrated Guidelines	Waki A [50]	2015
31	Po14	Understanding and Addressing Real-World Accessibility Issues in Mainstream Video Games	Porter J R [51]	2014
32	MB14	BraillePlay: Educational Smartphone Games for Blind Children	Milne L [52]	2014
33	TS14	Development of a Game Engine for Accessible Web-based Games	Torrente J [53]	2014
34	PK13	Guidelines of Serious Game Accessibility for the Disabled	Park H [54]	2013
35	Ga13	Game Accessibility: Enabling Everyone to Play	Garber L [55]	2013
36	WW13	Return on Investment in Game Accessibility for Cognition Impairments	Westin T [56]	2013
37	MM12	Assessment of Universal Design Principles for Analyzing Computer Games' Accessibility	Mustaquim M [57]	2012
38	TV11	Introducing Accessibility Features in an Educational Game Authoring Tool: The <e-adventure>Experience	Torrente J [58]	2011
39	OM10	Accessibility of a Social Network Game	Ossmann R [59]	2010
40	GS09	Designing Universally Accessible Games	Grammenos D [60]	2009

#	ID	Título	Autores	Año
41	MH08	Accessibility Challenge - a Game Show Investigating the Accessibility of Computer Systems for Disabled People	Morgan M [61]	2008
42	MO08	More than Just a Game: Accessibility in Computer Games	Miesenberger K [62]	2008
43	MP07	Finger Dance: A Sound Game for Blind People	Miller D [63]	2007
44	OM06	Guidelines for the Development of Accessible Computer Games	Ossmann R [64]	2006
45	GS06	Access Invaders: Developing a Universally Accessible Action Game	Grammenos D [65]	2006
46	OA06	Computer Game Accessibility: From Specific Games to Accessible Games	Ossmann R [66]	2006
47	CL03	The TiM Game Engine: Development of Computer Games Accessible to Blind and Partially Sighted Children	Callaos N [67]	2003

Tabla 4.3: Lista de artículos seleccionados para la revisión

Se ha utilizado la normalización (Jain y Bha, 2011), que preserva la relación entre los valores de los datos originales. Los valores de esta columna se transforman mediante el uso de la ecuación 4.1

$$Normalizacion = \frac{Valor - min(Valor)}{max(Valor) - min(Valor)} \tag{4.1}$$

Donde el min(Valor) es igual a 0, el max(Valor) es igual a 5, y el Valor es el valor calculado en la Tabla 4.4

4.5. Método combinado para la evaluación de la accesibilidad en juegos serios

En esta investigación, se propone la aplicación de un método combinado para evaluar la accesibilidad en los juegos serios, considerando las Pautas de Accesibilidad al Contenido en la Web (WCAG) 2.1. Como caso de estudio, se evalúa la accesibilidad en 82 juegos serios desarrollados por el proyecto PhET (Interactive Simulations, 2019). La evaluación comenzó el 19 de enero de 2020 y terminó el 20 de junio de 2020. En el estudio participaron dos evaluadores expertos en accesibilidad, que tenían experiencia desde 2015 y han aportado varios artículos en la materia. Cuando se presetaron discrepancias en la evaluación, se solicitó la colaboración de un tercer experto. En este estudio, el método combinado incluye la aplicación de dos herramientas automáticas y la evaluación manual. El método de evaluación se resume en los ocho pasos que se

		Evaluación de la calidad						
ID	**Nombre de la publicación**	**QA1**	**QA2**	**QA3**	**QA4**	**QA5**	**Valor**	**Normalización**
RS20	International Conference on Tangible, Embedded, and Embodied Interaction	1	1	1	1	0	4	0.8
SD20	Behaviour Information Technology	1	1	1	1	0.75	4.75	0.95
SA20a	International Conference on Applied Human Factors and Ergonomics	1	1	1	1	0.5	4.5	0.9
KO20	Information	1	1	1	1	0.5	4.5	0.9
SA20b	International Conference on Intelligent Human Systems Integration	1	1	1	1	0.5	4.5	0.9
KT19	International Conference on Smart Objects and Technologies for Social Good	1	1	1	1	0	4	0.8
DF19	International Conference on Smart Objects and Technologies for Social Good	1	1	1	1	0	4	0.8
OZ19	International Conference on the Design of Communication	1	1	1	1	0	4	0.8
CP19a	International Journal of Human Computer Studies	1	1	1	1	1	5	1
CM19	Universal Access in the Information Society	1	1	1	1	0.75	4.75	0.95
SD19	Conference on Human-Computer Interaction	1	1	1	1	0	4	0.8
CP19b	Games and Culture	1	1	1	1	1	5	1
MD19	Iberian Conference on Information Systems and Technologies	1	1	1	1	0.5	4.5	0.9
JG18	World Engineering Education Conference	1	1	1	1	0	4	0.8
KK18	Conference on Interaction Design and Children	1	1	1	1	0	4	0.8
JL18a	International Conference on Information Systems and Computer Science	1	1	1	1	0	4	0.8

		Evaluación de la calidad						
ID	**Nombre de la publicación**	**QA1**	**QA2**	**QA3**	**QA4**	**QA5**	**Valor**	**Normalización**
JL18b	International Conference on Information Theoretic Security	1	1	1	1	0.5	4.5	0.9
YC18	International Conference on ArtsIT	1	1	1	1	0.25	4.25	0.85
WK18	International Conference on Computers Helping People with Special Needs	1	1	1	1	0.75	4.75	0.95
WC18	The Computer Games Journal	1	1	1	1	0	4	0.8
LP17a	World Conference on Mobile and Contextual Learning	1	1	1	1	0	4	0.8
SJ17	International Conference on Education Technology and Computers	1	1	1	1	0	4	0.8
JL17	International Conference on Technological Ecosystems for Enhancing Multiculturality	1	1	1	1	0	4	0.8
LP17b	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
PC17	Entertainment Computing	1	1	1	1	0.75	4.75	0.95
AF17	International Conference on Universal Access in Human-Computer Interaction	1	1	1	1	0	4	0.8
LM16	International Conference on Human Computer Interaction	1	1	1	1	0	4	0.8
HS16	International Conference on Applied Human Factors and Ergonomics	1	1	1	1	0.5	4.5	0.9
DZ15	International Conference on PErvasive Technologies Related to Assistive Environments	1	1	1	1	0	4	0.8
WF15	International Conference on Universal Access in Human-Computer Interaction	1	1	1	1	0	4	0.8

		Evaluación de calidad						
ID	**Nombre de la publicación**	**QA1**	**QA2**	**QA3**	**QA4**	**QA5**	**Valor**	**Normalización**
Po14	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
MB14	International ACM SIGACCESS Conference on Computers Accessibility	1	1	1	1	0	4	0.8
TS14	International Conference on Games and Learning Alliance	1	1	1	1	0.75	4.75	0.95
PK13	International Conference on Information Science and Applications	1	1	1	1	0	4	0.8
Ga13	Computer	1	1	1	1	1	5	1
WW13	European Conference of the Association for the Advancement of Assistive Technology in Europe	1	1	1	1	0	4	0.8
MM12	International Conference on Computers for Handicapped Persons	1	1	1	1	0.75	4.75	0.95
TV11	International Conference on Advanced Learning Technologies	1	1	1	1	0	4	0.8
OM10	International Conference on Computers for Handicapped Persons	1	1	1	1	0.75	4.75	0.95
GS09	Computers in Entertainment	1	1	1	1	0.5	4.5	0.9
MH08	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
MO08	Symposium of the Austrian HCI and usability engineering group	1	1	1	1	0	4	0.8
MP07	International ACM SIGACCESS Conference on Computers and Accessibility	1	1	1	1	0	4	0.8
OM06	International Conference on Computers for Handicapped Persons	1	1	1	1	0	4	0.8

		Evaluación de calidad						
ID	**Nombre de la publicación**	**QA1**	**QA2**	**QA3**	**QA4**	**QA5**	**Valor**	**Normalización**
GS06	International Conference on Computers for Handicapped Persons	1	1	1	1	0	4	0.8
OA06	International Conference on Computer Games (CGAMES)	1	1	1	1	0	4	0.8
CL03	World Multiconference on Systemics, Cybernetics and Informatics	1	1	1	1	0	4	0.8

Tabla 4.4: Lista de artículos seleccionados y resultados de la evaluación de la calidad.

muestran en la Figura 4.2.

Figura 4.2: Método combinado para evaluar la accesibilidad en juegos serios

Fase 1: Seleccionar los juegos serios. En esta fase, se seleccionan los juegos serios

del proyecto PhET. Para seleccionar el tamaño de la muestra, se aplica la ecuación 4.2

$$n = \frac{NZ^2PQ}{(N-1)E^2 + Z^2PQ} \tag{4.2}$$

Donde n es el tamaño de la muestra a calcular, N es el tamaño del universo, en este caso, 87 juegos serios, con un nivel de confianza del 97 %, donde Z corresponde a 2.17, con un margen de error E = 0.03. Aplicando la fórmula, se obtuvo el valor de 82, que es el número de juegos serios, seleccionados secuencialmente, y evaluados en esta investigación por los dos expertos en accesibilidad.

La Tabla 4.5 contiene los juegos serios evaluados, incluyendo la identificación de cada juego y el nombre de los juegos serios dentro de cada URL. La URL completa se construye añadiendo al principio de cada dirección https://phet.colorado.edu/sims/html/. Por ejemplo, la dirección completa del primer juego serio es:

https://phet.colorado.edu/sims/html/acid-base-solutions/latest/acid-base-solutions_es.html.

Fase 2: Definir el tipo de usuario. Dos expertos en accesibilidad de aplicaciones de software llevan a cabo la evaluación de los juegos serios. Este estudio utilizó los critrios de la WCAG 2.1 para los usuarios con baja visión (Moreno, Valencia, Pérez, y Arrue, 2018). Según la World Health Organization [WHO] (2019), la ceguera y la deficiencia visual afectan al menos a 2,200 millones de personas en todo el mundo. De ellas, 1,000 millones tienen una deficiencia visual evitable o que aún no se ha abordado. La reducción de la visión puede tener efectos duraderos en diversos aspectos de la vida, y con el aumento de la edad, las personas mayores tienden a disminuir su capacidad visual relacionada con la presbicia (Bourne y otros, 2017)

Basándose en estas definiciones, los expertos en accesibilidad evaluaron los juegos serios aplicando los criterior de la WCAG 2.1 para identificar las barreras de accesibilidad. Los expertos tienen experiencia en la evaluación de aplicaciones móviles, accesibilidad Web y accesibilidad de recursos educativos desde 2015 y han publicado varios artículos en revistas de alto impacto relacionados con el tema.

Fase 3: Definir el escenario de prueba. En esta fase, se definen los escenarios para navegar e interactuar en juegos serios y alcanzar la meta. La tarea es: 1) entrar en los juegos serios, 2) revisar la funcionalidad de cada juego serio, y 3) comprobar si existen barreras que impidan la accesibilidad para los juegos serios. En este estudio de caso, una barrera de accesibilidad para una persona con baja visión (Brajnik, 2008) significa que la persona no puede moverse efectivamente de un punto a otro dentro de los juegos serios debido a problemas de agudeza visual.

Fase 4: Explorar cada juego serio para evaluarlo. En la cuarta fase, el usuario explora y se familiariza con los mecanismos de interacción de los juegos serios. En esta fase, los evaluadores identifican: 1) las funcionalidades de los juegos serios; 2) si el contenido es ajustable con el zoom y la apariencia del juego; y 3) el cambio de comportamiento según el dispositivo, el contexto y la configuración aplicada.

Fase 5: Listar las barreras basadas en WCAG. Esta fase es esencial, pues se enumeran las barreras relacionadas con los criterios de la WCAG 2.1 para la evaluación de los juegos serios. Las barreras se muestran en la Tabla 4.6, que contiene 29 directrices

ID	URL	Materia
1aci	acid-base-solutions/1.2.24/ acid-base-solutions_es.html	Química
2are	area-builder/1.1.20/ area-builder_es.html	Matemáticas
3are	area-model-algebra/1.2.1/ area-model-algebra_es.html	Matemáticas
4are	area-model-decimals/1.2.1/ area-model-decimals_es.html	Matemáticas
5are	area-model-introduction/1.2.1/ area-model-introduction_es.html	Matemáticas
6ari	area-model-multiplication/1.2.1/ area-model-multiplication_es.html	Matemáticas
7ato	arithmetic/1.0.24/ arithmetic_es.html	Matemáticas
8bal	atomic-interactions/1.1.0/ atomic-interactions_es.html	Química
9bal	balancing-act/1.1.24/ balancing-act_es.html	Matemáticas
10bal	balancing-chemical-equations/1.2.10/ balancing-chemical-equations_es.html	Química
11bee	balloons-and-static-electricity/1.4.14/ balloons-and-static-electricity_es.html	Ciencias de la Tierra
12ben	beers-law-lab/1.4.18/ beers-law-lab_es.html	Física
13bla	bending-light/1.1.20/ bending-light_es.html	Física
14bui	blackbody-spectrum/1.0.7/ blackbody-spectrum_es.html	Ciencias de la Tierra
15bui	build-a-fraction/1.0.12/ build-a-fraction_es.html	Matemáticas
16cap	build-an-atom/1.6.14/ build-an-atom_es.html	Física
17cha	capacitor-lab-basics/1.6.19/ capacitor-lab-basics_es.html	Física
18cir	charges-and-fields/1.0.47/ charges-and-fields_es.html	Física
19cir	circuit-construction-kit-dc/1.1.5/ circuit-construction-kit-dc_es.html	Física
20col	circuit-construction-kit-dc-virtual-lab/1.1.5/ circuit-construction-kit-dc-virtual-lab_es.html	Física

ID	URL	Materia
21con	color-vision/1.1.23/ color-vision_es.html	Biología
22cou	concentration/1.3.20/ concentration_es.html	Física
23cur	curve-fitting/1.0.0/ curve-fitting_es.html	Matemáticas
24dif	coulombs-law/1.0.9/ coulombs-law_es.html	Física
25ene	diffusion/1.0.4/ diffusion_es.html	Ciencias de la Tierra
26ene	energy-forms-and-changes/1.0.11/ energy-forms-and-changes_es.html	Física
27equ	energy-skate-park-basics/1.1.19/ energy-skate-park-basics_es.html	Física
28equ	equality-explorer/1.0.12/ equality-explorer_es.html	Matemáticas
29equ	equality-explorer-basics/1.0.12/ equality-explorer-basics_es.html	Matemáticas
30exp	equality-explorer-two-variables/1.0.12/ equality-explorer-two-variables_es.html	Matemáticas
31far	expression-exchange/1.1.14/ expression-exchange_es.html	Matemáticas
32for	faradays-law/1.1.23/ faradays-law_es.html	Física
33fra	forces-and-motion-basics/2.3.16/ forces-and-motion-basics_es.html	Física
34fra	fractions-equality/1.1.1/ fractions-equality_es.html	Matemáticas
35fra	fraction-matcher/1.2.1/ fraction-matcher_es.html	Matemáticas
36fra	fractions-intro/1.0.12/ fractions-intro_es.html	Matemáticas
37fri	fractions-mixed-numbers/1.0.12/ fractions-mixed-numbers_es.html	Matemáticas
38fun	friction/1.5.10/ friction_es.html	Física
39fun	function-builder/1.0.23/ function-builder_es.html	Matemáticas
40gas	function-builder-basics/1.0.14/ function-builder-basics_es.html	Matemáticas

ID	URL	Materia
41gas	gases-intro/1.0.5/ gases-intro_es.html	Ciencias de la Tierra
42gen	gas-properties/1.0.4/ gas-properties_es.html	Ciencias de la Tierra
43gra	gene-expression-essentials/1.0.16/ gene-expression-essentials_es.html	Biología
44gra	graphing-lines/1.3.10/ graphing-lines_es.html	Matemáticas
45gra	graphing-quadratics/1.1.5/ graphing-quadratics_es.html	Matemáticas
46gra	graphing-slope-intercept/1.1.9/ graphing-slope-intercept_es.html	Matemáticas
47gra	gravity-and-orbits/1.1.15/ gravity-and-orbits_es.html	Física
48gra	gravity-force-lab/2.2.0/ gravity-force-lab_es.html	Física
49hoo	gravity-force-lab-basics/1.0.0/ gravity-force-lab-basics_es.html	Física
50iso	hookes-law/1.0.23/ hookes-law_es.html	Química
51joh	isotopes-and-atomic-mass/1.1.9/ isotopes-and-atomic-mass_es.html	Química
52lea	john-travoltage/1.5.12/ john-travoltage_es.html	Física
53mak	least-squares-regression/1.1.20/ least-squares-regression_es.html	Matemáticas
54mas	make-a-ten/1.0.16/ make-a-ten_es.html	Matemáticas
55mas	masses-and-springs/1.0.10/ masses-and-springs_es.html	Matemáticas
56mol	masses-and-springs-basics/1.0.9/ masses-and-springs-basics_es.html	Física
57mol	molarity/1.5.1/ molarity_es.html	Química
58mol	molecules-and-light/1.4.14/ molecules-and-light_es.html	Ciencias de la Tierra
59mol	molecule-shapes/1.2.8/ molecule-shapes_es.html	Química
60mol	molecule-shapes-basics/1.2.8/ molecule-shapes-basics_es.html	Química

ID	URL	Materia
61neu	neuron/1.1.18/ neuron_es.html	Biología
62ohm	ohms-law/1.4.7/ ohms-law_es.html	Matemáticas
63pen	pendulum-lab/1.0.15/ pendulum-lab_es.html	Matemáticas
64ph	ph-scale/1.3.4/ ph-scale_es.html	Ciencias de la Tierra
65ph	ph-scale-basics/1.3.4/ ph-scale-basics_es.html	Biología
66pli	plinko-probability/1.1.18/ plinko-probability_es.html	Matemáticas
67pro	projectile-motion/1.0.15/ projectile-motion_es.html	Matemáticas
68pro	proportion-playground/1.0.15/ proportion-playground_es.html	Matemáticas
69rea	reactants-products-and-leftovers/1.2.11/ reactants-products-and-leftovers_es.html	Química
70res	resistance-in-a-wire/1.6.9/ resistance-in-a-wire_es.html	Matemáticas
71rut	rutherford-scattering/1.1.9/ rutherford-scattering_es.html	Química
72sta	states-of-matter-basics/1.1.8/ states-of-matter-basics_es.html	Física
73sta	states-of-matter/1.1.10/ states-of-matter_es.html	Física
74tri	trig-tour/1.0.22/ trig-tour_es.html	Matemáticas
75und	under-pressure/1.1.18/ under-pressure_es.html	Ciencias de la Tierra
76uni	unit-rates/1.0.17/ unit-rates_es.html	Matemáticas
77vec	vector-addition/1.0.0/ vector-addition_es.html	Matemáticas
78vec	vector-addition-equations/1.0.0/ vector-addition-equations_es.html	Matemáticas
79wav	wave-interference/2.0.2/ wave-interference_es.html	Ciencias de la Tierra
80wav	waves-intro/1.0.2/ waves-intro_es.html	Ciencias de la Tierra

ID	URL	Materia
81wav	wave-on-a-string/1.1.22/ wave-on-a-string_es.html	Ciencias de la Tierra
82bui	build-a-molecule/latest/ build-a-molecule_en.html	Química

Tabla 4.5: Juegos serios seleccionados para la evaluación.

consideradas en la evaluación manual de cada juego serio. La Tabla 4.6 muestra la pauta, la barrera, el principio de la WCAG 2.1, los criterios de éxito y el nivel.

Fase 6: Evaluar con herramientas automáticas y en forma manual. En esta fase, se evaluan los 82 juegos serios detallados en la Tabla 4.5. Se aplica una evaluación combinada usando dos herramientas automáticas: 1) Analizador de Contraste de Colores (CCA), versión 3.0.1 (The Paciello Group, 2020), una herramienta utilizada para analizar algunos criterios de la WCAG 2.1 estableciendo los colores de entrada del texto simple. También permite el soporte de la transparencia alfa en los colores de primer plano, incluye un simulador de daltonismo.

Esta herramienta permite tomar una muestra de los colores del primer y segundo plano para medir el contraste con el que se emite un informe con WCAG 2.1. 2) La Herramienta de Análisis de Epilepsia Fotosensible (PEAT), versión 1.6 (University of Maryland, 2016), permite evaluar en juegos o animaciones serias si el contenido presenta parpadeos o transiciones rápidas entre colores de fondo claros y oscuros que pueden generar convulsiones fotosensibles causadas por ciertos tipos de parpadeos en juegos serios, incluyendo los que se realizan con el ratón, que hacen que grandes áreas de la pantalla se enciendan y apaguen rápidamente. La herramienta aplica algunos de los criterios de WCAG 2.1 y 2.2, incluyendo restricciones relacionadas con la frecuencia, la luminancia, el área y el color de cualquier parpadeo. Antes de analizar los juegos serios con PEAT, los juegos se transforman en formato Audio Video Interleave (.AVI) usando un programa de procesamiento por lotes para tomar una muestra del video.

Fase 7: Registrar los datos de evaluación. En esta fase, se presenta el registro de los datos obtenidos de la evaluación de la accesibilidad de los juegos serios con las herramientas CCA y PEAT; el conjunto de datos de evaluación (Acosta-Vargas y Salvador-Ullauri, 2020)[1]. Los códigos asignados a cada columna, corresponden a los criterios de éxito del WCAG, donde C1 = 1.4.3 Contraste (Mínimo) AA, Texto Regular, C2 = 1.4.3 Contraste (Mínimo) AA, Texto Grande, C3 = 1.4.6 Contraste (Mejorado) AA, Texto Regular, C4 = 1. 4.6 Contraste (Mejorado) AAA, Texto Grande, C5 = 1.4.11 Contraste sin texto AA (Reajuste de botones), C6 = 1.4.11 Contraste sin texto AA (Otros), P1 = Estado, P2 = Fallos de flash de luminosidad, P3 = Fallos de flash rojo, P4 = Alertas de flash extendido. El número uno (1) indica que se ha superado la barrera, y el número cero (0) indica que no se ha superado.

En la Figura 4.3 se presentan los datos registrados en la evaluación manual de los juegos serios con WCAG 2.1, contiene el identificador asignado a cada juego serio con las 29 pautas. Se asigna el valor de uno (1) si se supera la barrera y el cero (0) cuando

[1] https://data.mendeley.com/datasets/t2tr35ww4c/5

Lineamiento	Barrera	WCAG 2.1	Criterio de éxito	Nivel
G01	Teclado accesible	Operable	2.1.1	A
G02	Fallos de destellos de luminicencia	Operable	2.3.1	A
G03	Animación desde interacciones	Operable	2.3.3	AAA
G04	Contenido resalta al enfocar	Perceptible	1.4.13	AA
G05	Letra fácil de leer	Perceptible	1.1.1	A
G06	Texto alternativo	Perceptible	1.1.1	A
G07	Subtítulos	Perceptible	1.2.4	AA
G08	Transcripciones automáticas	Perceptible	1.2.5	AA
G09	Lenguaje de señas	Perceptible	1.2.6	AAA
G10	Información y relaciones	Perceptible	1.3.1	A
G11	Características sensoriales	Perceptible	1.3.1	A
G12	Ajustes de configuración de pantalla	Perceptible	1.3.4	AA
G13	Reordenamiento de la interfaz	Perceptible	1.3.5	AA
G14	Uso de color	Perceptible	1.4.1	A
G15	Contraste sin texto	Perceptible	1.4.11	AA
G16	Elementos bien espaciados	Perceptible	1.4.12	A
G17	Buenas técnicas de audio	Perceptible	1.4.2	A
G18	Contraste (Mínimo)	Perceptible	1.4.3	AA
G19	Imágenes nítidas	Perceptible	1.4.5	AA
G20	Presentación visual	Perceptible	1.4.8	AAA
G21	Pausar, detener y esconder	Perceptible	2.2.2	A
G22	Contraste (Mejorado)	Perceptible	1.4.6	AAA
G23	Soporte de lector de pantalla	Robusto	4.1.2	A
G24	Mensajes de estado	Robusto	4.1.3	AA
G25	Idioma	Comprensible	3.1.1	A
G26	Navegación consistente	Comprensible	3.2.3	AA
G27	Etiquetas o instrucciones	Comprensible	3.3.2	A
G28	Ayuda	Comprensible	3.3.5	AAA
G29	Enfoque	Comprensible	3.2.1	A

Tabla 4.6: Lineamientos para evaluación de la accesibilidad en juegos serios

no se ha superado la barrera. En la Figura 4.3 el color más oscuro representa que la barrera fue superada y el color más claro que la barrera no fue superada.

Fase 8: Clasificar y analizar los datos. En esta fase se clasifican los datos de los juegos serios, considerando los cuatro principios de accesibilidad Web propuestos en WCAG 2.1. Se agrupan los datos obtenidos con las herramientas automáticas CCA y PEAT, con las que se analiza el contraste y la fotosensibilidad que afecta a los usuarios con epilepsia. Los datos obtenidos en la evaluación manual se agrupan para mostrar la presencia de cada uno de los principios de accesibilidad, los criterios de éxito y el nivel de accesibilidad. Este proceso lleva mucho tiempo y por lo tanto es muy exigente. Los datos registrados y el análisis están disponibles en Mendeley[2] para que la evaluación pueda ser reproducida (Acosta-Vargas y Salvador-Ullauri, 2020).

Finalmente, se analizan los resultados con herramientas de evaluación automáticas y manuales. Aplicando estadística descriptiva a los datos de evaluación, se tiene que el valor medio es 3.9, el error estándar es 0.21; la mediana es 5.0, la moda es 5.0, la desviación estándar es 1.9, la varianza de la muestra es 3.64, el valor mínimo es 1.0, el máximo es 7.0. La Figura 4.4 muestra la evaluación realizada con las herramientas CCA y PEAT.

Se encuentra que 24 juegos serios están en el rango de evaluación de 1 a 2.5 respecto al cumplimiento de los parámetros de contraste y fotosensibilidad evaluados, 10 juegos serios se encuentran de 2.5 a 4, los siguientes 30 de 4 a 5.5, y 18 juegos serios se encuentran de 5.5 a 7 puntos. De los datos de la Tabla 4.7, se encontró que los 82 juegos serios pasaron la prueba de fotosensibilidad.

La Tabla 4.7 muestra un resumen de la evaluación manual de 82 juegos serios; contiene la pauta, la barrera, el principio de accesibilidad, los criterios de éxito, el nivel, el total de juegos que superan la barrera y el porcentaje de juegos serios evaluados que superan la barrerta de accesibilidad. Se encontró que los 82 juegos serios cumplen con las siguientes pautas: 1) G05 relacionado con la fuente de fácil lectura, 2) G16 relacionado con los elementos bien espaciados, 3) G25 relacionado con el lenguaje, 4) G26 relacionado con la navegación consistente. La Figura 4.5 muestra el porcentaje de cumplimiento de los principios de accesibilidad de los 82 juegos serios evaluados. Se enecuentra que el principio perceptible se cumple en el 54.4 % del total de juegos serios evaluados, el comprensible registra el 27.4 % de cumplimiento, el operable registra el 18.2 %, y el robusto registra el 0.0 %. Se puede concluir que, en la evaluación de la accesibilidad de los 82 juegos serios, el principio más transgredido es el robusto.

4.6. Método heurístico para la evaluación de la accesibilidad en juegos serios

En la revisión de la literatura realizada en esta investigación, no se encontró ningún método de revisión automática o heurística aplicada a los juegos serios, por lo que tomó como partida la información existente sobre la evaluación heurística de la accesibilidad para sitios Web. Se encontarón los siguientes estudios.

[2] https://data.mendeley.com/datasets/t2tr35ww4c/5

Figura 4.3: Resultados de la evaluación manual de los juegos serios

Lineamiento	Barrera	WCAG 2.1 (Principio)	Criterio de éxito	Nivel	Total	%
G01	Teclado accesible	Operable	2.1.1	A	8	1.3
G02	Fallos de destellos de luminicencia	Operable	2.3.1	A	81	13
G03	Animación desde interacciones	Operable	2.3.3	AAA	27	4.2
G04	Contenido resalta al enfocar	Perceptible	1.4.13	AA	6	0.9
G05	Letra fácil de leer	Perceptible	1.1.1	A	82	13
G06	Texto alternativo	Perceptible	1.1.1	A	1	0.2
G07	Subtítulos	Perceptible	1.2.4	AA	0	0
G08	Transcripciones automáticas	Perceptible	1.2.5	AA	0	0
G09	Lenguaje de señas	Perceptible	1.2.6	AAA	0	0
G10	Información y relaciones	Perceptible	1.3.1	A	0	0
G11	Características sensoriales	Perceptible	1.3.1	A	0	0
G12	Ajustes de configuración de pantalla	Perceptible	1.3.4	AA	0	0
G13	Reordenamiento de la interfaz	Perceptible	1.3.5	AA	0	0
G14	Uso de color	Perceptible	1.4.1	A	32	5
G15	Contraste sin texto	Perceptible	1.4.11	AA	2	0.3
G16	Elementos bien espaciados	Perceptible	1.4.12	A	82	13
G17	Buenas técnicas de audio	Perceptible	1.4.2	A	20	3.1
G18	Contraste (Mínimo)	Perceptible	1.4.3	AA	62	9.7
G19	mágenes nítidas	Perceptible	1.4.5	AA	2	0.3
G20	Presentación visual	Perceptible	1.4.8	AAA	12	1.9
G21	Pausar, detener y esconder	Perceptible	2.2.2	A	27	4.2
G22	Contraste (Mejorado)	Perceptible	1.4.6	AAA	20	3.1
G23	Soporte de lector de pantalla	Robusto	4.1.2	A	0	0
G24	Mensajes de estado	Robusto	4.1.3	AA	0	0
G25	Idioma	Comprensible	3.1.1	A	82	13
G26	Navegación consistente	Comprensible	3.2.3	AA	82	13
G27	Etiquetas o instrucciones	Comprensible	3.3.2	A	5	0.8
G28	Ayuda	Comprensible	3.3.5	AAA	0	0
G29	Enfoque	Comprensible	3.2.1	A	6	0.9

Tabla 4.7: Resumen de la evaluación de la accesibilidad con el método manual

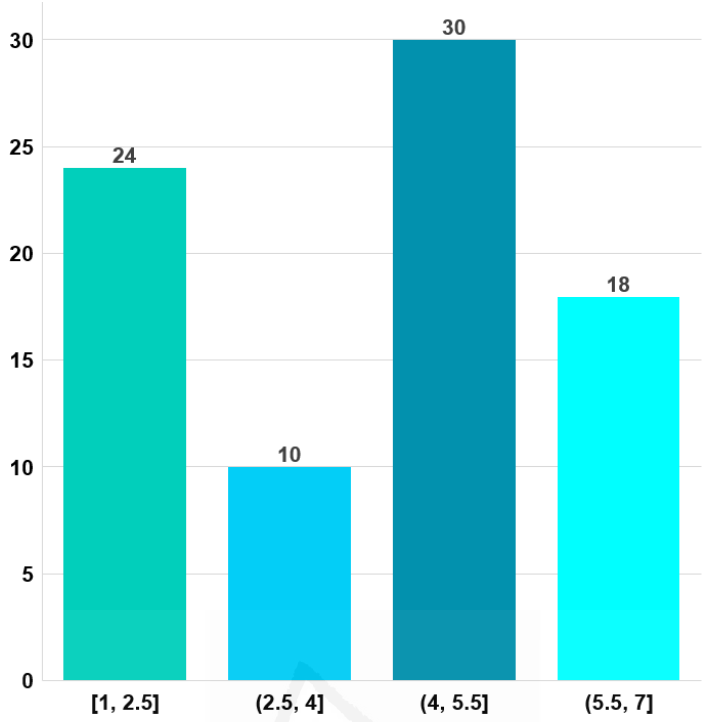


Figura 4.4: Evaluación de los juegos serios con CCA y PEAT

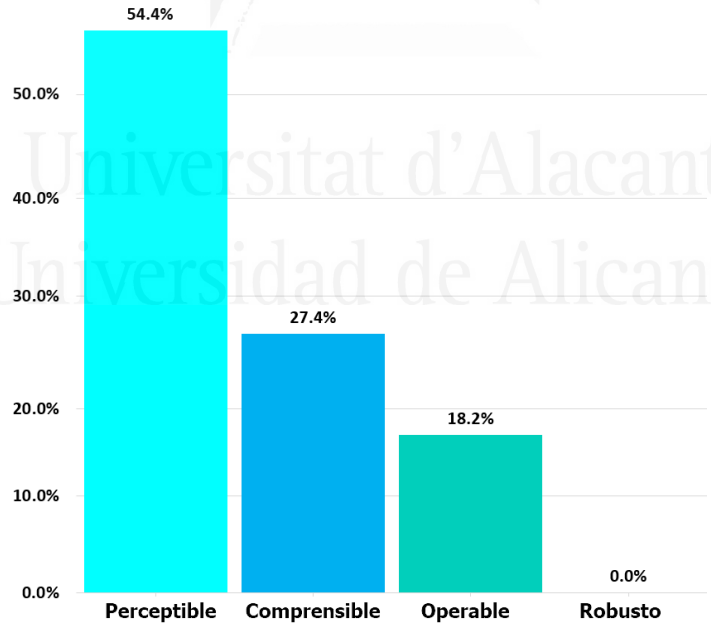


Figura 4.5: Criterios de éxitos de las WCAG en la evaluación manual de los juegos serios

Los autores Paddison y Englefield (2004) argumentan que los métodos heurísticos

de accesibilidad se crean como complemento de las pautas de accesibilidad. Además, la heurística permite a los evaluadores identificar, las secciones de una aplicación que tienen problemas de accesibilidad, de forma efectiva. Los resultados revelaron que el uso de los métodos heurísticos de accesibilidad, puede localizar un rango más amplio de barreras de accesibilidad. Sin embargo, los métodos heurísticos no proporcionan a los evaluadores información de conformidad, por lo que los estudios heurísticos no sustituyen a la experiencia del usuario.

Brajnik (2008) argumenta que los métodos de evaluación de la accesibilidad ayudan a mejorar la accesibilidad centrada en el usuario. El autor señala que los métodos de evaluación de la accesibilidad pueden encontrar problemas de accesibilidad, por ejemplo, infracciones de las pautas, modos de fallo, defectos de implementación. Un método de evaluación puede indicar cómo clasificar y calificar los temas en condiciones de gravedad y prioridad.

Se presenta un análisis de varios métodos de evaluación, uno de los cuales es el método *Barrier Walkthrough* (BW), que tiene las siguientes ventajas: baja complicación, permite validar los conocimientos, provee de una mejor corrección que el examen de conformidad, y produce índices de gravedad. Un estudio de los autores Braga, Pereira, Ferreira, y Da Silveira (2014), sostiene que es fundamental determinar si las interfaces son accesibles, lo que requiere una evaluación de accesibilidad. Una evaluación que utiliza herramientas automatizadas, no es suficiente; ya que es necesario realizar pruebas en humanos por expertos y usuarios con discapacidades. Los autores presentan un estudio para evaluar la accesibilidad y las barreras presentes en una aplicación para el Banco de Brasil empleando el método BW, que registra y define una secuencia de barreras que son susceptibles de clasificación por parte del usuario. El objetivo de este estudio es examinar si este enfoque puede ser tratado como un complemento de la evaluación automática cuando no se pueden hacer observaciones que involucren a usuarios reales. El método permitió una evaluación rápida y oportuna, disminuyendo la complicación de la evaluación. Con el estudio sugerido se detectaron problemas de usabilidad asociados con la accesibilidad, con lo cual se presentaron algunas sugerencias.

Los autores Lunn, Yesilada, y Harper (2009) sostienen que las metodologías de evaluación de accesibilidad suponen que deben cumplirse todas las directrices establecidas, para lograr la accesibilidad universal. Los autores señalan que el enfoque de BW aborda los problemas de la aplicación de las directrices sobre diversos grupos de usuarios. El proceso permite a los evaluadores determinar la gravedad de la barrera que se inspecciona. Se establece que las barreras pueden combinarse con el método BW para evaluar el impacto de una aplicación en los usuarios.

En un estudio anterior, los autores Acosta-Vargas, Salvador-Ullauri, y Luján-Mora (2019) indican que existen métodos cualitativos y cuantitativos para comprobar si una aplicación es accesible. Los autores presentan una modificación del método BW ofrecida por Giorgio Brajnik basada en las WCAG 2.1. El cambio consiste en incorporar la persistencia para determinar la gravedad de una barrera de accesibilidad. Con el proceso utilizado en el experimento, los evaluadores encontraron que el método permite: 1) medir la accesibilidad de las aplicaciones; 2) probar un proceso heurístico; 3) ayudar en las evaluaciones manuales, y 4) contribuir a los estudios asociados con la heurística de la accesibilidad.

Por tanto, el método heurístico basado en el método BW sugerido en los estudios (Brajnik, 2006, 2008; Brajnik, Yesilada, y Harper, 2011) puede ayudar a complementar la evaluación de la accesibilidad en los juegos serios. El método heurístico es un método sistemático basado en pruebas e inspecciones de errores en el que un evaluador piensa en algunas barreras potenciales de accesibilidad que corresponden a los principios de accesibilidad de las WCAG 2.1. Las barreras incorporan características según el tipo de usuario, el propósito, la perspectiva de uso y el sitio de los juegos serios para sacar conclusiones apropiadas relacionadas con la eficacia, la productividad, la satisfacción y la seguridad (Brajnik, 2006, 2008), con puntuaciones de severidad designadas a cada barrera de accesibilidad. En este estudio, las barreras se definen conforme a los siguientes parámetros: 1) La efectividad indica el grado de cumplimiento para lograr el objetivo del usuario con precisión; 2) La productividad se asocia con el tiempo, el esfuerzo y la carga cognitiva como prerrequisito para lograr un nivel específico de efectividad; 3) La satisfacción caracteriza la satisfacción y la aceptación por parte del usuario; implica la capacidad de aclimatación, y 4) La seguridad, representa la debilidad establecida en el juego serio evaluado. El método BW (Brajnik, 2006; Brajnik y otros, 2011) es una técnica de inspección de la accesibilidad creada a partir de principios de accesibilidad diseñados, teniendo en cuenta el grupo de usuarios, el tipo de tecnología de asistencia, la influencia de los usuarios, los tipos de juegos serios y los efectos causados. Sears (1997) considera que las técnicas de evaluación basadas en la inspección son estándar, ya que implican una instrucción menos formal. Aplica un método que combina evaluaciones heurísticas orientadas a las tareas que son fáciles de comprender y utilizar. Sears recomienda métodos para comprobar la autenticidad y la coherencia de las técnicas de evaluación. Los resultados de las evaluaciones heurísticas permiten identificar problemas más significativos que en las revisiones cognitivas. La severidad de una barrera, según el método BW (Brajnik, 2006; Brajnik y otros, 2011), está relacionada con las características físicas y cognitivas del usuario y el contexto en el que se realizan las actividades; de esta manera, es posible llegar a conclusiones con eficacia, productividad, satisfacción y seguridad, para lograr los parámetros de severidad aplicables. Este método recomienda utilizar dos factores para evaluar la severidad de una barrera: 1) el impacto de la barrera en la satisfacción y productividad del usuario, y 2) la persistencia con la que la barrera está presente (Brajnik y otros, 2011). El método BW establece que el evaluador puede medir la gravedad de la barrera en una escala entre uno (1) y tres (3), en la que el valor de uno (1) corresponde a un "problema menor", lo que implica que el usuario puede superar y evitar la barrera (Brajnik, 2006; Brajnik y Lomuscio, 2007).

4.7. Validación de resultados

En esta sección, se responden a las preguntas de la investigación sobre:

1. Un análisis bibliométrico con el objeto de recopilar información sobre los autores, datos de publicación del crecimiento de la investigación a lo largo del tiempo, revistas, conferencias, libros y capítulos de libros publicados, sobre la temática de juegos serios y accesibilidad.

2. Una revisión de la literatura para mapear los estudios según los conceptos de los juegos serios y las cinco preguntas de investigación.

4.7.1. Análisis bibliométrico

La Figura 4.6 muestra la evolución de la producción científica, presentando el número de documentos cada año. Los años de mayor producción científica en accesibilidad en los juegos serios son 2018 y 2019. Se encuentran ocho documentos para 2019, lo que corresponde al 17 %, siete documentos para 2018, lo que corresponde al 14.9 %. En 2017, se encuentran seis artículos, lo que corresponde al 12.8 %. En 2020, se encuentran cinco documentos, lo que corresponde al 10.6 %.

Se espera que este número aumente debido a esta aprecición se realizó hasta julio de 2020. En 2006, 2013 y 2014, hubo tres documentos cada año que suman 19.1 %. En 2008, 2015 y 2016, hubo dos documentos cada año que suman 12.8 %. Finalmente, en 2003, 2007, 2009, 2010, 2011 y 2012, hubo un documento que sumó 12.8 % cada año. La tasa de crecimiento anual de las publicaciones sigue la ecuación polinómica 4.3.

$$Y = 0{,}0216x^2 - 0{,}1639x + 0{,}6421 \tag{4.3}$$

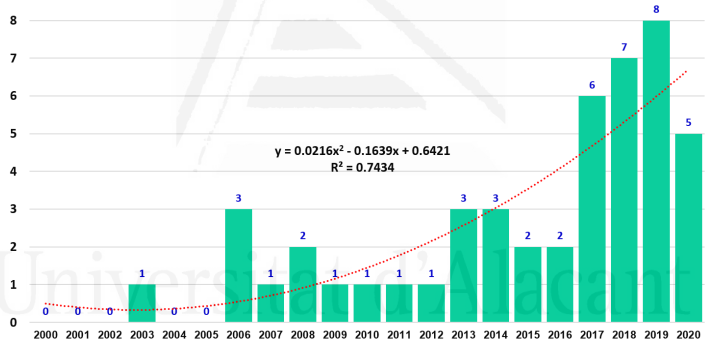


Figura 4.6: Documentos publicados de 2000 a 2020

La Figura 4.7 presenta 35 estudios de conferencias que representan el 74.5 % y 12 artículos de revistas que representan el 25.5 % del total. En esta revisión de literatura, el número más significativo de estudios encontrados se concentran en conferencias. El mayor número de documentos están indexados en Scopus.

4.7.2. Revisión de los estudios relacionados

En esta sección, se presenta un esquema de clasificación utilizando palabras clave; se realizaron las siguientes actividades: 1) se leyeron los resúmenes de 47 estudios primarios seleccionados y se buscaron palabras clave; 2) se leyeron las secciones de introducción y conclusión de cada uno de los estudios primarios elegidos para elaborar el esquema de clasificación; 3) se presentó la clasificación en cinco aspectos. La definición de los aspectos es la siguiente:

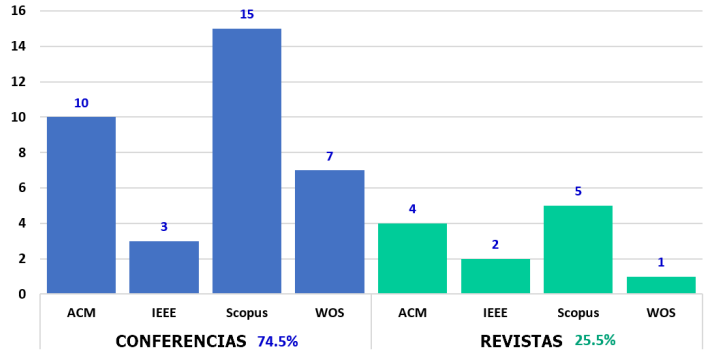


Figura 4.7: Documentos por tipo de publicación

1. Las pautas de accesibilidad para discapacitados, cuyo objetivo es proporcionar un estándar de fácil acceso a los juegos serios que satisfaga las necesidades de cada individuo en particular.

2. Las soluciones aplicadas que implican los métodos utilizados para hacer accesibles los juegos serios.

3. Las pautas de accesibilidad para discapacitados que proporcionan información para el juego serio.

4. Los tipos de contribuciones de la discapacidad (Statista, 2020) incluyendo el estudio formal, el método, el sistema o la experiencia, y

5. El tipo de investigación que incluye la validación, la solución, la evaluación, la retroalimentación y la experiencia (Petersen y otros, 2008).

Luego, se presentaron y discutieron las respuestas a las preguntas de investigación formuladas en este estudio; el conjunto de datos y el análisis están disponibles para su replicación en el repositorio de Mendeley (Acosta-Vargas y Salvador-Ullauri, 2020).

RQ1. ¿Son accesibles los juegos serios que se están desarrollando hoy en día? En esta investigación, se han seleccionado los estudios primarios que aplican la accesibilidad a los juegos serios basados en la Web. La Web tiene numerosas limitaciones, pero si el diseño se considera accesible a todas las personas, incluyendo a aquellas que presentan algún tipo de discapacidad, la aplicación será más inclusiva para muchos usuarios. La Tabla 4.8 presenta los principales estudios relacionados con accesibilidad de acuerdo a cada tipo de discapacidad.

En la revisión de los documentos se aplicaron las siguientes definiciones:

- **La discapacidad cognitiva o intelectual** es un problema que se caracteriza por un retraso en el desarrollo mental que interrumpe el proceso de aprendizaje.

- **La coordinación motriz, o la discapacidad física** es un problema relacionado con un deterioro significativo de una o más partes de las capacidades de movimiento del cuerpo.

Tipo de discapacidad	Identificador
Cognitiva (11 estudios)	CL03, CM19, HS16, JL18a, LP17a, MD19, OM06, SA20a, SA20b, WW13, YC18
Coordinación motora (3 estudios)	KO20, DF19, SD19
Sensorial: deficiencias de visión, audición (33 estudios)	JL17, JG18, RS20, SD20, KT19, OZ19, CP19a, CP19b, KK18, JL18b, WK18, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, Ga13, MM12, TV11, OM10, GS09, MH08, MO08, MP07, GS06, OA06

Tabla 4.8: Estudios por discapacidad

- **La discapacidad Sensorial**, este tipo de discapacidad está relacionada con: 1) la visión, que incluye a los usuarios con baja visión y sordera; 2) la discapacidad auditiva, que proporciona sordera y pérdida de audición.

Según los datos de la Tabla 4.8 se encontraron 33 estudios primarios sobre la discapacidad sensorial que representan el 72 % y 11 estudios aplican la accesibilidad para la discapacidad cognitiva con el 22 % del total. Finalmente, tres estudios sobre coordinación motora que corresponden al 6 % del total.

RQ2. ¿Cuáles son las propuestas para aumentar la accesibilidad en los juegos serios? La Tabla 4.9 presenta las propuestas para incrementar la accesibilidad por tipo de discapacidad; en la revisión de documentos, se aplican las siguientes definiciones:

- WCAG 2.0: incluye los estudios primarios que aplicaron las Pautas de Accesibilidad al Contenido en la Web con la versión 2.0 para aumentar la accesibilidad en los juegos serios.
- WCAG 2.1: incluye los estudios primarios que aplicaron las Pautas de Accesibilidad al Contenido en la Web con la versión 2.1 para aumentar la accesibilidad a los juegos serios. Los criterios de las WCAG 2.1 son el mecanismo más avanzado y aceptado para crear contenido accesible, y no se limitan exclusivamente al contenido Web (W3C, 2018).
- Otras pautas contienen los estudios primarios que ayudan a aumentar la accesibilidad en los juegos serios aplicando las pautas sin especificar el estándar.
- Dispositivos externos: contiene los estudios primarios que ayudan a aumentar la accesibilidad utilizando algún tipo de apoyo adecuado a las características motoras, cognitivas y sensoriales de las personas. Los dispositivos externos facilitan el acceso a los juegos serios, y en ellos está incluido el uso de tecnología de asistencia.

RQ3. ¿Cuáles son las soluciones de accesibilidad propuestas para los juegos serios? La Tabla 4.10 presenta siete soluciones de accesibilidad para juegos serios por discapacidad;

Lineamientos	Cognitiva	Coordinación motora	Sensorial (deficiencias de visión, audición)
WCAG 2.0 (7 estudios)	SA20a.		SD20, CP19a, WK18, AF17, WF15, PK13.
WCAG 2.1 (2 estudios)	SA20b.		WC18.
Otros lineamientos (24 estudios)	CL03, CM19, LP17a, MD19, OM06.	KO20, DF19, SD19.	JG18, RS20, KT19, OZ19, CP19b, KK18, PC17, DZ15, MB14, MM12, TV11, GS09, MH08, MP07, GS06, OA06.
Dispositivos externos (14 estudios)	HS16, JL18a, WW13, YC18.		JL17, JL18b, SJ17, LP17b, LM16, Po14, TS14, Ga13, OM10, MO08.

Tabla 4.9: Lineamientos por discapacidad.

contiene el tipo de solución aplicada y referencias; en la revisión de los documentos se utilizan las siguientes definiciones:

- Pautas de accesibilidad: contiene los estudios primarios que dan soluciones a los problemas de accesibilidad aplicando alguna norma o estándar.
- Requisitos de accesibilidad: incluye estudios primarios que brindan soluciones a los problemas de accesibilidad, sugiriendo examinar el estado de los juegos serios.
- Tecnologías de asistencia contiene estudios en los que se aplican tecnologías de asistencia para lograr la accesibilidad en juegos serios.
- Juego paralelo: cuenta con estudios primarios en los que dan soluciones de accesibilidad aplicando el juego paralelo, universos paralelos o realidades alternativas que mejoran la experiencia sacando al jugador de la realidad a la que está acostumbrado ayudándole a mejorar su concentración.
- Dispositivos externos: contienen estudios de adaptación de dispositivos externos para brindar soluciones de accesibilidad para juegos serios.
- Juegos de empresas: incluyen estudios primarios donde la accesibilidad depende de los estándares de la empresa que desarrolla juegos serios.

- Diseño creativo: contiene estudios donde la aplicación de diseño innovador aborda algunos de los problemas de accesibilidad. La solución por tipo de discapacidad tiene: 1) 22 estudios y corresponde al 46.8 % del total, consta de pautas de accesibilidad; 2) aplica dispositivos externos con 14 revisiones primarias, lo que corresponde al 29.8 % del total; 3) la solución propuesta consiste en requisitos de accesibilidad, con cuatro estudios que representan el 8.5 %; 4) la propuesta de aplicación del diseño creativo, con tres estudios primarios, representa el 6.4 %; 5) la aplicación del concepto de juego paralelo con dos estudios, que representan el 4.3 %; 6) la aplicación de tecnologías asistenciales, tiene un estudio, correspondiente al 2.1 %; (7) la interacción con juegos de empresas, con una reseña, que representa el 2.1 % del total.

Solución	**Cognitiva**	**Coordinación motora**	**Sensorial (deficiencias de visión, audición)**
Lineamientos de accesibilidad (22 estudios)	SA20a, SA20b, MD19, LP17a, CL03.	DF19, SD19.	JG18, KT19, CP19b, WK18, WC18, PC17, DZ15, WF15, MB14, PK13, MM12, TV11, MH08, MP07, OA06.
Requerimientos de accesibilidad (4 estudios)	CM19		OZ19, CP19a, AF17.
Aplicación de tecnologías de asistencia (1 estudio)	OM06		
Aplicación del concepto de juego paralelo (2 estudios)			GS09, GS06.
Aplicación de dispositivos externos (14 studies)	JL18a, YC18, HS16, WW13.		JL17, JL18b, SJ17, LP17b, LM16, Po14, TS14, Ga13, OM10, MO08.
Juegos de empresa (1 estudio)		KO20	
Diseño creativo (3 estudios)			RS20, SD20, KK18.

Tabla 4.10: Solución de accesibilidad por tipo de discapacidad.

RQ4. ¿Qué métodos se aplican en el diseño de juegos serios? La Tabla 4.11 presenta un resumen de los métodos por discapacidad aplicados en el diseño de juegos serios con las referencias de los estudios seleccionados; en la revisión de los documentos, se utilizaron las siguientes definiciones:

- Cualitativo: el método cualitativo es inductivo y sigue un diseño flexible, y los registros se realizan mediante narración, observación participante y entrevistas no estructuradas. Este método se manifiesta en los hechos, procesos, observaciones, estudios de caso, entrevistas, análisis y las opiniones de los autores son muy subjetivas porque no hay medición de los elementos. Este método incluye estudios a pequeña escala, enfatiza la validez de la investigación a través de la proximidad a la realidad empírica y no suele probar teorías o hipótesis. La base de este método es la intuición; en general, no permite análisis estadístico.
- Cuantitativo: El método cuantitativo produce datos numéricos, lo que permite recopilar y analizar los datos. En este método, la objetividad es la forma de llegar al conocimiento; usa específicos y medidas controladas, buscando certeza. Incluye estudios descriptivos bajo la concepción objetiva a través de una estrategia deductiva. Este método contiene estudios que aplican mixtos métodos y encuestas para la recopilación de datos.

Método	**Cognitiva**	**Coordinación motora**	**Sensorial (deficiencias de visión, audición)**
Cualitativo (41 estudio)	OM06, SA20b, CM19, MD19, JL18a, YC18, LP17a, WW13, CL03.	KO20, DF19, SD19.	JL17, JG18, RS20, KT19, CP19a, KK18, JL18b, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, Ga13, MM12, TV11, OM10, GS09, MH08, MO08, MP07, GS06, OA06.
Cuantitativo (6 estudios)	SA20a, HS16		SD20, OZ19, CP19b, WK18.

Tabla 4.11: Métodos aplicados al diseño de juegos serios por discapacidad.

La Tabla 4.11 contiene: 1) 41 estudios que aplican el método cualitativo, lo que representa el 87.2 %, 2) seis estudios utilizan el enfoque cuantitativo, lo que corresponde al 12.8 % del total.

RQ5. ¿Qué tipo de investigación y contribución se utilizan en accesibilidad en juegos serios? Para responder a esta pregunta, se revisaron los documentos según el tipo de investigación por discapacidad, como se muestra en la Tabla 4.12.

A continuación de listan las definiciones que fueron aplicadas en el proceso de revisión de los artículos (Petersen y otros, 2008):

- Investigación de evaluación: proporciona la solución implementada e investiga un problema práctico, aplica prueba de matemáticas, encuesta, estudio de caso, experimento de campo para validar la afirmación del conocimiento.

Tipos de investigación	**Cognitiva**	**Coordinación motora**	**Sensorial (deficiencias de visión, audición)**
Investigación de evaluación (2 estudios)			CP19b, WK18.
Experiencia (37 estudios)	OM06, SA20b, CM19, MD19, JL18a, YC18, LP17a, WW13, CL03.	DF19, SD19.	JL17, JG18, RS20, SD20, KT19, OZ19, CP19a, KK18, JL18b, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, TV11, OM10, GS09, MP07, GS06.
Documento de opinión (5 estudios)			Ga13, MM12, MH08, MO08, OA06.
Propuesta de solución (1 estudio)	SA20a.		
Investigación de validación (2 estudios)	HS16.	KO20.	

Tabla 4.12: Estudios según el tipo de investigación por discapacidad.

- Experiencia: contiene estudios de caso, proyectos o informes sobre experiencias, proporciona lecciones aprendidas.
- Documento de opinión: proporciona la opinión del autor sobre el procedimiento a seguir o la forma cómo se debe hacer algo.
- Propuesta de solución: ofrece una técnica novedosa, o al menos una mejora relevante sobre un procedimiento definido en otras investigaciones.
- Investigación de validación: presenta técnicas investigadas que aún no se han implementado en la práctica y son novedosas. Es metodológicamente sólido y completo, incluye experimentos, creación de prototipos, pruebas de propiedades y uso de simulaciones.

Se encontró: 1) 37 estudios aplican "Experiencia", lo que representa el 78.7 % del total. 2) Cinco estudios involucran "Papel de opinión" con un 10.6 %. 3) Dos estudios utilizan "Investigación de evaluación" correspondiente al 4.3 %. 4) Dos estudios utilizan "Investigación de validación" con un 4.3 %. 5) Un estudio que aplica una "propuesta de solución" que representa el 2.1 % del total.

4.8. Tipos de discapacidad

La World Health Organization [WHO] (2016), define a la discapacidad como un término general que abarca las deficiencias, las limitaciones de la actividad y las restricciones de la participación. La discapacidad es vista como algo complejo que refleja una interacción entre las características de la asociación humana y las peculiaridades de la sociedad en la que existe. Las deficiencias en particular, se refieren a las dificultades que afectan a una estructura corporal. Todas las personas cuentan con una serie de habilidades sensoriales que les permiten interactuar adecuadamente y de diferente manera con el mundo que les rodea. Sin embargo, algunos individuos se han visto afectados por la disminución parcial o total de uno o varios de sus sentidos. De allí, que se entienda como discapacidad la situación en las que un sujeto ve limitada su participación en algún ámbito debido a una deficiencia intelectual o sensorial. Esto implica la existencia de una limitación como consecuencia del mal funcionamiento del organismo del individuo en comparación con otras personas o en comparación de un estado anterior a la presencia de esta limitación; lo cual afecta especialmente a la participación social del sujeto dentro de su comunidad.

Para facilitar la clasificación de las discapacidades, se ha definido la Clasificación Internacional de Funcionamiento, Discapacidad y Salud (CIF) (World Health Organization [WHO], 2001). La CIF, es una clasificación de los componentes de salud del funcionamiento y la discapacidad. La CIF tiene dos partes, cada una está integrada por dos componentes:

- **Parte 1. Funcionamiento y Discapacidad**
- Funciones y Estructuras Corporales

- Actividades y Participación
- **Parte 2. Factores Contextuales**
- Factores Ambientales
- Factores Personales.

Las funciones corporales son las funciones fisiológicas de los sistemas corporales (incluyendo funciones psicológicas). La discapacidad está definida como el resultado de una compleja relación entre la condición de salud de una persona, sus factores personales, y los factores externos que representan las circunstancias en las que vive esa persona. A causa de esta relación, los distintos ambientes pueden tener efectos distintos en un individuo con una condición de salud. Un entorno con barreras, o sin facilitadores, restringirá el desempeño del individuo; mientras que otros entornos que sean más facilitadores pueden incrementarlo. La sociedad puede dificultar el desempeño de un individuo tanto porque cree barreras o porque no proporcione elementos facilitadores.

Es así, como los factores ambientales influyen directamente en el desenvolvimiento de las actividades de todas las personas. Los factores ambientales constituyen el ambiente físico, social y actitudinal en el que las personas viven y conducen sus vidas La CIF reconoce las siguientes como funciones corporales utilizadas para indicar la magnitud de una deficiencia:

- Funciones mentales
- Funciones sensoriales y dolor
- Funciones de la voz y el habla
- Funciones de los sistemas cardiovascular, hematológico, inmunológico y respiratorio
- Funciones de los sistemas digestivo, metabólico y endocrino
- Funciones genitourinarias y reproductoras
- Funciones neuromusculoesqueléticas y relacionadas con el movimiento
- Funciones de la piel y estructuras relacionadas

Las aplicaciones Web y particularmente los videojuegos educativos presentan una serie de barreras de accesibilidad que afectan especialmente a las funciones sensoriales y mentales de los individuos. Por eso, esta investigación pone especial interés en los siguiente tipos de discapacidades:

- Discapacidad Física o motora.- tiene relación con la disminución o perdida de la capacidad de un individuo para mover con libertad su cuerpo o parte de él.
- Discapacidad sensorial visual.- tiene relación con la disminución o perdida de la capacidad de percibir mediante la vista las imágenes de los objetos del entorno en el que se encuentra el sujeto.

- Discapacidad sensorial auditiva.- tiene relación con la disminución o ausencia total de la capacidad que tiene un sujeto de percibir los sonidos de su entorno.

- Discapacidad intelectual.-tiene relación con la disminución de la capacidad intelectual de un individuo en niveles inferiores a 70 medido dentro de un coeficiente intelectual. Este tipo de discapacidad afecta al sujeto especialmente en su participación social y académica.

Las causas de la discapacidad pueden ser muy variadas, pero se agrupan en congénitas o adquiridas. Dentro de las causas adquiridas gran parte de ellas se deben al aumento de enfermedades crónicas y al envejecimiento de la población. Entre 1990 y 2013, se realizó un estudio para determinar cuáles eran las principales causas de discapacidad en el mundo (IHME, Human Development Network, The World Bank, 2013). Este estudio fue realizado por el Instituto para la Medición y Evaluación de la Salud (IHME por sus siglas en inglés), en Seattle. El estudio fue realizado a 187 países en todos los continentes con el objeto de identificar los tipos de enfermedades, dolores o causas externas que causan discapacidad en sus habitantes.

Según el estudio, más del 95 % de las personas en el mundo sufren de algún problema en su salud. Allí se demuestra que, aunque las tasas de mortalidad disminuyen, las personas se enferman debido a enfermedades no mortales. La depresión, lidera la lista de las principales causas de discapacidad en el mundo. El dolor lumbar se perfila como la segunda causa más importante. De la misma manera existen varios factores que inciden sobre la adquisición de enfermedades. Entre esos factores están el género, la edad e incluso el nivel de educación de las personas. Existe un predominio de personas de género masculino que presenta discapacidad. Es así como en edades superiores a los 64 años los hombres presentan mayor probabilidad de adquirir alguna enfermedad que les provoque algún tipo de discapacidad. El nivel de educación también influye, pues las personas con mayor nivel de educación son menos propensas a enfermarse.

Un estudio realizado por la OMS (Gore y otros, 2011) revela que los trastornos mentales representan 45 % de los problemas causantes de discapacidad entre jóvenes de 10 y 24 años, por encima de accidentes de tráfico y de enfermedades infecciosas y parasitarias, como malaria y VIH. Se estima que para el año 2030 la depresión será la principal causa de discapacidad en todo el mundo, sin importar niveles socioeconómicos, países, creencias o culturas. Se calcula que afecta a más de 300 millones de personas en todo el mundo.

Algunos de los síntomas de la depresión son la disminución o pérdida de energía, desinterés o indiferencia por lo que en otro momento fue parte de las motivaciones de la vida cotidiana, trastornos de sueño, del apetito y del deseo sexual. La depresión puede presentar irritabilidad y una variada sintomatología somática (síntomas ubicados preferentemente en el aparato digestivo y/o cardiovascular). Esto repercute en modificaciones importantes tanto en el ámbito laboral, como en el académico o social.

La OMS argumenta que la salud de los jóvenes ha sido en buena medida ignorada en la salud pública mundial, porque se les percibe como sanos. Los jóvenes se beneficiarían de mayor atención y prevención. Organizaciones sin fines de lucro como IThrive Games Foundation (McDonald, Heidi, 2018) tienen como objetivo mejorar la salud mental de los adolescentes a través de los juegos y de la educación. Este tipo de organizaciones

es importante debido a que mucha gente que experimenta depresión puede volcarse a los videojuegos como una vía de escape, una especie de auto-medicación que crea un parche, tapando lo que hay detrás. Orientar el uso de los videojuegos como una efectivo método para mejorar el interés de las personas en su educación puede ser una opción a otros tipos de recursos didácticos. Los videojuegos destinados a la educación son una realidad. Sin embargo, muchos han sido concebidos para funcionar en plataformas propietarias. Es debido a esto que los videojuegos desarrollados sobre la Web pueden resultar una interesante alternativa, considerando que cualquier plataforma que disponga de un navegador Web estándar podría ejecutarlos sin mayor inconveniente.

Además, es necesario considerar que dentro de las personas que harán uso de los videojuegos destinados a la educación se encuentran aquellos individuos que presentan algún tipo de discapacidad.

La discapacidad de los individuos afecta a toda la sociedad de diferentes maneras y ámbitos, convirtiéndose, por tanto, en un problema social. Esto implica que muchos organismos busquen la forma de mejorar el entorno en que se desenvuelven las personas haciendo que los servicios y prestaciones sean más accesibles para todos.

Por un lado, muchas personas que presentan algún tipo de discapacidad desean integrarse a las actividades de su comunidad sin ser tratados de manera diferente a la diversidad de los participantes. Por otro lado, muchos de ellos necesitan gastar más tiempo en realizar tareas que otras personas lo hacen en forma inmediata. Es por esa razón, que se busca servicios accesibles para todos, con el objeto de facilitar su uso.

Es necesario recordar que muchas veces las limitaciones o barreras no están en las personas sino en la infraestructura que utilizan. Cabe recalcar, que la accesibilidad de los recursos no estaría completa sin la colaboración voluntaria y oportuna de las personas que los utilizan. Motivo por el cual la educación, asistida por videojuegos puede resultar un mecanismo muy apropiado para mejorar la motivación de los estudiantes en el aprendizaje y propiciar la investigación (Lukosch, Bekebrede, Kurapati, y Lukosch, 2018) siempre y cuando se desarrolle considerando la accesibilidad.

4.8.1. Discapacidad visual y baja visión

De acuerdo con la WHO (2019) se estima que en el mundo existen aproximadamente 1300 millones de personas que viven con alguna forma de deficiencia visual.

Con respecto a la visión de lejos, existen alrededor de 188.5 millones de personas con una deficiencia visual moderada, 217 millones que tienen una deficiencia visual de moderada a grave y 36 millones son personas ciegas.

Las principales causas de la visión deficiente están relacionadas con los errores de refracción no corregidos y las cataratas. En el grupo de edad con baja visión se encuentran las personas de más de 50 años.

Según la OMS, la discapacidad visual incluye discapacidad visual moderada, grave, y la ceguera. El sistema visual comprende tres partes relacionadas sistemáticamente 1) los órganos periféricos, 2) el nervio óptico y 3) el centro visual en el córtex cerebral.

La visión funciona únicamente cuando estas tres partes trabajan conjuntamente. Si cualquiera de las tres no funciona por problemas de una inflamación, un tumor o una lesión, se pierde la percepción visual, puesto que la vista es responsable del

80 % de nuestro contacto con el entorno (Roselló Leyva, Bernal Reyes, Rojas Rondón, Roselló Silva, y Lázaro Izquierdo, 2015).

La baja visión es el grado de visión parcial o reducida que permite su utilización como canal primario para aprender y lograr información y limita las capacidades de las personas a la hora de realizar actividades cotidianas, pero precisa de adaptaciones sencillas para poder llevar a cabo algunas de ellas como con ayudas ópticas o con ampliaciones (de Miguel, 2003). En esta investigación se pondrá un especial interés en dirigir los esfuerzos a evaluar la accesibilidad para personas que presentan alguna discapacidad visual, de los videojuegos educativos basados en la Web.

4.8.2. Discapacidad visual en la educación

El 80 % de la información que recibe el estudiante es por medio del sentido de la visión. Es por ello que las instituciones educativas y los educadores tienen la obligación de conocer las necesidades de los estudiantes y brindarles una respuesta educativa de calidad. Los retos cognitivos de los estudiantes con discapacidad visual no son los mismos de aquellos que no presentan este tipo de discapacidad. Las medidas educativas tomadas por los centros de educación deben ajustarse a las necesidades de cada individuo. Las exigencias académicas se ven incrementadas para las personas que presentan discapacidad visual produciendo mayor estrés, especialmente porque este tipo de estudiantes sienten que no tienen la suficiente autonomía para realizar sus actividades de aprendizaje de una manera fluida. El material didáctico y las condiciones del aula deben ser las apropiadas para brindar a todos los estudiantes similares tipos e intensidad de estímulos. La capacidad de representar conceptos abstractos y objetos en los estudiantes que presentan discapacidad visual se ve disminuida al no recibir los estímulos que obtienen el común de los estudiantes. Una alternativa para mejorar estos estímulos es introducir en el aula materiales que faciliten la asimilación de la información que se desea transmitir. Los juegos serios en general tienen el propósito de estimular la imaginación de los estudiantes y facilitar el aprendizaje de temáticas abstractas. Gracias a las nuevas tecnologías de la información se ha incrementado el conjunto de herramientas disponibles para la enseñanza de conceptos, permitiendo un tratamiento individual y personalizado para cada tipo de estudiante. Aprovechando la tecnología, se pueden crear juegos serios especialmente diseñados para personas con discapacidad visual. Incluso se pueden modificar los juegos serios tradicionales para que puedan ser usados por cualquier tipo de estudiante independientemente del tipo de discapacidad que presenten. Sin embargo, es necesario considerar una serie de lineamientos que permitan un diseño accesible. Debido a la variedad de necesidades, este estudio se centra en descubrir y evaluar los lineamientos a ser cubiertos para resolver los problemas de accesibilidad de las personas con discapacidad visual. La presencia de profesionales especializados en el diseño de juegos serios destinados a personas con discapacidad visual es, por tanto, apremiante. Estos profesionales deben tener claros cuales son los lineamientos que deben evaluar y considerar en el momento de diseñar y producir juegos serios destinados a personas con discapacidad visual.

Parte II

TRABAJOS PUBLICADOS

5 Lista de publicaciones

Los artículos publicados se presentan en orden cronológico. La Figura 5.1 muestra la línea de tiempo de producción de las publicaciones relacionadas con la accesibilidad en juegos serios que sirven de apoyo para las publicaciones incluidas en este compendio.

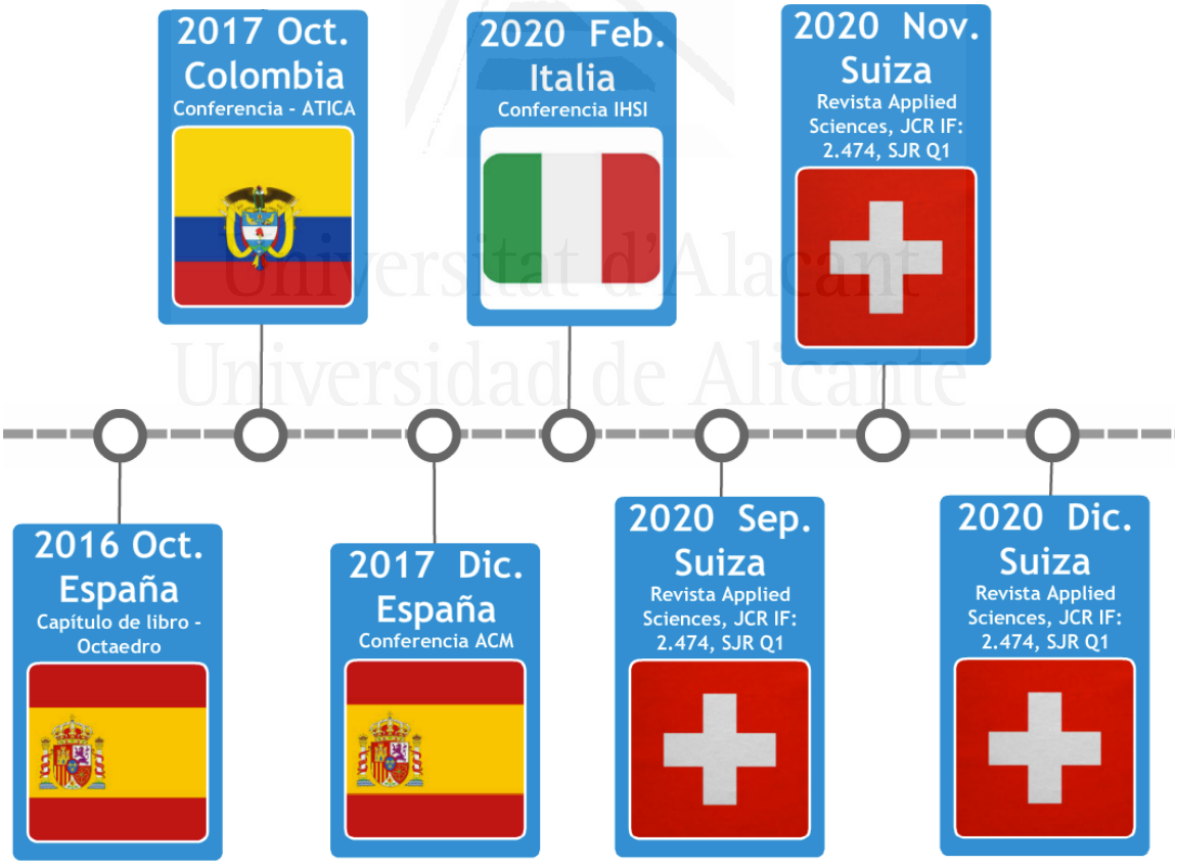


Figura 5.1: Línea de tiempo de publicaciones

En esta línea de tiempo se visualiza el tipo de publicación, que puede ser un artículo de revista, artículo incluido en memoria de congreso o un capítulo de libro, el lugar y la fecha de publicación.

Los artículos cuentan con un nivel de calidad óptimo, ya que los mismos han sido enviados a revistas con procesos exigentes de revisión y evaluación por pares, de los cuales tres tienen un un factor de impacto de 2.474 en el Journal Citation Report de Q2; y en SCImago Journal Rank con un factor de imapcto de 0.42 de Q1.

La Figura 5.1 presenta tres conferencias y un artículo de libro que fueron trabajos previos en los que se estudió el desarrollo de juegos serios y sus problemas de accesibilidad, para las personas con problemas de visión y problemas cognitivos. En paralelo, se trabajó en el análisis de la literatura; nunca se paró de revisar la literatura existente; que se plasmó en un trabajo de revisión de literatura. Además, se publicó un artículo de revista relacionado con un método combinado para evaluar la accesibilidad en juegos serios. Finalmente, para complementar este estudio se publicó un artículo sobre un método heurístico para evaluar la accesibilidad en juegos serios basados en la web para personas con baja visión.

6 Producción de Videojuegos Orientados a la Enseñanza Mediante Lenguajes de Programación por Bloques Aplicables a Aulas Virtuales Mediante SCORM

Referencia:
Salvador-Ullauri, L. and Luján-Mora, S. and Acosta-Vargas, P. (2016). Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM. En: Tecnología, innovación e investigación en los procesos de enseñanza-aprendizaje (pp. 2992-3001). Octaedro. (Salvador-Ullauri y otros, 2016c)

Disponible en:

- http://hdl.handle.net/10045/61851

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios educativos.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico: juegos educativos para la enseñanza en aulas virtuales.
3. Evaluación del nivel de accesibilidad de los juegos serios educativos.

Producción de videojuegos orientados a la enseñanza mediante lenguajes de programación por bloques aplicables a aulas virtuales mediante SCORM

Luis Salvador-Ullauri[1], Sergio Luján-Mora[2] y Patricia Acosta-Vargas[3]

[1] *Escuela Politécnica Nacional*
[2] *Universidad de Alicante*
[3] *Universidad de Las Américas*

RESUMEN

No todos los estudiantes de la asignatura de programación dentro de la carrera de informática encuentran motivación para aprender o realizar las tareas a ellos encomendadas. En este artículo se proponen estrategias para que la mayor parte de ellos mejoren el interés por realizar eficazmente sus labores académicas y también adquieran conocimientos más profundos. Realizar diseños funcionales de aplicaciones divertidas atrae el interés de los estudiantes. Los diseños funcionales son prototipos desechables que inspiran la creación de aplicaciones más serias mediante el uso de lenguajes de programación completos. Los lenguajes de programación por bloques atraen la atención de los estudiantes debido a la facilidad que prestan para crear muy rápidamente prototipos de presentaciones animadas y videojuegos destinados a la educación. Si a estos prototipos se les agrega la capacidad de interacción con las aulas virtuales, el resultado es un conjunto de productos valorados académica y comercialmente. Un producto valorado por los usuarios constituye un incentivo adicional para que los estudiantes de programación piensen en la posibilidad de aprender jugando y jugar aprendiendo mientras inventan nuevos modelos de material didáctico.

PALABRAS CLAVE: e-learning, videojuegos, programación por bloques, aprendizaje, SCORM.

ABSTRACT

Not all students of the subject of programming within the informatics are motivated to learn or perform the tasks entrusted to them. In this article, strategies directed for these students improve their interest in order to perform effectively their academic work and obtain more deep knowledge are proposed. Make functional designs of some funny applications attracts the interest of students. Functional designs are disposable prototypes underlying the creation of more serious applications. Programming languages based in blocks attract the attention of the students because they provide ease to create prototypes of animated presentations and video games for education, very quickly. If the ability to interact with virtual classrooms is added to these prototypes, the result is a set of academic and commercially valued products. A product valued by users constitutes an additional incentive for students of programming think about the ability to learn by playing and play by learning while they invent new models of teaching materials

KEY WORDS: e-learning, learning, programming based in blocks, videogames, SCORM.

1. INTRODUCCIÓN

En este artículo se propone la generación de videojuegos destinados al aprendizaje por parte de los estudiantes de la asignatura de programación, mediante la incorporación de herramientas de construcción por bloques y el formato SCORM (*Sharable Content Object Reference Model*). El objetivo es que dichos juegos sean desarrollados pensando en la posibilidad de interactuar con los sistemas LMS *(Learning Management System*). De esta manera se espera que puedan ser utilizados como mecanismos de evaluación para medir capacidades de memoria, entendimiento e innovación de los usuarios de dichos sistemas. Las puntuaciones de la medición de estas capacidades deben ser almacenadas en los LMS una vez que hayan sido comparadas con parámetros referenciales previamente establecidos, para otorgar una calificación.

Aunque el videojuego puede utilizar una escala diferente de puntuaciones propia de su naturaleza, esta es traducida internamente a una puntuación acorde al LMS. La escala del LMS permite la comparación y análisis de valores de varios participantes. Actualmente las herramientas de construcción por bloques no presentan opciones para generar aplicaciones compatibles con el formato SCORM. La especificación SCORM pueden facilitar la comunicación de videojuegos con implementaciones especiales de servidores que hospeden los videojuegos exclusivamente y que se adapten a las debilidades del formato y las transformen en fortalezas (Aguado, Torrente, Martínez-Ortiz, & Fernández-Manjón, 2011).

La creación de aplicaciones que permitan recordar una serie de conceptos y métodos es muy importante. Un estudiante que entiende una asignatura la valora y tiene la voluntad de utilizarla. De esta manera, los estudiantes que inician en el estudio de programación valoran el uso de las herramientas de programación por bloques, porque les resulta más sencillo entenderlas (Resendiz, 2011). Estas aplicaciones normalmente son presentaciones animadas que al evolucionar se transforman en sencillos videojuegos que pretenden transmitir o reforzar una capacidad. Esta capacidad esta primeramente relacionada con la memoria o la memorización de conceptos. En una segunda etapa intentan unir aquello que recuerdan, entendiendo lo que construyen y sus consecuencias. Finalmente, los resultados útiles les motivan a seguir en la línea que han adoptado. Por el contrario, cuando existen tareas que son poco o nada requeridas, los desmotivan y hace que dirijan su atención a otras actividades donde reciben aprobación por parte de profesores y compañeros. No es importante la complejidad del objeto cuando el entendimiento está presente. La aceptación de las herramientas de programación por bloques, por parte de los estudiantes, constituye un incentivo potencial para apoyar el diseño rápido de videojuegos y otros tipos de aplicaciones. Nuestra propuesta sugiere la adopción de la programación orientada a bloques como una alternativa para generar productos que permitan además del aprendizaje, la evaluación de estudiantes en cursos MOOC (*Massive Open Online Course) (*Medina Merodio, y otros, 2014). Esto implica que factores como la accesibilidad y la usabilidad del videojuego también deben ser consideradas (Sanchez-Gordon & Sergio Luján-Mora, 2016). Pero por el momento nuestro interés se centra en que dichos productos puedan ser incorporados con éxito dentro de las aulas virtuales. El gran tamaño de las aplicaciones generadas con el tipo de herramientas propuestas implica que los videojuegos desarrollados seguramente deberán ser divididos en niveles independientes para que sean eficazmente ejecutados. Las aplicaciones, al ser empaquetadas mediante la tecnología SCORM, deben mantener su independencia. Eso implica que pueden ser utilizadas y distribuidas en distintos medios de almacenamiento removibles. Muchas editoriales apoyan el contenido de sus textos con discos compactos que contienen aplicaciones interactivas y sencillos videojuegos desechables. Es decir, la demanda de innovación de contenidos es constante, tanto en el material impreso, como en las aulas virtuales.

1.1 Problema/cuestión

Muchos conceptos, deben obligatoriamente aprenderse dentro de ciertas asignaturas como la materia Programación dentro de la carrea de Informática. En esta materia se requiere principalmente la memorización de ciertas fórmulas útiles mediante la repetición constante de su práctica. Para ello los instructores envían tareas que deben ser necesariamente realizadas. Sin embargo, los estudiantes, al no conocer el beneficio que conlleva ejecutarlas, tratan de evitarlas o no asumirlas adecuadamente.

1.2 Revisión de la literatura

Muchos autores concuerdan en la necesidad de que el estudiante practique adecuadamente ciertas técnicas que hagan que su trabajo de programación mejore y sea valorado en el mercado ocupacional y académico (Jones & Boyle, 2007). Dichas técnicas y metodologías son adaptadas por los instructores para darles un nuevo enfoque que facilite su aceptación por parte de los estudiantes (Calderón, 2008). Sin embargo, las generaciones actuales de estudiantes prefieren nuevas experiencias para aprender los canceptos que han sido probados con éxito anterormente y la instrucción de dichos conceptos es más fácil entenderla jugando (Queiruga, Fava, Gómez, Kimura, & Bartneche, 2014).

El juego ha sido un mecanismo de apoyo muy utilizado en la enseñanza y en la actualidad este mecanismo ha evolucionado hacia lo que se conoce como videojuegos. Primero aplicado a la instrucción en escuelas y colegios (Zabala, Morán, & Blanco, 2013) y luego llevada a las universidades mediante similar razonamiento: facilitar la enseñanza. Es así que la creatividad en el diseño de aplicaciones se abre cuando aquellas herramientas originalmente destinadas a los infantes llegan a las manos de estudiantes universitoarios, educadores y profesionales de la computación (Brennan, Chung, & Hawson, 2011). Al mirar su trabajo y sus actividades con aquellos ojos con los cuales observaban el mundo en su niñez, toda herramienta resulta novedosa y útil (Brennan, Balch, & Chung, Creative Computing, 2014), es decir, el objeto que percibe es apenas un estímulo para que el estudiante mejore su actitud frente a lo que se pretende enseñar. No es requerido inventar nada nuevo, sino más bien hacer uso adecuado de lo que existe. La comunicación entre las aplicaciones generadas y las aulas virtuales usarán el formato SCORM (Resendiz, 2011). Además, esta práctica brindará la oportunidad de conocer a profundidad el formato y proponer alternativas a sus utilización, dando continuidad a estudios previos (Aguado, Torrente, Martínez-Ortiz, & Fernández-Manjón, 2011). También se requiere que los estudiantes conozcan, apliquen y utilicen los escenarios de aprendizaje que tienen a su disposición e integren dichas herraminetas a su trabajo. Es el caso de dos estrategias muy marcadas: el uso de videojuegos orientados a la enseñanza propia y de otros (González, Cabrera, & Gutiérrez, 2007), y el aprendizaje por medio de cursos MOOC (Medina Merodio, y otros, 2014). Ambas temáticas han sido muy explotadas en los últimos años y siguen proporcionando material para la innovacion de técnicas orientadas a las enseñanza y el aprendizaje.

1.3 Propósito

El propósito de este estudio es orientar el desarrollo de los cursos de programación hacia el diseño y creación de aplicaciones que satisfagan las necesidades del mercado laboral, en el ámbito de la informática. Existe demanda por material didáctico innovador dentro de las empresas editoriales que distribuyen libros de enseñanza para escuelas y colegios, y también en muchas empresas dedicadas a la capacitación presencial o por medio de aulas virtuales. Muchos estudiantes no pueden acceder a ese mercado laboral debido especialmente a su falta de capacitación y a los riesgos que conlleva el tratar de realizar un trabajo sin conocer. Sin embargo, el conocer involucra ciertos “sacrificios” que

los estudiantes y en ocasiones los instructores tampoco quieren asumirlos. Por esta razón, se requieren formas motivacionales para inducir tanto a estudiantes como a educadores a asumir los retos relacionados con la educación, volviendo a dar un valor permanente a su actividad, reestableciendo la perseverancia en el estudio y el trabajo, y finalmente mejorando la integridad que los involucrados buscan constantemente en sus actividades. Existen tecnologías y mecanismos para todos los gustos y esta propuesta apenas cubre la integración de cuatro posibles estrategias: uso de programación por bloques, uso de videojuegos, uso de estándares de comunicación y uso de aulas virtuales.

2. MÉTODO

El método seguido para llevar a cabo el desarrollo de las aplicaciones usando las herramientas de construcción por bloques y SCORM, ha sido ejecutado en cuatro etapas:

1. Instrucción básica sobre las generalidades de la programación,
2. desarrollo de pequeñas aplicaciones mediante herramientas de construcción por bloques,
3. implementación de los diseños en lenguajes profesionales, y
4. mecanismos de integración con las aulas virtuales, en especial con cursos MOOC.

2.1 Descripción del contexto y de los participantes

Existen cuatro actores involucrados dentro del ámbito de la enseñanza, estos son: las empresas editoras de libros para escuelas y colegios, las empresas de capacitación, las universidades (en las cuales están incluidos los profesores universitarios, que dependiendo del contexto en el que laboren pueden tomar el rol de instructores o incluso de estudiantes) y los estudiantes. Las empresas editoras de libros para escuelas y colegios desconfían de la capacidad de los profesionales para asumir las responsabilidades que involucra el trabajo en el ambiente competitivo donde desempeñan su actividad. Las empresas de capacitación realizan esfuerzos por mantenerse en el mercado mediante la oferta de productos innovadores que incluye el uso de aulas virtuales. Las universidades afrontan el problema de la deserción estudiantil, ante las exigencias propias de su actividad y en el mejor de los casos los estudiantes pueden decidir cambiarse a universidades con menores exigencias. Finalmente, los estudiantes, no están dispuestos a pagar la cuota de esfuerzo que requiere su enseñanza, si no tienen muestras de que su trabajo va a ser valorado adecuadamente en el mercado laboral.

Muchos de los estudiantes prefieren recurrir a otras alternativas más lucrativas ante las exigencias de una preparación que no garantiza su éxito profesional. Es por esa razón que, integrando las necesidades de los actores antes descritos, los instructores nos vemos en la necesidad de motivar a los estudiantes a desarrollar su actividad con visión sobre los requerimientos de las empresas donde posiblemente tengan la oportunidad de desarrollar sus capacidades y su economía.

2.2 Instrumentos

Para lograr la integración antes mencionada, han sido seleccionadas tecnologías que satisfagan las necesidades de los cuatro actores. Esas tecnologías son:

- Uso de herramientas de programación por bloques para la obtención de diseños rápidos y funcionales de aplicaciones a manera de videojuegos simples.
- Uso de lenguajes de alto nivel para desarrollar en forma profesional los diseños antes concebidos.
- Uso del formato SCORM para permitir que las aplicaciones desarrolladas no sean utilizadas únicamente en medios de distribución como discos compactos, que se agregan a los libros, sino que puedan ser útiles también dentro de las aulas virtuales.

- Orientación de las aplicaciones, especialmente hacia el apoyo de los cursos MOOC, que son muy populares actualmente y que resultan ser una estrategia válida para las actividades de las empresas de capacitación públicas y privadas.

2.3 Procedimiento

El procedimiento seguido es el siguiente:

Primero, es necesario instruir a los estudiantes en conceptos elementales de programación para que el uso de las herramientas de desarrollo de aplicaciones por bloques, pueda ser aceptado y entendido con mayor facilidad.

Luego, los estudiantes observan y valoran dichas herramientas que les permiten crear aplicaciones animadas con mucha facilidad y que además están disponibles en línea. Esto abre su imaginación al diseño de pequeños videojuegos orientados a la enseñanza propia, en lo que respecta al desarrollo de programas, y de otros, en lo relacionado a la creación de aplicaciones para personas con capacidades especiales y menores de edad.

En seguida, los estudiantes toman conciencia de que las aplicaciones antes diseñadas, deben ser codificadas mediante herramientas profesionales que les permitan transformar dichas aplicaciones, en productos serios y aceptables para usuarios reales. Esto involucra el uso de herramientas de uso común que contienen características que facilitan el desarrollo simple de este tipo de aplicaciones, pero que no tienen el suficiente grado de flexibilidad para permitirles plasmar sus ideas.

Finalmente, al tratar de integrar eficazmente sus productos dentro de tecnologías como las aulas virtuales, se dan cuenta de que existen algunas variaciones en la forma como estos contenedores comunican y distribuyen sus contenidos. Esto les lleva a pensar en la búsqueda y aceptación de estándares para la comunicación con las aulas virtuales, aun cuando estos formatos no tengan todas las características que desearían, pero que sin embargo constituyen una alternativa viable y modesta para la interacción entre tecnologías. De esta manera los estudiantes y los instructores encontramos cierta motivación a realizar nuestras actividades en conjunción con la búsqueda de innovaciones que satisfagan la demanda del mercado.

3. RESULTADOS

En forma general, existe una manera diferente de crear productos dentro del mundo académico y dentro del mundo empresarial. Es así que en el mundo académico es posible imaginar un producto que permitiría a la ciencia avanzar, aunque este sea momentáneamente inaplicable e inservible. Las empresas de capacitación, por el contrario, buscan la aceptación inmediata de sus productos, y para ello se requiere transformarlos en necesidades para estudiantes o usuarios dispuestos a pagar por ellos.

Unir estas dos formas de concebir la creación de productos, puede resultar incómodo, pero necesario, pues todo producto y su desarrollo requiere de aceptación, recursos y apoyo por parte de los usuarios. Un producto que tiene aceptación se desarrollará de forma más rápida y efectiva que aquel que únicamente resulta ser un ideal. Muchos productos que carecieron de apoyo académico, encontraron su realización gracias a la aceptación de los usuarios y luego se convirtieron en objeto de estudio.

Para lograr esto se dividió la impartición de la asignatura de programación en cuatro etapas:

- Aprendizaje esencial.
- Diseño de aplicaciones usando herramientas orientadas a bloques.
- Programación con lenguajes profesionales.
- Agregación de SCORM.

Durante la fase de aprendizaje de los conceptos básicos de programación los estudiantes sintieron poco agrado, aunque alguna curiosidad por conocer la materia. Es así que sus primeras prácticas en laboratorio estuvieron cargadas de una entusiasta expectativa por aprender. Esta expectativa fue decreciendo a medida que se daban cuenta de la rigurosidad de la sintaxis de los lenguajes de programación y la poca funcionalidad que sus aplicaciones tenían frente al esfuerzo entregado. Las cuatro etapas del método se muestran en la siguiente Figura 1.

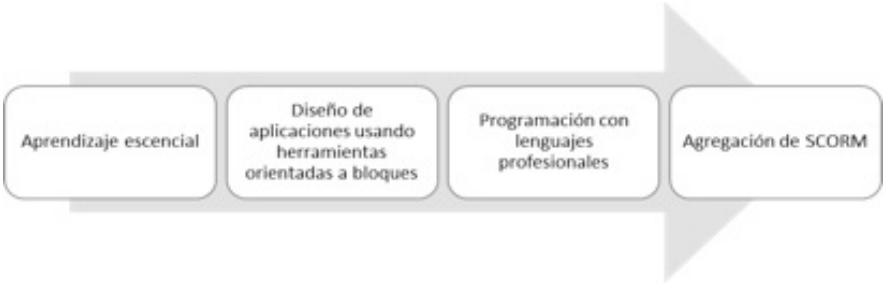


Figura 1.- Etapas del proceso de desarrollo de videojuegos

En la segunda etapa, los estudiantes sienten satisfacción por la facilidad con la cual pueden desarrollar pequeñas animaciones que cautivan su interés, aunque no encuentran en ellas practicidad. Necesitan algo que sea más acorde con su nivel, y sienten la premura de aceptar el uso de lenguajes de programación profesionales.

Una herramienta muy popular de programación por bloques es Scratch (Lifelong Kindergarten en el MIT Media Lab, 2016), esta herramienta es utilizada en muchas escuelas y colegios. Es utilizada para la enseñanza de la programación a niños y adultos. Scratch es una herramienta de programación visual que permite la unión de bloques para construir la lógica de un programa con presencia gráfica, normalmente un videojuego. En la Figura 2 se puede observar una de las aplicaciones desarrolladas en el curso usando Scratch, la interface amigable de esta herramienta sirve de motivación para la creación de aplicaciones entretenidas. El nivel de complejidad que alcanzan este tipo de aplicaciones puede ser muy elevado dependiendo del tiempo de dedicación que se asigne a la programación de las mismas. Sin embargo, la intención de su utilización es servir como motivación para el uso de otros lenguajes de programación con características más avanzadas y con mejores prestaciones, como se describe en la etapa siguiente.

Figura 2.- Diseño de videojuegos usando herramientas de programación por bloques.

En la tercera etapa, sin embargo, descubren que toda esta tarea involucra una gran laboriosidad y por tanto sienten la necesidad de que sus ideas y su trabajo tenga valor. Desde ahora sus esfuerzos estarán encaminados tomando en cuenta su economía y satisfaciendo las necesidades de posibles clientes. Aunque las herramientas de creación de contenidos por bloques son sencillas, la calidad de los productos no siempre es buena. También existen mecanismos para utilizar SCORM junto con herramientas como Scratch, pero la intención es transferir el diseño a otros lenguajes de programación y motivar su aprendizaje. Se desarrollan aplicaciones con Java, Javascript, HTML5 y CSS3, incluso se hace uso de herramientas que incorporan SCORM y generan código HTML5 como Storyline (Articulate Global, Inc, 2016), para apresurar el desarrollo de los productos. En la Figura 3, puede observarse la primera pantalla de una aplicación desarrollada íntegramente usando HTML5.

Figura 3.- Implementación en HTML5 de un simulador de cajero automático

Finalmente, el ampliar el mercado para sus productos involucra la aceptación de formatos, normas y estándares de comunicación. El formato SCORM es una alternativa para abarcar el mayor número de aulas virtuales como destino para sus creaciones.

Luego se procede a evaluar los videojuegos con grupos de personas que tienen diversas observaciones sobre su uso. Durante nuestra experiencia de trabajo fue difícil atender los requerimientos de los usuarios sin configurar varias aulas, ya que Moodle no presentaba la suficientemente flexibilidad para permitir que un mismo curso pueda ser configurado para satisfacer a todos los grupos.

4. DISCUSIÓN Y CONCLUSIONES

El proceso de desarrollo de videojuegos educativos toma su tiempo. El lograr realizar una aplicación funcional en lenguaje HTML5 que interactúe con el aula virtual tomó aproximadamente un mes. Fue necesario dividir una aplicación en cuatro módulos para permitir que se cargara adecuadamente desde el navegador. Por tanto, es importante que los videojuegos sean pequeños y que se evalúe un nivel cada vez.

Cada módulo SCORM fue configurado como un curso de una única actividad SCORM dentro de Moodle. La razón, no todos los usuarios tienen interés de dedicar su atención a múltiples niveles de un videojuego. Los participantes evaluados prefieren aprobar un nivel a la vez, antes de involucrarse con el siguiente, especialmente si su evaluación va a ser tomada en cuenta.

Los videojuegos generados permiten que el usuario intente resolver los retos sin conocer, para que el usuario se autoevalúe. Luego le brindan al usuario la oportunidad de aprender. En una segunda oportunidad el usuario puede volver a intentar resolver el videojuego y su actividad es evaluada y registrada.

El incluir cada videojuego en un curso independiente dentro del aula virtual permite que se activen y desactiven con facilidad los respectivos niveles. Sin embargo, varios grupos de usuarios deseaban que la interfaz incluyera el logo de su grupo u organización. Esta es una falencia de Moodle, no permite que los grupos de usuarios puedan tener su propio perfil y que se desplieguen únicamente los cursos (niveles) en los cuales están inscritos los usuarios, sin mostrar otros cursos disponibles en la plataforma.

Los usuarios desean que los resultados de los cursos y de las evaluaciones puedan ser intercambiados y usados desde otros sistemas informáticos y curriculares. Sin embargo, Moodle en específico, brinda un conjunto limitado de servicios web que permiten una interacción mínima.

Si se desarrollan cursos para ser utilizados únicamente con SCORM, se podría pensar en generar un aula que administre este tipo de material exclusivamente y que tome en cuenta las falencias mencionadas anteriormente.

Las últimas versiones de Moodle nos han resultado un poco más difíciles de entender y de mantener pues con versiones anteriores resultaba muy simple modificar el código para agregar funcionalidad a la plataforma. Sin embargo, las nuevas versiones de manejan correctamente el formato SCORM, no así las anteriores.

En trabajos previos se hicieron evaluaciones sobre la posibilidad de usar SCORM, con videojuegos (Aguado, Torrente, Martínez-Ortiz, & Fernández-Manjón, 2011). Sin embargo, no se consideró que los usuarios no desean interactuar con videojuegos complejos o de alta transferencia de datos. Ellos prefieren que sean simples, muy didácticos y explicativos, y sobre todo que les permita aprobar.

Es recomendable considerar los siguientes consejos para implementar esta estrategia educativa en otras instituciones: entender la realidad que perciben los estudiantes, transformar dicha realidad en un juego, jugar el juego sin el uso de la tecnología, transformarlo en un algoritmo y finalmente, crear el producto para ser usado en una computadora.

5. REFERENCIAS

Articulate Global, Inc. (02 de 09 de 2016). articulate. Obtenido de articulate: https://es.articulate.com/products/storyline-why.php

Aguado, Á. D., Torrente, J., Martínez-Ortiz, I. y Fernández-Manjón, B. (2011). Análisis del Uso del Estándar SCORM para la Integración de Juegos Educativos. *IEEE-RITA, 6*(3), 118-127.

Brennan, K., Balch, C., & Chung, M. (06 de 08 de 2014). *Creative Computing*. Recuperado de Scratched: http://scratched.gse.harvard.edu/guide/files/CreativeComputing20140806.pdf

Brennan, K., Chung, M., & Hawson, J. (23 de 09 de 2011). *Creative Computing a design-based introduction to computational thinking*. Recuperado de Scratched: http://scratched.gse.harvard.edu/sites/default/files/curriculumguide-v20110923.pdf

Calderón, R. P. (2008). Una Herramienta y Técnica para la Enseñanza de la Programación. *Congreso Internacional de Cómputo en Optimización y Software (CICOS*) (pp. 229-239). México.

González, J. L., Cabrera, M. J. y Gutiérrez, F. L. (2007). Diseño de videojuegos aplicados a la Educación Especial. *VIII Congreso Internacional de Interacción Persona Ordenador* (pp. 35-45). Zaragoza.

Jones, R., & Boyle, T. (2007). Learning Object Patterns for Programming. *Interdisciplinary Journal of Knowledge and Learning Objects*, *3*, 9-28.

Lifelong Kindergarten en el MIT Media Lab. (02 de 09 de 2016). Scratch. Obtenido de Scratch: https://scratch.mit.edu/

Medina, J. A., García, A., García, E., Díez, T., Domínguez, M. J. y Bengochea, L. (2014). Desarrollo de un curso MOOC sobre creación de contenidos digitales y materiales educativos multimedia accesibles. *VI Congreso Internacional sobre Aplicación de Tecnologías de la Información y Comunicaciones Avanzadas (ATICA2014)*, (pp. 133-139). Madrid.

Queiruga, C., Fava, L., Gómez, S., Kimura, I. M. y Bartneche, M. B. (2014). El juego como estrategia didáctica para acercar la programación a la escuela secundaria. *XVI Workshop de Investigadores en Ciencias de la Computación (WICC)* (pp. 358-362). Ushuahia.

Resendiz, A. (2011). *Escenarios de aprendizaje basados en SCORM. Congreso Internacional Edutec* (pp. 1-11). Pachuca. Obtenido de Entorno Virtual de Formación: http://gte2.uib.es/edutec/sites/default/files/congresos/edutec11/Ponencias/Mesa%203/Escenarios%20de%20aprendizaje%20basados%20en%20SCORM.pdf

Sanchez-Gordon, S. y Luján-Mora, S. (2016). How Could MOOCs Become Accessible? The Case of edX and the Future of Inclusive Online Learning. *Journal of Universal Computer Science* (J.UCS), *22*(1), 55-81.

Zabala, G., Morán, R. y Blanco, S. (2013). Una propuesta de enseñanza de programación en escuela media mediante el desarrollo de videjuegos con eToys. *11vo Simposio sobre la Sociedad de la Informacion (SSI)* (pp. 303-325). Sociedad Argentina de Informática e Investigación Operativa.

BREVE RESEÑA CURRICULAR DE LOS AUTORES

Salvador-Ullauri, Luis

Luis Salvador Ullauri es Profesor Temporal por contrato en la Escuela Politécnica Nacional en la facultad de Ingeniería de Sistemas de Quito, Ecuador. Ingeniero en Sistemas de Computación e Informática por la Escuela Politécnica Nacional de Quito (Ecuador). Obtuvo su grado de Master en Docencia en Instituciones de Educación Superior en la Escuela Politécnica Nacional (Ecuador) en el año 2008.

Sus temas principales de investigación incluyen los algoritmos de programación, el desarrollo de videojuegos, el uso de tecnologías relacionadas con la educación, la accesibilidad y la usabilidad web, el desarrollo de las aplicaciones web, el e-learning, los cursos de tipo MOOC (Massive Open Online Courses) y la programación orientada a objetos.

Es profesor de las asignaturas “Programación de Aplicaciones Web”, “Programación de Aplicaciones Móviles”, “Programación básica” y “Uso de aplicaciones ofimáticas”. Ha sido profesor de las asignaturas “Programación”, “Estructuras de Datos”, “Sistemas Operativos”, “Servidores Web” y “Programación en Internet”.

Desde el año 2007 dicta cursos abiertos en otras universidades como la Escuela Politécnica Salesiana y la Universidad de Las Américas de Quito (Ecuador), así como en el Centro de Educación Continua de la Escuela Politécnica Nacional. Está involucrado con proyectos relacionados al uso de aulas virtuales.

Luján-Mora, Sergio

Sergio Lujan Mora es Profesor Titular de Universidad del Departamento de Lenguajes y Sistemas Informáticos de la Universidad de Alicante. Ingeniero Informático por la Universidad de Alicante (España). Obtuvo su grado de Doctor Ingeniero en Informática en la Universidad de Alicante (España) en el año 2005.

Sus temas principales de investigación incluyen la accesibilidad y la usabilidad web, el desarrollo de las aplicaciones web, el e-learning, los cursos de tipo MOOC (Massive Open Online Courses) y la programación orientada a objetos.

Es profesor de las asignaturas "Programación Hipermedia I" y "XML". Ha sido profesor de las asignaturas "Programación y Estructuras de Datos" y "Programación en Internet".

Desde el año 2012 también trabaja en el desarrollo de cursos abiertos en línea a gran escala (conocidos en inglés como MOOC). Coordina los cursos iDESWEB (http://idesweb.es/), iXML (http://ixml.es/) y AWEB (http://accesibilidadweb.es/).

Acosta-Vargas, Patricia

Patricia Acosta Vargas es Coordinador de la Facultad de formación General y profesora tiempo completo de Lenguaje Digital en la Universidad de Las Ampericas en Quito, Ecuador. Ingeniera en Sistemas de Computación e Informática por la Escuela Politécnica Nacional de Quito (Ecuador). Obtuvo su grado de Master en Docencia en Instituciones de Educación Superior en la Escuela Politécnica Nacional (Ecuador) en el año 2008.

Sus temas principales de investigación incluyen uso adecuado y accesible de los sistemas de ofimática, el uso y configuración de aulas virtuales, el uso y creación de tecnologías relacionadas con la educación, la accesibilidad y la usabilidad web, el e-learning, los cursos de tipo MOOC (Massive Open Online Courses) y los negocios electrónicos.

Es profesora de las asignaturas "Computación aplicada", "Ofimática básica", "Ofimática avanzada", "Negocios electrónicos", "Excel avanzado y macros con VBA" e "Informática aplicada".

Desde el año 2007 dicta cursos abiertos virtuales en el Centro de Educación Continua de la Escuela Politécnica Nacional y en la Universidad Técnica Particular de Loja. Está involucrada con proyectos relacionados al uso de aulas virtuales.

7 Juego Serio Móvil de Cálculo Binario para Personas con Discapacidad Visual

Referencia:
Salvador-Ullauri, L., Jaramillo-Alcázar, A.,Luján-Mora, S. (2017). Juego serio móvil de cálculo binario para personas con discapacidad visual. En: Proceedings ATICA2017 Tecnología. Accesibilidad. Educar en la sociedad red, ISBN: 978-84-16599-50-9. (pp. 266-273). (Salvador-Ullauri y otros, 2017)

Disponible en:

- http://www.cc.uah.es/Atica/documentos/LibroActasATICA2017.pdf

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico: juegos serios accesibles para usuarios con baja visión.

A Serious Game Accessible to People with Visual Impairments

Luis Salvador-Ullauri
Escuela Politécnica Nacional
Ladrón de Guevara E11-253, Ecuador
593-2-2976300
lsalvador@cec-epn.edu.ec

Angel Jaramillo-Alcázar
Universidad de Las Américas
Av. Granados E12-41, Ecuador
593-2-3981000 ext. 172
angel.jaramillo@udla.edu.ec

Sergio Luján-Mora
University of Alicante
San Vicente del Raspeig s/n, Spain
34-9-65903400 ext. 2962
sergio.lujan@ua.es

ABSTRACT
Serious games allow people to learn through fun activities. This type of video game has a growing demand and its use has spread to several areas of education. However, accessibility for several kinds of disabilities has not been considered in its design due to the challenges it poses. However, there are video game development companies that have defined certain accessibility guidelines for several kinds of impairments. Many accessible games have been evaluated for different types of impediments and a set of high and low-level accessibility strategies has been obtained so that game developers can use them to improve their designs. These initiatives allow the development of serious accessible games in different areas of education. This article presents a serious game proposal accessible to people with visual impairments. The video game is aimed at reinforcing the binary calculation skills of engineering students.

CCS Concepts
• **Human-centered computing → Accessibility design and evaluation methods** • **Theory of computation → Convergence and learning in games** • **Applied computing → Interactive learning environments.**

Keywords
Accessibility; binary calculation; disabilities; serious games.

1. INTRODUCTION
The number of people with disabilities is growing all over the world [1] and this has originated initiatives where accessibility has taken center stage. Serious games are a category of video games designed to support educational processes [2].

Nowadays, the video gaming industry is one of the fastest growing areas. Revenues from digital games represent $94.4 billion, or 87 % of the world market. [3]. One of the reasons why gaming is thriving is due to the fact that it consists of many segments; as a result, the development of serious games has also increased. Serious games allow teachers to apply new teaching methods, and are widely recognized as having considerable potential to foster and support active learning [4].

Serious gaming is becoming a successful business, reaching into defense training, education, medicine, and policy [5]. A diverse set of industries such as education, health care, defense, and even politics, among others, are utilizing serious games for training purposes [6].

On the other hand, around 15 % of people worldwide have a disability. Disability affects hundreds of millions of families in developing countries. More than one billion people in the world live with some form of disability, of whom nearly 200 million experience considerable functional difficulties[1]. These people have to live with social, educational and entertainment limitations because of their disabilities. Many people with disabilities do not have equal access to health care, education, employment opportunities, and disability-related services, facing exclusion from daily life activities [1]. There is powerful evidence on the impact of barriers encountered by disabled people on a daily basis as a consequence of the inaccessibility to tools [7].

Accessibility can be defined as "the usability of a product, service, environment or facility by people with the widest range of capabilities" [8]. In addition, accessibility in video games is a factor that should be considered in software development [9].

Taking into account the large number of people with disabilities, it is important to offer alternatives for academic reinforcement based on the different needs identified in engineering studies and considering improvement levels if accessibility parameters are included. This article presents a serious game proposal for the reinforcement of binary calculus with accessibility features for people with visual impairments. In this way, students with this type of disability can use the game as well as those who do not have a disability condition.

The rest of this article is organized as follows: Section 2 details the method of development of the proposed application; Section 3 discusses the results of the developed application; Section 4 concludes the research and outlines future work.

2. DEVELOPMENT OF SERIOUS ACCESSIBLE PLAY
In order to develop the proposed serious game, a specific model was chosen among several models of existing simple video games such as: puzzles, obstacles and shooting. Of the three model options, the shooting model was chosen because it is the easiest to adapt for selecting different options. In addition, shooting games were the best-selling video games in the United States in 2016 (see Figure 1); the United States is the country with the most active players in the world in accordance with data taken from the 2016 Essential Facts About the Computer and Video Game Industry report [10].

ICETC 2017, December 20–22, 2017, Barcelona, Spain

ACM ISBN 978-1-4503-5435-6/17/12…$15.00
https://doi.org/10.1145/3175536.3175576

Besides, tens of millions of disabled consumers have relied on video games as a source of relief from their infirmities, as well as a sense of accomplishment or belonging, according to the survey conducted by Information Solutions Group on behalf of PopCap Games.

According to the survey, more than one in five (20.5%) casual video game players has a physical, mental or developmental disability. A total of 13,296 casual game players responded to the survey, with 2,728 respondents (20.5%) identifying themselves as "mildly" (22%), "moderately" (54%) or "severely" (24%) disabled; of those, 46% indicated that their primary disability was physical, 29% said it was mental, and 25% stated they had a developmental or learning disability. Over two thirds (69%) of disabled respondents were female, and a third (35%) of all respondents had another person such as a parent, adult offspring, spouse, guardian or caregiver assist them in taking the survey.

These results are based on online surveys completed by 2,728 respondents randomly selected between April 2 and April 17, 2008. In theory, in 19 cases out of 20, the results will differ by no more than 1.9 percentage points from what would have been obtained by seeking out and polling all PopCap.com users. Survey subjects were presented with exhaustive lists of various types of disabilities organized by category in order to assist in accurately categorizing themselves [11].

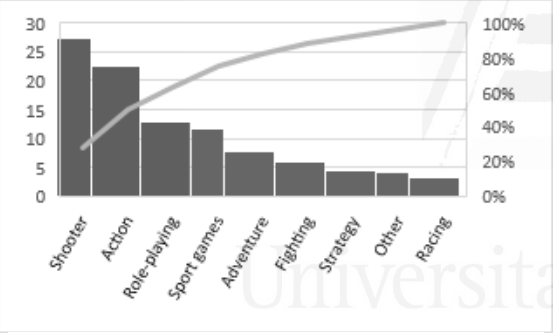


Figure 1. Video game sales in the United States in 2016

According to the World Health Organization's (WHO) international classification of diseases [12], the visual function is divided into four levels:

- Normal vision.
- Moderate visual impairment.
- Severe visual impairment.
- Blindness.

Each disability has its own particularities and therefore its own accessibility parameters.

A prototype of accessible video game for people with visual impairments is proposed by adapting the guidelines for serious game accessibility for the disabled of Park and Kim [13], Besides, the accessible serious video game follows the recommendations proposed by A. Jaramillo and S. Luján [14] for its development. Based on this model, its context is adapted for educational needs.

The serious game designed presents the challenge of identifying the decimal value of a binary number and provides enough time to select the correct option.

The basic game must meet some initial internal characteristics related with the guidelines to develop accessible video games. Table 1 shows the requirements that a videogame targeted to people with visual impairments should consider.

Table 1. Requirements for the video game

Characteristic	Priority
Use simple language	High
Customizable fonts (color, sizes)	High
Enemy marking	High
Accessible menus	High
Allow interfaces to be resized	High
Color-Blind options	High
Adequate distributed virtual controls	High
No essential information in a color alone	High
High-contrast mode	Medium
Use explicit auditory feedback	Medium
Possibility for repetition	Medium
No information outside the player's eye-line	Medium
Customized head-up display	Medium
Save settings	Medium
Turn off/hide background animation	Medium
Pause while text is being read	Medium
Switch off/on graphic elements	Low
Simple to difficult progression	Low
Speed settings	Low
Sound compass o voiced GPS	Low
Text to speech capability	Low
Auto aim, ability to lock on a target	Low
Adjustable sensitivity	Low
No 3D graphics mode	Low
In-game tutorial	Low

2.1 Description of the requirements

The video game has several buttons to reflect and fulfill each of the requirements specified above. Figure 2 shows a description of each control button available on the video game.

The control buttons are used to associate the internal values of accessibility parameters with the game's user interface.

2.1.1 Use simple language

This requirement comes from the first low-level accessibility guideline for video games.

Users demand information and instant action. Clear and simple language makes the game content easy to read and helps all people gather information faster. Texts use simple language to

reinforce the main concepts and skills. The game presents only the minimal text to understand its logic.

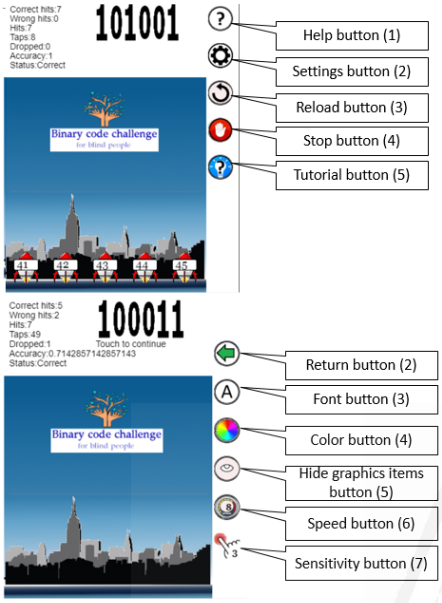


Figure 2. Video game control buttons and the number of keys associated with each of them

2.1.2 *Customizable fonts*

It is possible to customize three kinds of fonts and three combinations of colors from the user interface; also, a great number of combinations can be configured internally, and which can be validated in the Color Blindness Simulator[1]

2.1.3 *Enemy marking*

When the user selects the correct option, the pointer is colored with green and when the wrong option is selected the pointer is colored with red. Besides, a square shape surrounds the option under the pointer.

However, if people cannot distinguish these colors, graphical information is added to the pointer at the time the selection is made.

The Enemy Marking property can be used along with feedback information to help the user understand the status of his or her selection.

2.1.4 *Accessible menus*

The configuration buttons are located at the right side of the screen and can be selected using the pointer, touching on the screen or pressing any key of the keyboard from 1 to 7 in accordance with the position that that button has on the screen. When the user selects a button, a distinctive sound is played. So, the user can associate the position of the button with the sound, and can proceed to play a sequence of sounds to reach a specific configuration.

2.1.5 *Allow interfaces to be resized*

The user interface adapts to the visible area of the screen. All items on the screen change with the interface. However, the resolution of video game depends on the height of the visible area of the screen to maintain the correct dimensions of each element.

2.1.6 *Color-blind options*

The video game has an option to change the color of the graphic elements in the black and white color scheme. This color scheme appears similarly for all diseases related to color blindness. Using the color blindness simulator, it is possible to prove it.

2.1.7 *Adequate distributed virtual controls*

The options to change the values of the features of the game have one-touch controls. This allows the user to select its favorite settings with a simple touch. The controls are located to the right of the user. The space between controls has a suitable distance that can be modified by software code.

2.1.8 *No essential information in a color alone*

The color of information is distributed in three kinds of colors: score, challenge and buttons. However, the color scheme can be changed by using the respective button to select other colors for all elements of the video game. Besides, the information related to the challenge of the game has a special font and color.

2.1.9 *High-contrast mode*

The color settings contain the combination of high contrast colors. The user can then select this option to display the entire video game in high contrast mode.

2.1.10 *Use explicit auditory feedback*

When the user selects an option, the video game plays an audio to indicate whether the selected option is correct or incorrect. Each video game option button has a sound associated with it.

2.1.11 *Possibility for repetition*

Each challenge in the video game can be re-started by giving the player more time to solve it. And, when the game is over, it can be reloaded to start another game. There is a button to this purpose.

2.1.12 *No information outside the player's eye line*

Most important video game information is available directly in front of the user's view. This information includes the main game area, the scoring area and the options menu.

2.1.13 *Customized head-up display*

The head-up screen can be configured with the option menu buttons for various combinations of layouts.

2.1.14 *Save settings*

The configuration of accessibility settings for the video game is stored in the permanent storage of the browser via the local storage function if available. If this function is not available in the browser, this option is ignored.

2.1.15 *Turn off/hide background animation*

The background can be hidden using the appropriate control. The original setup of the shooting game is transformed into a simple configuration without images that can distract the user.

2.1.16 *Pause while text is being read*

It is possible to stop the game by using a specific control made for this purpose. If the user needs to stop the game to read the score or any text considered important, the video game can be stopped.

[1]http://www.color-blindness.com/coblis-color-blindness-simulator

2.1.17 Switch off/on graphic elements

The same control designed to hide the background allows the user to turn on/off graphic elements of the video game. This minimizes the number of distracting elements.

2.1.18 Simple to difficult progression

The game is designed to increase the level of difficulty in each challenge. It starts by proposing the identification of low-digit binary numbers and increases the number of digits in each new challenge.

2.1.19 Speed settings

The speed of the video game can be increased by using the appropriate control designed for this purpose.

2.1.20 Sound compass o voiced GPS

Although the video game does not have an audible compass, a clock sound is included to indicate the possible position of the options or the time remaining before the challenge ends.

2.1.21 Text to speech capability

Every piece of important information is audibly reproduced to the user for hearing assistance.

2.1.22 Auto aim, ability to lock on a target

The video game allows enclosing with a rectangle the option on which the pointer is located at a certain moment.

2.1.23 Adjustable sensitivity

The touch sensitivity can be adjusted with the appropriate control designed for this purpose.

2.1.24 No 3D graphics mode

The video game was developed in 2D interface to facilitate the comprehension and usability of the same.

2.1.25 In-game tutorial

The tutorial button displays a screen with information on how resolve any challenge.

3. SERIOUS GAME ANALYSIS

Many people learn by playing. It is not surprising, then, that educational videogames are also being made aware of those people who have some kind of disability and who find space as a recreational tool for people with disabilities.

Ainscow, Booth and Dyson [15] refer to three variables for any student's school life: presence, learning and participation. Participation, in this case, has been neglected in the development of video games aimed at educating people with certain types of diseases. In this way, people involved in the development of video games can also contribute to the generation of educational products by providing technological solutions to the needs of people with different disabilities.

The experience of using serious games, however, may differ between users, as with any type of learning material. For this reason, this article proposes a solution that joins a vast list of attempts to make education increasingly inclusive. The user requirements are collected according to the accessibility needs of each individual [16].

The programming of the serious game presented in this paper contains in its code the parameterization process which allows its adaptability to different types of disabilities. The adaptation would be made according to the changing requirements of each user and can be evaluated with the appropriate procedures [17]. It would be enough to associate the internal parameterization implemented in the coding with new controls in the user interface to allow those variables to be modified by the user.

A copy of the last version of the video game is available in Internet[2]

4. CONCLUSIONS AND FUTURE WORK

This research aims to contribute to the learning and entertainment methodologies for the visually impaired, which cannot access serious games due to their condition. It is important to promote these kinds of initiatives in order to include accessibility parameters in the design and implementation of video games. The availability of serious, non-accessible games contradicts Article 24 in the United Nations Convention on the Rights of Persons with Disabilities [18] because it prevents persons with disabilities from having access to equitable education compared to persons without disabilities.

In recent years, the mobile devices market has grown and with them access to video games has also increased. This is a great opportunity for serious games as they can be incorporated into this market segment. This study allows us to exemplify in a simple serious game the importance of incorporating accessibility into videogames, especially those related to education. It also opens up new opportunities to generate new learning mechanisms for students. This type of video game would allow learning objectives to be achieved in educational institutions regardless of the area of focus of the game.

Education is an area with high potential for application of video games since it seeks to promote people's motivation and engagement [19]. In addition, the attitude of students towards new tools is often positive [20]. However, in some studies it was observed that, over time, gamified students were less motivated, strengthened and satisfied [21]. An alternative is the use of social gamification since it yields better results [22]. Although, the effectiveness of gamification varies according to the individual attributes [23]. Some studies suggest that, in certain contexts, the elements of the game act as extrinsic incentives [24]. It is necessary to determine what these contexts are, in this idea, the develop of serious video games is supported.

On the other hand, in the future it is proposed to carry out accessibility and acceptance tests with visually impaired people in order to validate the effectiveness of the video game. More accessibility features could also be included, as well as focusing on another disability therefore it is important to continue to develop accessible video games and provide better opportunities for people with disabilities. Achieving an inclusive design as a model for the development of video games is part of the challenges considered by future research work.

5. REFERENCES

[1] WHO, W. 2011. World Report. World report on disability. WHO/NMH/VIP/11.01 (Geneva, 2011).

[2] Ulicsak, M. 2010. Games in Education: Serious Games. *A FutureLab Literature Review*. FutureLab. (2010), 139.

[3] The global games market will reach $108.9 billion in 2017 with mobile taking 42%: 2017. https://newzoo.com/insights/articles/the-global-games-

[2] http://saccec.com/juego

market-will-reach-108-9-billion-in-2017-with-mobile-taking-42/.

[4] Romero, M. et al. 2014. Can Serious Games Contribute to Developing and Sustaining 21st Century Skills? *Games and Culture*. SAGE Publishing. 10, 2 (Sep. 2014), 148-177. DOI= https://doi.org/10.1177/1555412014548919.

[5] Parsons, D. et al. 2012. Mobile gaming - A serious business! In *Proceedings 2012 17th IEEE International Conference on Wireless, Mobile and Ubiquitous Technology in Education*. (Takamatsu, Japan, March 27 - 30, 2012), WMUTE '12. IEEE, 17-24. DOI= 10.1109/WMUTE.2012.11.

[6] Steinmetz, R. and Göbel, S. 2012. Challenges in serious gaming as emerging multimedia technology for education, training, sports and health. In *Proceedings of the 18th international conference on Advances in Multimedia Modeling Lecture Notes in Computer Science*. (Klagenfurt, Austria, January 04 - 06, 2012). MMM '12. ACM, New York, NY, 3. DOI= https://doi.org/10.1007/978-3-642-27355-1.

[7] Fell, E. 2017. Against Discrimination: Equality Act 2010 (UK). DOI= 10.15405/epsbs.2017.01.25

[8] International Organization for Standardization (ISO). 2008. ISO 9241-171:2008. *Ergonomics of human-system interaction - Part 171*. Guidance on software accessibility. Geneva.

[9] Bierre, K. et al. 2005. Game not over: Accessibility issues in video games. In *Proceedings of the 3rd International Conference on Universal Access in Human Computer Interaction*. (Las Vegas NV, USA, July 22 - 27, 2005), UAHCI '05. 22-27. DOI= https://doi.org/0-8058-5807-5.

[10] Entertainment Software Association. 2016. Essential facts 2017. *ESA Report 2017*. 2016, (2016), 1–3.

[11] Battersby S. 2013. *A Flexible Object Orientated Design Approach for the Realisation of Assistive Technology*. Doctoral Thesis. Nottingham Trent University. 18-19.

[12] International Classification of Diseases (ICD) 10. 2016.

[13] Park, H.J. and Kim, S.B. 2013. Guidelines of serious game accessibility for the disabled. In *Proceedings of 2013 International Conference on Information Science and Applications*. (Suwon, South Korea, June 24 -26, 2013). ICISA '13. IEEE. 1-3. DOI= 10.1109/ICISA.2013.6579380.

[14] Jaramillo-Alcázar, A. and Luján-Mora, S. 2017. Mobile Serious Games: An Accessibility Assessment for People with Visual Impairments. In *Proceedings of International Conference Technological Ecosystems for Enhancing Multiculturality*. (Cadiz, Spain, October 18 - 20, 2017), TEEM '17. ACM, New York, NY.

[15] Ainscow, M. et al. 2006. Improving Schools, Developing Inclusion? Improving Schools. *Developing Inclusion*. 1-27. DOI= https://doi.org/10.4324/9780203967157.

[16] Miñón, R. et al. 2014. An approach to the integration of accessibility requirements into a user interface development method. *Science of Computer Programming*. Elsevier, 86, (Jun. 2014), 58-73. DOI= https://doi.org/10.1016/j.scico.2013.04.005.

[17] Evers, C. et al. 2014. The user in the loop: Enabling user participation for self-adaptive applications. *Future Generation Computer Systems*. 34, (May. 2014), 110-123. DOI= https://doi.org/10.1016/j.future.2013.12.010.

[18] United Nations. 2006. Convention on the rights of persons with disabilities. *Treaty Series*. 2515, (New York, USA, December 13, 2006), 3.

[19] Simões, J., Redondo, R. D. and Vilas, A. F. 2013. A social gamification framework for a K-6 learning platform. *Computers in Human Behavior*, 29, 2, (Mar. 2013), 345-353. DOI= https://doi.org/10.1016/j.chb.2012.06.007.

[20] de-Marcos, L., Domínguez, A., Saenz-de-Navarrete, J. and Pagés, C. 2014. An empirical study comparing gamification and social networking on e-learning. *Computers & Education*, 75, (Jun. 2014), 82-91. DOI= https://doi.org/10.1016/j.compedu.2014.01.012.

[21] Hanus, M. D. and Fox, J. 2015. Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & Education*, 80, (Jan. 2015), 152-161. DOI= https://doi.org/10.1016/j.compedu.2014.08.019.

[22] de-Marcos, L., Garcia-Lopez, E. and Garcia-Cabot, A. 2016. On the effectiveness of game-like and social approaches in learning: Comparing educational gaming, gamification & social networking. *Computers & Education*, 95, (Apr. 2016) 99-113. DOI= https://doi.org/10.1016/j.compedu.2015.12.008.

[23] Buckley, P. and Doyle, E. 2017. Individualising gamification: An investigation of the impact of learning styles and personality traits on the efficacy of gamification using a prediction market. *Computers & Education*, 106, (Mar. 2017), 43-55. DOI= https://doi.org/10.1016/j.compedu.2016.11.009.

[24] Mekler, E. D., Brühlmann, F., Tuch, A. N. and Opwis, K. 2017. Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior*, 71, (Jun. 2017), 525-534. DOI= https://doi.org/10.1016/j.chb.2015.08.048.

8 A Serious Game Accessible to People with Visual Impairments

Referencia:
Salvador-Ullauri, L., Jaramillo-Alcázar, A., Luján-Mora, S. (2017). A Serious Game Accessible to People with Visual Impairments. En: Proceedings of the 2017 9th International Conference on Education Technology and Computers (pp. 84–88). ACM. 10.1145/3175536.3175576 (Salvador-Ullauri y otros, 2017)

Disponible en:

- https://dl.acm.org/doi/10.1145/3175536.3175576
- https://doi.org/10.1145/3175536.3175576

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico en usuarios con discapacidad visual.

A Serious Game Accessible to People with Visual Impairments

Luis Salvador-Ullauri
Escuela Politécnica Nacional
Ladrón de Guevara E11-253, Ecuador
593-2-2976300
lsalvador@cec-epn.edu.ec

Angel Jaramillo-Alcázar
Universidad de Las Américas
Av. Granados E12-41, Ecuador
593-2-3981000 ext. 172
angel.jaramillo@udla.edu.ec

Sergio Luján-Mora
University of Alicante
San Vicente del Raspeig s/n, Spain
34-9-65903400 ext. 2962
sergio.lujan@ua.es

ABSTRACT
Serious games allow people to learn through fun activities. This type of video game has a growing demand and its use has spread to several areas of education. However, accessibility for several kinds of disabilities has not been considered in its design due to the challenges it poses. However, there are video game development companies that have defined certain accessibility guidelines for several kinds of impairments. Many accessible games have been evaluated for different types of impediments and a set of high and low-level accessibility strategies has been obtained so that game developers can use them to improve their designs. These initiatives allow the development of serious accessible games in different areas of education. This article presents a serious game proposal accessible to people with visual impairments. The video game is aimed at reinforcing the binary calculation skills of engineering students.

CCS Concepts
• **Human-centered computing** → **Accessibility design and evaluation methods** • **Theory of computation** → **Convergence and learning in games** • **Applied computing** → **Interactive learning environments.**

Keywords
Accessibility; binary calculation; disabilities; serious games.

1. INTRODUCTION
The number of people with disabilities is growing all over the world [1] and this has originated initiatives where accessibility has taken center stage. Serious games are a category of video games designed to support educational processes [2].

Nowadays, the video gaming industry is one of the fastest growing areas. Revenues from digital games represent $94.4 billion, or 87 % of the world market. [3]. One of the reasons why gaming is thriving is due to the fact that it consists of many segments; as a result, the development of serious games has also increased. Serious games allow teachers to apply new teaching methods, and are widely recognized as having considerable potential to foster and support active learning [4].

Serious gaming is becoming a successful business, reaching into defense training, education, medicine, and policy [5]. A diverse set of industries such as education, health care, defense, and even politics, among others, are utilizing serious games for training purposes [6].

On the other hand, around 15 % of people worldwide have a disability. Disability affects hundreds of millions of families in developing countries. More than one billion people in the world live with some form of disability, of whom nearly 200 million experience considerable functional difficulties[1]. These people have to live with social, educational and entertainment limitations because of their disabilities. Many people with disabilities do not have equal access to health care, education, employment opportunities, and disability-related services, facing exclusion from daily life activities [1]. There is powerful evidence on the impact of barriers encountered by disabled people on a daily basis as a consequence of the inaccessibility to tools [7].

Accessibility can be defined as "the usability of a product, service, environment or facility by people with the widest range of capabilities" [8]. In addition, accessibility in video games is a factor that should be considered in software development [9].

Taking into account the large number of people with disabilities, it is important to offer alternatives for academic reinforcement based on the different needs identified in engineering studies and considering improvement levels if accessibility parameters are included. This article presents a serious game proposal for the reinforcement of binary calculus with accessibility features for people with visual impairments. In this way, students with this type of disability can use the game as well as those who do not have a disability condition.

The rest of this article is organized as follows: Section 2 details the method of development of the proposed application; Section 3 discusses the results of the developed application; Section 4 concludes the research and outlines future work.

2. DEVELOPMENT OF SERIOUS ACCESSIBLE PLAY
In order to develop the proposed serious game, a specific model was chosen among several models of existing simple video games such as: puzzles, obstacles and shooting. Of the three model options, the shooting model was chosen because it is the easiest to adapt for selecting different options. In addition, shooting games were the best-selling video games in the United States in 2016 (see Figure 1); the United States is the country with the most active players in the world in accordance with data taken from the 2016 Essential Facts About the Computer and Video Game Industry report [10].

ICETC 2017, December 20–22, 2017, Barcelona, Spain

ACM ISBN 978-1-4503-5435-6/17/12…$15.00
https://doi.org/10.1145/3175536.3175576

Besides, tens of millions of disabled consumers have relied on video games as a source of relief from their infirmities, as well as a sense of accomplishment or belonging, according to the survey conducted by Information Solutions Group on behalf of PopCap Games.

According to the survey, more than one in five (20.5%) casual video game players has a physical, mental or developmental disability. A total of 13,296 casual game players responded to the survey, with 2,728 respondents (20.5%) identifying themselves as "mildly" (22%), "moderately" (54%) or "severely" (24%) disabled; of those, 46% indicated that their primary disability was physical, 29% said it was mental, and 25% stated they had a developmental or learning disability. Over two thirds (69%) of disabled respondents were female, and a third (35%) of all respondents had another person such as a parent, adult offspring, spouse, guardian or caregiver assist them in taking the survey.

These results are based on online surveys completed by 2,728 respondents randomly selected between April 2 and April 17, 2008. In theory, in 19 cases out of 20, the results will differ by no more than 1.9 percentage points from what would have been obtained by seeking out and polling all PopCap.com users. Survey subjects were presented with exhaustive lists of various types of disabilities organized by category in order to assist in accurately categorizing themselves [11].

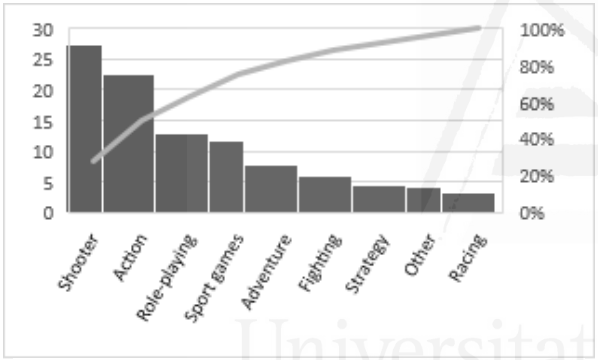


Figure 1. Video game sales in the United States in 2016

According to the World Health Organization's (WHO) international classification of diseases [12], the visual function is divided into four levels:

- Normal vision.
- Moderate visual impairment.
- Severe visual impairment.
- Blindness.

Each disability has its own particularities and therefore its own accessibility parameters.

A prototype of accessible video game for people with visual impairments is proposed by adapting the guidelines for serious game accessibility for the disabled of Park and Kim [13], Besides, the accessible serious video game follows the recommendations proposed by A. Jaramillo and S. Luján [14] for its development. Based on this model, its context is adapted for educational needs.

The serious game designed presents the challenge of identifying the decimal value of a binary number and provides enough time to select the correct option.

The basic game must meet some initial internal characteristics related with the guidelines to develop accessible video games. Table 1 shows the requirements that a videogame targeted to people with visual impairments should consider.

Table 1. Requirements for the video game

Characteristic	Priority
Use simple language	High
Customizable fonts (color, sizes)	High
Enemy marking	High
Accessible menus	High
Allow interfaces to be resized	High
Color-Blind options	High
Adequate distributed virtual controls	High
No essential information in a color alone	High
High-contrast mode	Medium
Use explicit auditory feedback	Medium
Possibility for repetition	Medium
No information outside the player's eye-line	Medium
Customized head-up display	Medium
Save settings	Medium
Turn off/hide background animation	Medium
Pause while text is being read	Medium
Switch off/on graphic elements	Low
Simple to difficult progression	Low
Speed settings	Low
Sound compass o voiced GPS	Low
Text to speech capability	Low
Auto aim, ability to lock on a target	Low
Adjustable sensitivity	Low
No 3D graphics mode	Low
In-game tutorial	Low

2.1 Description of the requirements

The video game has several buttons to reflect and fulfill each of the requirements specified above. Figure 2 shows a description of each control button available on the video game.

The control buttons are used to associate the internal values of accessibility parameters with the game's user interface.

2.1.1 Use simple language

This requirement comes from the first low-level accessibility guideline for video games.

Users demand information and instant action. Clear and simple language makes the game content easy to read and helps all people gather information faster. Texts use simple language to

reinforce the main concepts and skills. The game presents only the minimal text to understand its logic.

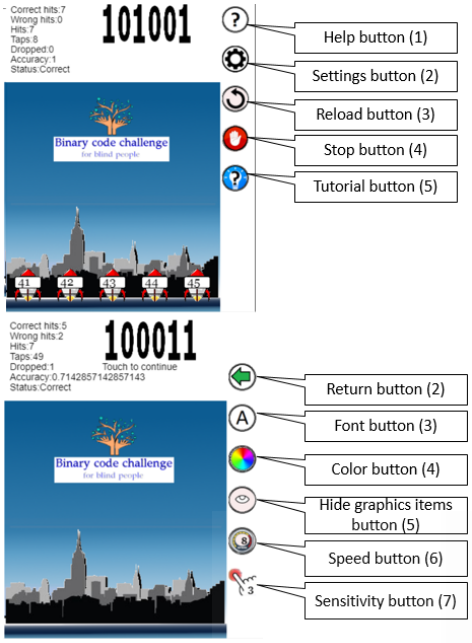


Figure 2. Video game control buttons and the number of keys associated with each of them

2.1.2 Customizable fonts

It is possible to customize three kinds of fonts and three combinations of colors from the user interface; also, a great number of combinations can be configured internally, and which can be validated in the Color Blindness Simulator[1]

2.1.3 Enemy marking

When the user selects the correct option, the pointer is colored with green and when the wrong option is selected the pointer is colored with red. Besides, a square shape surrounds the option under the pointer.

However, if people cannot distinguish these colors, graphical information is added to the pointer at the time the selection is made.

The Enemy Marking property can be used along with feedback information to help the user understand the status of his or her selection.

2.1.4 Accessible menus

The configuration buttons are located at the right side of the screen and can be selected using the pointer, touching on the screen or pressing any key of the keyboard from 1 to 7 in accordance with the position that that button has on the screen. When the user selects a button, a distinctive sound is played. So, the user can associate the position of the button with the sound, and can proceed to play a sequence of sounds to reach a specific configuration.

[1]http://www.color-blindness.com/coblis-color-blindness-simulator

2.1.5 Allow interfaces to be resized

The user interface adapts to the visible area of the screen. All items on the screen change with the interface. However, the resolution of video game depends on the height of the visible area of the screen to maintain the correct dimensions of each element.

2.1.6 Color-blind options

The video game has an option to change the color of the graphic elements in the black and white color scheme. This color scheme appears similarly for all diseases related to color blindness. Using the color blindness simulator, it is possible to prove it.

2.1.7 Adequate distributed virtual controls

The options to change the values of the features of the game have one-touch controls. This allows the user to select its favorite settings with a simple touch. The controls are located to the right of the user. The space between controls has a suitable distance that can be modified by software code.

2.1.8 No essential information in a color alone

The color of information is distributed in three kinds of colors: score, challenge and buttons. However, the color scheme can be changed by using the respective button to select other colors for all elements of the video game. Besides, the information related to the challenge of the game has a special font and color.

2.1.9 High-contrast mode

The color settings contain the combination of high contrast colors. The user can then select this option to display the entire video game in high contrast mode.

2.1.10 Use explicit auditory feedback

When the user selects an option, the video game plays an audio to indicate whether the selected option is correct or incorrect. Each video game option button has a sound associated with it.

2.1.11 Possibility for repetition

Each challenge in the video game can be re-started by giving the player more time to solve it. And, when the game is over, it can be reloaded to start another game. There is a button to this purpose.

2.1.12 No information outside the player's eye line

Most important video game information is available directly in front of the user's view. This information includes the main game area, the scoring area and the options menu.

2.1.13 Customized head-up display

The head-up screen can be configured with the option menu buttons for various combinations of layouts.

2.1.14 Save settings

The configuration of accessibility settings for the video game is stored in the permanent storage of the browser via the local storage function if available. If this function is not available in the browser, this option is ignored.

2.1.15 Turn off/hide background animation

The background can be hidden using the appropriate control. The original setup of the shooting game is transformed into a simple configuration without images that can distract the user.

2.1.16 Pause while text is being read

It is possible to stop the game by using a specific control made for this purpose. If the user needs to stop the game to read the score or any text considered important, the video game can be stopped.

2.1.17 Switch off/on graphic elements

The same control designed to hide the background allows the user to turn on/off graphic elements of the video game. This minimizes the number of distracting elements.

2.1.18 Simple to difficult progression

The game is designed to increase the level of difficulty in each challenge. It starts by proposing the identification of low-digit binary numbers and increases the number of digits in each new challenge.

2.1.19 Speed settings

The speed of the video game can be increased by using the appropriate control designed for this purpose.

2.1.20 Sound compass o voiced GPS

Although the video game does not have an audible compass, a clock sound is included to indicate the possible position of the options or the time remaining before the challenge ends.

2.1.21 Text to speech capability

Every piece of important information is audibly reproduced to the user for hearing assistance.

2.1.22 Auto aim, ability to lock on a target

The video game allows enclosing with a rectangle the option on which the pointer is located at a certain moment.

2.1.23 Adjustable sensitivity

The touch sensitivity can be adjusted with the appropriate control designed for this purpose.

2.1.24 No 3D graphics mode

The video game was developed in 2D interface to facilitate the comprehension and usability of the same.

2.1.25 In-game tutorial

The tutorial button displays a screen with information on how resolve any challenge.

3. SERIOUS GAME ANALYSIS

Many people learn by playing. It is not surprising, then, that educational videogames are also being made aware of those people who have some kind of disability and who find space as a recreational tool for people with disabilities.

Ainscow, Booth and Dyson [15] refer to three variables for any student's school life: presence, learning and participation. Participation, in this case, has been neglected in the development of video games aimed at educating people with certain types of diseases. In this way, people involved in the development of video games can also contribute to the generation of educational products by providing technological solutions to the needs of people with different disabilities.

The experience of using serious games, however, may differ between users, as with any type of learning material. For this reason, this article proposes a solution that joins a vast list of attempts to make education increasingly inclusive. The user requirements are collected according to the accessibility needs of each individual [16].

The programming of the serious game presented in this paper contains in its code the parameterization process which allows its adaptability to different types of disabilities. The adaptation would be made according to the changing requirements of each user and can be evaluated with the appropriate procedures [17]. It would be enough to associate the internal parameterization implemented in the coding with new controls in the user interface to allow those variables to be modified by the user.

A copy of the last version of the video game is available in Internet[2]

4. CONCLUSIONS AND FUTURE WORK

This research aims to contribute to the learning and entertainment methodologies for the visually impaired, which cannot access serious games due to their condition. It is important to promote these kinds of initiatives in order to include accessibility parameters in the design and implementation of video games. The availability of serious, non-accessible games contradicts Article 24 in the United Nations Convention on the Rights of Persons with Disabilities [18] because it prevents persons with disabilities from having access to equitable education compared to persons without disabilities.

In recent years, the mobile devices market has grown and with them access to video games has also increased. This is a great opportunity for serious games as they can be incorporated into this market segment. This study allows us to exemplify in a simple serious game the importance of incorporating accessibility into videogames, especially those related to education. It also opens up new opportunities to generate new learning mechanisms for students. This type of video game would allow learning objectives to be achieved in educational institutions regardless of the area of focus of the game.

Education is an area with high potential for application of video games since it seeks to promote people's motivation and engagement [19]. In addition, the attitude of students towards new tools is often positive [20]. However, in some studies it was observed that, over time, gamified students were less motivated, strengthened and satisfied [21]. An alternative is the use of social gamification since it yields better results [22]. Although, the effectiveness of gamification varies according to the individual attributes [23]. Some studies suggest that, in certain contexts, the elements of the game act as extrinsic incentives [24]. It is necessary to determine what these contexts are, in this idea, the develop of serious video games is supported.

On the other hand, in the future it is proposed to carry out accessibility and acceptance tests with visually impaired people in order to validate the effectiveness of the video game. More accessibility features could also be included, as well as focusing on another disability therefore it is important to continue to develop accessible video games and provide better opportunities for people with disabilities. Achieving an inclusive design as a model for the development of video games is part of the challenges considered by future research work.

5. REFERENCES

[1] WHO, W. 2011. World Report. World report on disability. WHO/NMH/VIP/11.01 (Geneva, 2011).

[2] Ulicsak, M. 2010. Games in Education: Serious Games. *A FutureLab Literature Review*. FutureLab. (2010), 139.

[3] The global games market will reach $108.9 billion in 2017 with mobile taking 42%: 2017. https://newzoo.com/insights/articles/the-global-games-

[2] http://saccec.com/juego

market-will-reach-108-9-billion-in-2017-with-mobile-taking-42/.

[4] Romero, M. et al. 2014. Can Serious Games Contribute to Developing and Sustaining 21st Century Skills? *Games and Culture*. SAGE Publishing. 10, 2 (Sep. 2014), 148-177. DOI= https://doi.org/10.1177/1555412014548919.

[5] Parsons, D. et al. 2012. Mobile gaming - A serious business! In *Proceedings 2012 17th IEEE International Conference on Wireless, Mobile and Ubiquitous Technology in Education*. (Takamatsu, Japan, March 27 - 30, 2012), WMUTE '12. IEEE, 17-24. DOI= 10.1109/WMUTE.2012.11.

[6] Steinmetz, R. and Göbel, S. 2012. Challenges in serious gaming as emerging multimedia technology for education, training, sports and health. In *Proceedings of the 18th international conference on Advances in Multimedia Modeling Lecture Notes in Computer Science*. (Klagenfurt, Austria, January 04 - 06, 2012). MMM '12. ACM, New York, NY, 3. DOI= https://doi.org/10.1007/978-3-642-27355-1.

[7] Fell, E. 2017. Against Discrimination: Equality Act 2010 (UK). DOI= 10.15405/epsbs.2017.01.25

[8] International Organization for Standardization (ISO). 2008. ISO 9241-171:2008. *Ergonomics of human-system interaction - Part 171*. Guidance on software accessibility. Geneva.

[9] Bierre, K. et al. 2005. Game not over: Accessibility issues in video games. In *Proceedings of the 3rd International Conference on Universal Access in Human Computer Interaction*. (Las Vegas NV, USA, July 22 - 27, 2005), UAHCI '05. 22-27. DOI= https://doi.org/0-8058-5807-5.

[10] Entertainment Software Association. 2016. Essential facts 2017. *ESA Report 2017*. 2016, (2016), 1–3.

[11] Battersby S. 2013. *A Flexible Object Orientated Design Approach for the Realisation of Assistive Technology*. Doctoral Thesis. Nottingham Trent University. 18-19.

[12] International Classification of Diseases (ICD) 10. 2016.

[13] Park, H.J. and Kim, S.B. 2013. Guidelines of serious game accessibility for the disabled. In *Proceedings of 2013 International Conference on Information Science and Applications*. (Suwon, South Korea, June 24 -26, 2013). ICISA '13. IEEE. 1-3. DOI= 10.1109/ICISA.2013.6579380.

[14] Jaramillo-Alcázar, A. and Luján-Mora, S. 2017. Mobile Serious Games: An Accessibility Assessment for People with Visual Impairments. In *Proceedings of International Conference Technological Ecosystems for Enhancing Multiculturality*. (Cadiz, Spain, October 18 - 20, 2017), TEEM '17. ACM, New York, NY.

[15] Ainscow, M. et al. 2006. Improving Schools, Developing Inclusion? Improving Schools. *Developing Inclusion*. 1-27. DOI= https://doi.org/10.4324/9780203967157.

[16] Miñón, R. et al. 2014. An approach to the integration of accessibility requirements into a user interface development method. *Science of Computer Programming*. Elsevier, 86, (Jun. 2014), 58-73. DOI= https://doi.org/10.1016/j.scico.2013.04.005.

[17] Evers, C. et al. 2014. The user in the loop: Enabling user participation for self-adaptive applications. *Future Generation Computer Systems*. 34, (May. 2014), 110-123. DOI= https://doi.org/10.1016/j.future.2013.12.010.

[18] United Nations. 2006. Convention on the rights of persons with disabilities. *Treaty Series*. 2515, (New York, USA, December 13, 2006), 3.

[19] Simões, J., Redondo, R. D. and Vilas, A. F. 2013. A social gamification framework for a K-6 learning platform. *Computers in Human Behavior*, 29, 2, (Mar. 2013), 345-353. DOI= https://doi.org/10.1016/j.chb.2012.06.007.

[20] de-Marcos, L., Domínguez, A., Saenz-de-Navarrete, J. and Pagés, C. 2014. An empirical study comparing gamification and social networking on e-learning. *Computers & Education*, 75, (Jun. 2014), 82-91. DOI= https://doi.org/10.1016/j.compedu.2014.01.012.

[21] Hanus, M. D. and Fox, J. 2015. Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & Education*, 80, (Jan. 2015), 152-161. DOI= https://doi.org/10.1016/j.compedu.2014.08.019.

[22] de-Marcos, L., Garcia-Lopez, E. and Garcia-Cabot, A. 2016. On the effectiveness of game-like and social approaches in learning: Comparing educational gaming, gamification & social networking. *Computers & Education*, 95, (Apr. 2016) 99-113. DOI= https://doi.org/10.1016/j.compedu.2015.12.008.

[23] Buckley, P. and Doyle, E. 2017. Individualising gamification: An investigation of the impact of learning styles and personality traits on the efficacy of gamification using a prediction market. *Computers & Education*, 106, (Mar. 2017), 43-55. DOI= https://doi.org/10.1016/j.compedu.2016.11.009.

[24] Mekler, E. D., Brühlmann, F., Tuch, A. N. and Opwis, K. 2017. Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior*, 71, (Jun. 2017), 525-534. DOI= https://doi.org/10.1016/j.chb.2015.08.048.

9 Accessibility Evaluation of Video Games for Users with Cognitive Disabilities

Referencia:
Salvador-Ullauri, L. and Acosta-Vargas, P. and Luján-Mora, S. (2020). Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. En: International Conference on Intelligent Human Systems Integration (IHSI) (pp. 853-859). Springer, Cham. (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020)

Disponible en:

- https://link.springer.com/chapter/10.1007/978-3-030-39512-4_130
- https://doi.org/10.1007/978-3-030-39512-4_130

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico: juegos serios destinados a usuarios con discapacidad cognitiva.
3. Evaluación del nivel de accesibilidad de los juegos serios para personas con discapacidad cognitiva.

Accessibility Evaluation of Video Games for Users with Cognitive Disabilities

Luis Salvador-Ullauri[1], Patricia Acosta-Vargas[2(✉)], and Sergio Luján-Mora[1]

[1] Department of Software and Computing Systems, University of Alicante, Alicante, Spain
lasul@alu.ua.es, sergio.lujan@ua.es
[2] Intelligent and Interactive Systems Lab, Universidad de Las Américas, Quito, Ecuador
patricia.acosta@udla.edu.ec

Abstract. Currently, there are many students with cognitive problems to learn new concepts in theoretical classes. For students to improve the learning process from the knowledge transmitted in class, we propose a method to motivate the development of computer applications to reinforce the learning of new concepts. This research presents a method for evaluation of accessible video games. In order to evaluate accessibility in a videogame, the Web Content Accessibility Guidelines 2.1 will be considered, which includes barriers for users with cognitive disabilities. This category of users involves people with limited ability to process and memorize information, make decisions, or learn. The proposed method can be replicated for users with other types of disabilities and can be applied during the game development cycle to ensure a more inclusive and accessible product.

Keywords: Accessibility · Cognitive · Disabilities · Evaluation · Method · Video games · WCAG 2.1

1 Introduction

Today, video games are fascinating to observe, fun to play, and very attractive to students. Besides, educational video games allow students to develop useful cognitive skills, which may be essential in the course of their lives. Education with video games improves some aspects of cognitive functioning [1], such as memory, attention span, and reaction time, as well as multitasking and general cognitive control [2]. At present, the number of students with learning difficulties accessing university environments is increasing [3–5], highlighting the importance of making adaptations that correspond to the needs of the new students. In order to improve students' understanding of the different concepts taught in class, the design and development of accessible video games are used. However, it is necessary to establish design guidelines to develop truly accessible video games that improve the understanding of the information of each subject. The Convention on the Rights of Persons with Disabilities (CRPD) [6] establishes the right of access to information for all people, using accessible formats

and appropriate technologies that mainly assist people with different disabilities. Therefore, accessibility parameters must be taken into account by developers when programming applications [7]. Research is taking on the challenge of implementing video games to improve the education of people with cognitive disabilities [8]. However, most research on games for cognitive disabilities are focused on therapy and rehabilitation. Of this way, a work about the use of serious games [9] establishes a set of design principles aimed at the appropriate development of educational games for people with cognitive disabilities. In order to verify these guidelines and establish the cognitive barriers presented in serious video games, a group of ten video games will be evaluated using these design principles and those established by the Web Content Accessibility Guidelines (WCAG) 2.1 [10]. These principles are used in order to evaluate ten serious games taken from PhET project of the Colorado University. Consequently, this study firstly proposes to apply these principles to evaluate developed serious games and then, to develop improved serious game using the lessons learned.

The rest of the article is structured as follows: Sect. 2 includes the background and related work. Section 3 presents the method; Sect. 4 presents the results and the discussion. Finally, Sect. 5 presents conclusions and future work.

2 Background and Related Work

Currently, there are several investigations on the use of educational video games to improve the cognitive process of students of different ages. The Learning Strategies Program, funded by the Defense Advanced Research Projects Agency, was the entity that carried out the most systematic and remarkable attempt to use video games to understand and improve human performance and cognition [11]. Many brain training programs have been conducted and, in conclusion, it has been stated that video games can significantly improve cognitive function [12]. However, even games that promote intellectual challenge are not always effective in inducing cognitive improvement in players [13]. Besides, training studies suggest that differences between non-players and players are not only correlative but that there is a causal relationship between improved perceptual and cognitive abilities and the use of educational video games [14]. Space capability has been shown to play an essential role in achievements in the disciplines of science, technology, engineering, and mathematics (STEM). One way to improve spatial capacity is through video gameplay [15].

Therefore, these works suggest that playing video games may have perceptual and cognitive benefits. However, the implementation of accessible video games intended to aid cognitive development is a relatively new idea. Two studies reviewed whether action video games can have a perceptual effect on children's perception. First study analyzes perceptual benefits of video game use [16], while the second study deals with the cognitive benefits of using such video games [17]. These studies together conclude that using video games improves working memory, but not perceptual processing speed. Therefore, educational video games have been observed to have positive effects that include improved learning, promotion of personal development, the ability to motivate people, and mental/physical rehabilitation. It is necessary to bear in mind that

multimedia content, such as educational video games and simulations in general, present accessibility challenges that must be addressed in order to maintain the inclusion of e-learning [18]. Although the accessibility of websites is reasonably covered, in other areas, such as the development of video games and serious simulations, attempts are still being made to find the most appropriate way to improve accessibility [19, 20]. In this context, educational accessibility technologies can affect the future opportunities of people with cognitive problems due to limited means of access. Thus, other work has focused on providing design guidelines for the design of user interfaces and simple methodologies for the development of accessible educational video games [19]. Therefore, serious games use strategies that are often applied in special education, such as immediate feedback, context-based teaching and learning, and repetition [21].

Thus, in some cases, the ineffectiveness of educational video games may be the result of usability and accessibility problems not considered in their design [22]. It is because of these design issues that many developers of educational video games and simulations seek to create simple design interfaces that are attractive and fun while improving users' memory and attention skills [23]. Similarly, design guidelines have been defined that continue to work well for evaluating finished games and have increased awareness of accessibility in educational games [24]. WCAG include requirements that address cognitive accessibility that is used to validate and generate a subset of guidelines aimed at evaluating selected serious video games.

3 Method

Figure 1 summarizes the method applied by WCAG 2.1 for the evaluation of video games, involving a process with nine sequential steps.

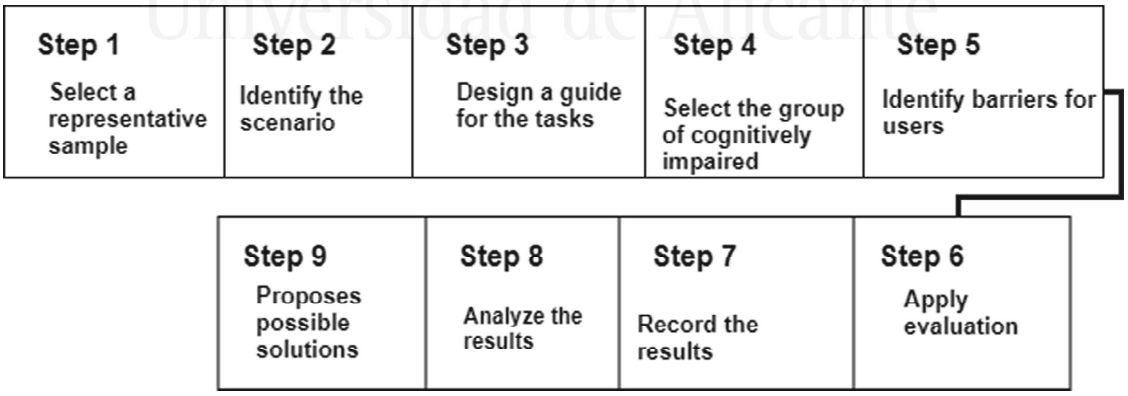


Fig. 1. Method for evaluating accessibility in video games

Serious video games were selected based on the relationship between game performance and specific cognitive skills related to mathematics. The name of the ten serious games evaluated are Area Builder, Area Model Algebra, Area Model Decimal,

Area Model Introduction, Area Model Multiplication, Arithmetic, Build a fraction, Fraction matcher, Fractions equality and, Fractions mixed numbers. These video games belong to the set of educational video games offered in the PhET project of the University of Colorado[1]. The tasks performed in order to evaluate the selected educational video games include the considerations listed in Table 1, contains the identificatory, group, consideration, and, WCAG 2.1.

Table 1. List of tasks performed on the evaluated video games

Id	Group	Consideration	Guideline WCAG 2.1
A	Interface	A limited number of objects	Navigable
B	Interface	Enough size of objects	Readable
C	User control	Enough time to interact with the objects	Enough time
D	User control	Button to restart the game	Input assistance
E	Identification with the game	Motivational elements	Input assistance
F	Identification with the game	Configurable elements	Input assistance
G	Feedback	Rewarding mechanisms	Input assistance
H	Feedback	Simple texts to show results	Predictable
I	Transmission of concepts	Representation of concepts clearly	Readable
J	Transmission of concepts	Implicit educational content	Predictable

In order to identify the exact scenario to evaluate these video games is necessary to consider that a game is usable when the players do not have to struggle with the game interface, and the game mechanic is understandable to the player [25]. Five users who had learning problems in Mathematics were selected to evaluate the games. According to Nielsen et al., the best results come from testing with no more than five users. The reason why it can be applied in the case of video game accessibility [26].

4 Results and Discussion

Figure 2 presents the barriers identified for the games evaluated by the five users. According to the results obtained, all the games have a button to restart the game and enough time to interact with the game elements.

[1] https://phet.colorado.edu/es_PE/simulations.

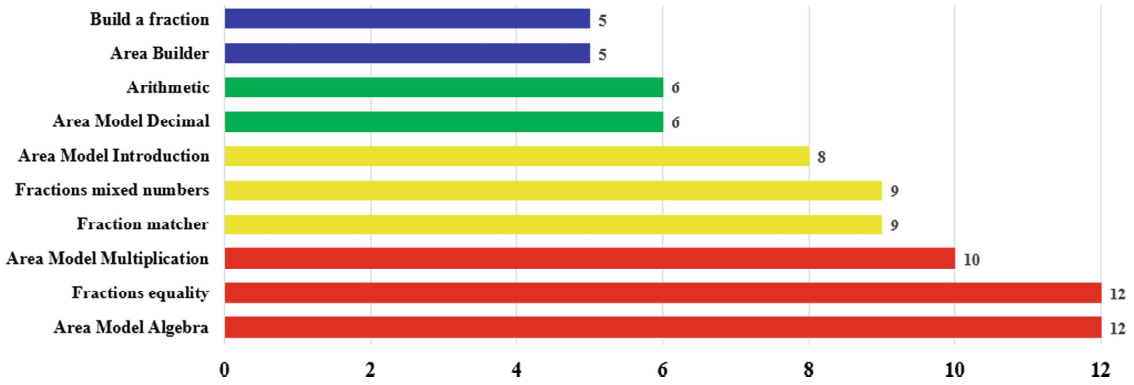


Fig. 2. Barriers found by the evaluators

However, the evaluators consider that it is necessary to add more motivation elements and reward mechanisms. The data set for analysis and replication of the evaluation is available in the Mendeley repository[2].

Frequently repeated errors are related to "Input assistance" and "Predictable" with 23% each, "Readable" with 22%, followed by "Navigable" with 17%, and "Navigable" with 15%. We can observe that in users with a cognitive disability, the principle that is repeated more frequently is the "Understandable."

Many of the games have predictable, repetitive mechanisms that do not contribute to a better understanding of the subject although they allow users to find simple procedures to solve the proposed challenges.

5 Conclusions and Future Works

The inclusion of users with cognitive problems and the improved use of video games for education can be achieved by reducing the number of barriers identified in educational video games, which should also be considered in the development of new educational applications. The results of the educational video games evaluated reveal that these applications do not reach an adequate level of accessibility to be used by people with cognitive problems, although they comply with some of the accessibility requirements. Therefore, we suggest considering improving the accessibility in the future development of educational simulations and educational video games.

References

1. Toril, P., Reales, J.M., Ballesteros, S.: Video game training enhances cognition of older adults: a meta-analytic study. Psychol. Aging **29**(3), 706–716 (2014)
2. Anguera, J.A., Boccanfuso, J., Rintoul, J.L., Al-Hashimi, O., Faraji, F., Janowich, J., Kong, E., Larraburo, Y., Rolle, C., Johnston, E., Gazzaley, A.: Video game training enhances cognitive control in older adults. Nature **501**(7465), 97–101 (2013)

[2] http://dx.doi.org/10.17632/tjm7cwcd46.1.

3. Nganji, J.T., Brayshaw, M., Tompsett, B.: Ontology-based e-learning personalisation for disabled students in higher education. Innov. Teach. Learn. Inf. Comput. Sci. **10**(1), 1–11 (2011)
4. von der Mühlen, S., Richter, T., Schmid, S., Berthold, K.: How to improve argumentation comprehension in university students: experimental test of a training approach. Instr. Sci. **47** (2), 215–237 (2019)
5. Lambert, D.C., Dryer, R.: Quality of life of higher education students with learning disability studying online. Int. J. Disabil. Dev. Educ. **65**(4), 393–407 (2018)
6. World Health Organization (WHO): United Nations Expert Group Meeting on Building Inclusive Society and Development through Promoting ICT Accessibility: Emerging Issues and Trends (2012)
7. Díaz-Bossini, J.M., Moreno, L.: Accessibility to mobile interfaces for older people. Procedia Comput. Sci. **27**, 57–66 (2013). https://doi.org/10.1016/j.procs.2014.02.008
8. Torrente, J., del Blanco, Á., Moreno-Ger, P., Fernández-Manjón, B.: Designing serious games for adult students with cognitive disabilities. LNCS, pp. 603–610 (2012). https://doi.org/10.1007/978-3-642-34478-7_73
9. Tomé, R.M., Pereira, J.M., Oliveira, M.: Using serious games for cognitive disabilities. LNCS, pp. 34–47 (2014). https://doi.org/10.1007/978-3-319-11623-5_4
10. World Wide Web Consortium: Web Content Accessibility Guidelines (WCAG) 2.1 (2018). https://www.w3.org/TR/WCAG21/. Accessed 30 May 2019
11. Baniqued, P.L., Kranz, M.B., Voss, M.W., Lee, H., Cosman, J.D., Severson, J., Kramer, A. F.: Corrigendum: cognitive training with casual video games: points to consider. Front. Psychol. **5** (2014). https://doi.org/10.3389/fpsyg.2014.00234
12. Boot, W.R., Champion, M., Blakely, D.P., Wright, T., Souders, D.J., Charness, N.: Video games as a means to reduce age-related cognitive decline: attitudes, compliance, and effectiveness. Front. Psychol. **4** (2013). https://doi.org/10.3389/fpsyg.2013.00031
13. Pohl, C., Kunde, W., Ganz, T., Conzelmann, A., Pauli, P., Kiesel, A.: Gaming to see: action video gaming is associated with enhanced processing of masked stimuli. Front. Psychol. **5** (2014). https://doi.org/10.3389/fpsyg.2014.00070
14. Ventura, M., Shute, V., Wright, T., Zhao, W.: An investigation of the validity of the virtual spatial navigation assessment. Front. Psychol. **4**, 852 (2013)
15. Van Ravenzwaaij, D., Boekel, W., Forstmann, B.U., Ratcliff, R., Wagenmakers, E.-J.: Action video games do not improve the speed of information processing in simple perceptual tasks. J. Exp. Psychol. Gen. **143**(5), 1794–1805 (2014). https://doi.org/10.1037/a0036923
16. Blacker, K.J., Curby, K.M., Klobusicky, E., Chein, J.M.: Effects of action video game training on visual working memory. J. Exp. Psychol. Hum. Percept. Perform. **40**(5), 1992–2004 (2014). https://doi.org/10.1037/a0037556
17. Torrente, J., del Blanco, Á., Moreno-Ger, P., Martínez-Ortiz, I., Fernández-Manjón, B.: Implementing accessibility in educational videogames with <e-Adventure>. In: Proceedings of the First ACM International Workshop on Multimedia Technologies for Distance Learning – MTDL 2009 (2009). https://doi.org/10.1145/1631111.1631122
18. Grammenos, D., Savidis, A., Stephanidis, C.: Unified design of universally accessible games. In: Universal Access in Human-Computer Interaction. Applications and Services, pp. 607–616 (2007). https://doi.org/10.1007/978-3-540-73283-9_67
19. Jaramillo-Alcázar, A., Luján-Mora, S., Salvador-Ullauri, L.: Inclusive education: mobile serious games for people with cognitive disabilities: Enfoque UTE **9**(1), 53–66 (2018). https://doi.org/10.29019/enfoqueute.v9n1.236. ISSN 1390-9363
20. Jaramillo-Alcázar, A., Luján-Mora, S., Salvador-Ullauri, L.: Accessibility assessment of mobile serious games for people with cognitive impairments. In: 2017 International

Conference on Information Systems and Computer Science (INCISCOS), pp. 323–328. IEEE. (2017). https://doi.org/10.1109/INCISCOS.2017.12. ISBN 978-1-5386-2644-3
21. Kwon, J., Lee, Y.: Serious games for the job training of persons with developmental disabilities. Comput. Educ. **95**, 328–339 (2016). https://doi.org/10.1016/j.compedu.2016.02.001
22. Hersh, M.A., Leporini, B.: An overview of accessibility and usability of educational games. Adv. Game-Based Learn. 1–40 (2013). https://doi.org/10.4018/978-1-4666-1987-6.ch001
23. Chi, H., Agama, E., Prodanoff, Z.G.: Developing serious games to promote cognitive abilities for the elderly. In: 2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH) (2017). https://doi.org/10.1109/segah.2017.7939279
24. Cairns, P., Power, C., Barlet, M., Haynes, G.: Future design of accessibility in games: a design vocabulary. Int. J. Hum. Comput. Stud. **131**, 64–71 (2019). https://doi.org/10.1016/j.ijhcs.2019.06.010
25. Korhonen, H.: Evaluating playability of mobile games with the expert review method (2016)
26. Nielsen Norman Group: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/. Accessed 28 Sept 2019

10 Combined Method for Evaluating Accessibility in Serious Games

Referencia:
Salvador-Ullauri, L.; Acosta-Vargas, P.; Gonzalez, M.; Luján-Mora, S. Combined Method for Evaluating Accessibility in Serious Games. Applied Sciences. 2020, 10, 6324.(Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020a)

Disponible en:

- https://www.mdpi.com/2076-3417/10/18/6324
- https://doi.org/10.3390/app10186324

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios educativos.
2. Recopilación del estado de la cuestión en accesibilidad en juegos serios.
3. Identificación de los requisitos de accesibilidad en juegos serios con un método combinado.
4. Evaluación de la accesibilidad de una muestra aleatoria de 82 juegos serios desarrollados por Physical Education Technology Interactive Simulations en la Universidad de Colorado.

Article

Combined Method for Evaluating Accessibility in Serious Games

Luis Salvador-Ullauri [1], Patricia Acosta-Vargas [2,*], Mario Gonzalez [2] and Sergio Luján-Mora [1]

[1] Department of Software and Computing Systems, University of Alicante, 03690 Alicante, Spain; lasu1@alu.ua.es (L.S.-U.); sergio.lujan@ua.es (S.L.-M.)
[2] Intelligent and Interactive Systems Laboratory, Universidad de Las Américas, Quito 170125, Ecuador; mario.gonzalez.rodriguez@udla.edu.ec
* Correspondence: patricia.acosta@udla.edu.ec

Received: 5 August 2020; Accepted: 2 September 2020; Published: 11 September 2020

Abstract: Nowadays, one of the learning resources in the educational area are serious games, also called training games; they are games designed with a different purpose than fun, whose main objective is to reinforce the new concepts more creatively. However, not all existing serious games are accessible in a way that allows access to a more significant number of users. Therefore, this research proposes to apply a combined method to evaluate accessibility in serious games, considering the Web Content Accessibility Guidelines (WCAG) 2.1. As a case study, we evaluated the accessibility of 82 serious games developed by Physical Education Technology Interactive Simulations at the University of Colorado. We propose to replicate this combined method for users with various types of disabilities, considering the various accessibility barriers. As future work, we suggest generating an accessibility heuristic evaluation focused on serious games, based on the accessibility issues identified. Finally, we believe it is essential to strengthen accessibility policies in each country, as well as implement best practices that generate innovation by incorporating diversity in building and designing more inclusive serious games.

Keywords: accessibility; assessment; combined method; evaluation; interactive simulations; serious games; Web Content Accessibility Guidelines (WCAG) 2.1

1. Introduction

Belitski and Heron [1] argue that it is essential to complement formal education with teaching methods supported by group activities, simulations, and serious games. Serious games, including interactive simulations, are a powerful means of supporting college student learning [2]. Among the main benefits of simulations is to clarify concepts and improve understanding of the different topics taught in higher education institutions. Several authors agree that serious games improve students' comprehension skills as they learn [3].

Aviation and militia-oriented, high-definition video games have been giving way to other types of games based on computers, consoles, and mobile devices, thanks to the reduction of technology costs. Education in the 21st century [4] requires the acquisition of new skills by teachers and students. Many of these skills are intimately related to new science, technology, engineering, and mathematics (STEM).

The prominent representatives of governments, businesses, and academia focus on how technology can help in the acquisition of these new skills. For example, Microsoft carries out events aimed at disseminating and promoting the use of video games in education. EduGameDay is an example of this type of event where professionals from the education sector and the video game industry demonstrate the advantage of using this resource as a pedagogical tool.

Another example of the initiative of the use of video games in education is GameOn. This video game is a text-based adventure, developed by IBM, built to help students explore microservice architectures and related concepts.

In this way, the acquisition of the skills necessary for education in the 21st century [4] can improve with the incorporation of technological tools in learning processes, including in the medical and health area; serious games could be used to facilitate these learning processes.

Of course, the use of serious games can be an alternative to current didactic tools [5], but these resources must be carefully designed so that their usefulness is valued. Some research affirms the indisputable benefits of including serious games in education, while other research points to the need for a more thorough evaluation of these types of resources before using them in the classroom [6].

Recent studies affirm that the use of video games in education has not been fully adopted because it is necessary to evaluate teachers' understanding and acceptance and their effectiveness within different educational contexts. Teachers need to be convinced about the usefulness of using video games in class, and they need to understand how they can evaluate the knowledge acquired [7]. While some remain skeptical, most agree that serious games have great potential for learning [8,9].

Although the use of videogames has increased in the United States and several European countries, it is necessary to evaluate their effectiveness, which may be subject, as happens with other media, to an adequate didactic design as well as accessibility. Evaluating the accessibility of video games is a crucial factor in promoting the evaluation of their educational content. Among the main benefits of an accessible video game, we can enumerate the following: (1) allows the inclusion of all types of users; (2) improves access to learning content; (3) helps to achieve better learning outcomes; (4) allows the reuse of content on multiple devices; and (5) allows users with a permanent or temporary disability to receive and understand its educational content, as well as be able to use it correctly.

According to data from the World Health Organization (WHO), around a billion users worldwide suffer some form of physical or mental disability [10]. Therefore, accessibility in serious games is essential to provide a better interaction between users and video games. Without a doubt, the main reason for designing accessible serious games is to provide access to a more significant number of users, including people with some type of disability.

Therefore, this research proposes to apply a combined method to evaluate accessibility in serious games, taking into account the Web Content Accessibility Guidelines (WCAG) 2.1. In this research, we evaluated the accessibility of 82 serious games developed in HTML5 by Physical Education Technology (PhET) Interactive Simulations at the University of Colorado [11]. PhET offers fun, free, interactive simulations in Mathematics, Biology, Chemistry, Earth Science, and Physics [12] that are based on research. It has a total of 83 simulations developed in HTML5, 57 applications in Java via CheerpJ, 63 simulations developed in Java, and 12 applications in Flash. The applications can be executed online or downloaded to a computer. All simulations include the HTML5 source code and PhET's Javascript, located on PhET's GitHub page. The PhET project has several sponsors that make these resources free to all teachers and students.

In this study, we consider web accessibility as a starting point, which implies how users perceive, navigate, understand and interact on the web [13]; therefore, it is essential to keep in mind that the level of accessibility is the fundamental basis to facilitate access to serious games, especially for users with disabilities.

The manual method applied in this investigation comprises nine phases: (1) select serious games; (2) define the type of user; (3) define the test scenario; (4) explore each game to evaluate; (5) list the barriers based on Web Content Accessibility Guidelines (WCAG) 2.1; (6) evaluate with automatic tools and manually; (7) record evaluation data; (8) classify and analyze data; and (9) provide suggestions to improve accessibility. Besides, in the evaluation, the authors considered the WCAG 2.1 [14,15] based on five parameters: (1) accessible content; (2) visible focus; (3) accessible with a keyboard; (4) association of labels and controls; (5) controls for animation and audio. This research invites reflection and considers

the importance of complying with and applying accessibility standards in the design of serious games considering diversity.

This research can serve as a guide for serious game designers and developers to apply WCAG 2.1 with an acceptable level of accessibility; additionally, this study can serve as a starting point for future work related to accessibility in serious games.

This research is structured as follows: Section 1 presents the introduction; Section 2 describes the background and previous work related to accessibility in serious games; Section 3 presents the method and the case study; Section 4 discusses the evidence and results; Section 5 presents conclusions and future work.

2. Background and Related Work

Currently, there are a large number of websites offering serious simulations and games. Statista [16] estimated that market revenue based on serious games worldwide is expected to grow from USD 3.5 billion in 2018 to 24 billion in 2024. Furthermore, in these times of social distancing [17], serious gaming has become highly supportive of teaching resources in the educational area. However, not all serious games are accessible. Accessibility refers to the condition if someone, regardless of their disability, can use serious games without barriers that prevent regular use and interaction with it.

2.1. Serious Games

The definition of serious games has been around before computing devices and entertainment. According to Schell [18], the definition indicates that games include goals, challenges, and rules to win or lose. Abt [19] indicates that "serious games" have an explicit and carefully thought-out educational purpose and are not intended to be played with fun only in mind. López et al. [20] argue that a serious game retains all the characteristics of a typical game, but point to a higher purpose than mere fun.

Jaramillo-Alcázar et al. [21] formulate that serious games allow the teaching of various types of concepts but that various games are not accessible since they do not focus on groups with disabilities. Salvador-Ullauri et al. [22] explain that it is a great challenge to implement serious games to support learning processes, especially for people with cognitive disabilities. In previous studies [22], the authors evaluated accessibility in ten serious games considering WCAG 2.0 [23]. The results revealed that serious games did not reach an adequate level of accessibility.

2.2. Accessibility

According to Park and Kim [24], accessibility in serious games makes it possible to guarantee that any user in any technical circumstance can access the content; for this reason, in our research, we applied WCAG 2.1 [14], the last official version of June 5, 2018, that provides recommendations to make content more accessible including people with disability. WCAG 2.1 consists of 4 principles, 13 guidelines, and 78 compliance criteria, and includes an undetermined number of sufficient techniques and advice. The four principles are the same as those presented in WCAG 2.0 [23]:

Principle 1: Perceivable—All users must be able to perceive the content in a visual, sound, or tactile way; Principle 2: Operable—Users must be able to use and navigate the interface components; Principle 3: Understandable—Both the content and the controls of the interface for its management must be understandable to the user; Principle 4: Robust—Content must be robust to be interpreted reliably by the most significant number of users with current and future technologies.

WCAG 2.1 [14] proposes success criteria associated with one of the following compliance levels: Level "A": Minimum level of accessibility, when not reaching it, users cannot access the content of the web; Level "AA": Intermediate level, implies that it is difficult for users to access the content; Level "AAA": Maximum level, when the users can access the content without difficulty.

The authors found several accessibility studies in interactive simulations as part of the serious games contributing to this research. All these works were selected considering the interests of

the scientific community to integrate people with disabilities into the academic world using new technologies.

Araújo et al. [25] argued that video games are increasingly popular but are not accessible, which represents a significant challenge for accessibility experts and game designers. The authors presented a study on the existing guidelines and recommendations for accessibility in video games, and they proposed 10 design recommendations for people with visual disabilities.

Cairns et al. [26] indicated that video games provide a cultural outlet where more players can be included and interact to do activities in a balanced way between different users. This event is possible if we create design environments that provide inclusive opportunities. The authors suggest including the guidelines with a language of accessibility of the game; they propose to (1) include a structure for the vocabulary of the game, (2) empower to meet the challenges of the game, (3) improve the player experience. Besides, they show how incorporating the guidelines in the development of video games provide accessible experiences to a more significant number of users.

Park and Kim [24] argued that the legislation of the accessibility guidelines could guarantee easy access to web content, considering users with disabilities but not in video games, since the contents of the web or mobile application consist of reasonably simple information in comparison with the contents of the video game. The content of the video game includes a more significant number of (1) characters, (2) players, (3) conflicts between them, and (4) updating a character when completing a mission. Therefore, they explain that it is necessary to analyze and classify the accessibility guidelines to evaluate each video game.

Waki et al. [27] stated that, currently, the lack of accessibility in digital games imposes barriers for people with disabilities. The authors propose a process to evaluate a set of integrated guidelines. The results revealed that the set of integrated guidelines allows determining the accessibility of digital games and refine the set of integrated guidelines.

Westin et al. [28] formulated that accessibility in video games consists of eliminating the possible barriers that prevent people with disabilities from accessing video games. The authors compared WCAG 2.1 with a set of accessibility guidelines for digital games. They compared 107 guidelines for accessible games.

Wilson and Crabb [29] indicated that video games, in particular, games on mobile devices, have evolved rapidly throughout the world. One problem identified in this topic is the accessibility that users face, especially if they have some kind of disability. In conclusion, the authors were able to determine the participants' knowledge of accessibility guidelines and identify opinions on the importance of applying accessibility guidelines when creating accessible content for mobile games.

Spyridonis and Daylamani-Zad [30] argued the designers' lack of commitment in designing serious games in the application of WCAG. They proposed to (1) focus on user-centered design, (2) identify the types of users, (3) apply WCAG to serious game mechanics, (4) measure user satisfaction, and (5) apply mixed methods. The results revealed that when applying the WCAG, the serious games presented an innovative and attractive solution.

3. Method and Case Study

In this research, we propose the application of a combined method to evaluate accessibility in serious games, considering the Web Content Accessibility Guidelines (WCAG) 2.1. As a case study, we evaluated the accessibility in 82 serious games developed by the PhET project [12]. The evaluation started on 19 January 2020 and ended on 20 June 2020. The study involved two expert evaluators in accessibility, who had experienced since 2015 and have contributed several articles in the area when there were discrepancies in the evaluation of the collaboration of a third expert was requested. In this study, the combined method includes the application of two automatic tools and manual evaluation. The evaluation method is summarized in the eight steps shown in Figure 1.

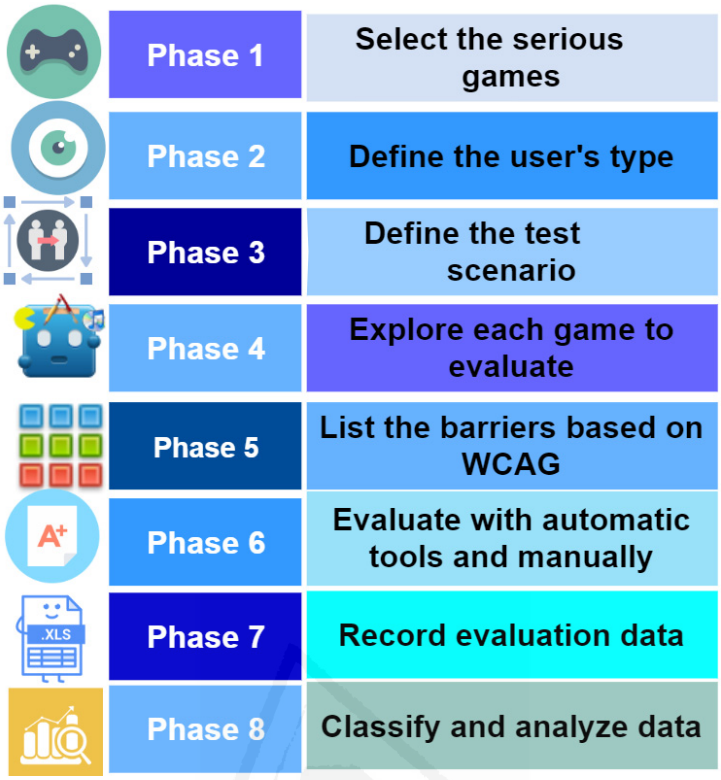


Figure 1. Diagram of accessibility evaluation of serious games.

Phase 1: Select the serious games. In this phase, we selected the serious games of the PhET project. To select the sample size, we apply equation (1).

$$n = \frac{NZ^2PQ}{(N-1)E^2 + Z^2PQ} \tag{1}$$

where n is the sample size to be calculated, N is the size of the universe, in this case, 87 serious games, with a confidence level of 97%, where Z corresponds to 2.17, with an error margin $E = 0.03$. Applying the formula, we obtained the value of 82, which is the number of serious games, selected sequentially, and evaluated in this research by the two accessibility experts.

Table 1 contains the evaluated serious games, including the identification of each game and the name of the serious games within each URL (The complete URL is constructed by adding to the beginning of each address https://phet.colorado.edu/sims/html/. For example, the complete address for the first serious game is https://phet.colorado.edu/sims/html/acid-base-solutions/latest/acid-base-solutions_es.html).

Table 1. Serious games were selected for evaluation.

ID	URL	Subject
1aci	acid-base-solutions/1.2.24/acid-base-solutions_es.html	Chemistry
2are	area-builder/1.1.20/area-builder_es.html	Math
3are	area-model-algebra/1.2.1/area-model-algebra_es.html	Math
4are	area-model-decimals/1.2.1/area-model-decimals_es.html	Math
5are	area-model-introduction/1.2.1/area-model-introduction_es.html	Math
6ari	area-model-multiplication/1.2.1/area-model-multiplication_es.html	Math
7ato	arithmetic/1.0.24/arithmetic_es.html	Math
8bal	atomic-interactions/1.1.0/atomic-interactions_es.html	Chemistry
9bal	balancing-act/1.1.24/balancing-act_es.html	Math
10bal	balancing-chemical-equations/1.2.10/balancing-chemical-equations_es.html	Chemistry

Table 1. *Cont.*

ID	URL	Subject
11bee	balloons-and-static-electricity/1.4.14/balloons-and-static-electricity_es.html	Earth science
12ben	beers-law-lab/1.4.18/beers-law-lab_es.html	Physics
13bla	bending-light/1.1.20/bending-light_es.html	Physics
14bui	blackbody-spectrum/1.0.7/blackbody-spectrum_es.html	Earth science
15bui	build-a-fraction/1.0.12/build-a-fraction_es.html	Math
16cap	build-an-atom/1.6.14/build-an-atom_es.html	Physics
17cha	capacitor-lab-basics/1.6.19/capacitor-lab-basics_es.html	Physics
18cir	charges-and-fields/1.0.47/charges-and-fields_es.html	Physics
19cir	circuit-construction-kit-dc/1.1.5/circuit-construction-kit-dc_es.html	Physics
20col	circuit-construction-kit-dc-virtual-lab/1.1.5/circuit-construction-kit-dc-virtual-lab_es.html	Physics
21con	color-vision/1.1.23/color-vision_es.html	Biology
22cou	concentration/1.3.20/concentration_es.html	Physics
23cur	curve-fitting/1.0.0/curve-fitting_es.html	Math
24dif	coulombs-law/1.0.9/coulombs-law_es.html	Physics
25ene	diffusion/1.0.4/diffusion_es.html	Earth science
26ene	energy-forms-and-changes/1.0.11/energy-forms-and-changes_es.html	Physics
27equ	energy-skate-park-basics/1.1.19/energy-skate-park-basics_es.html	Physics
28equ	equality-explorer/1.0.12/equality-explorer_es.html	Math
29equ	equality-explorer-basics/1.0.12/equality-explorer-basics_es.html	Math
30exp	equality-explorer-two-variables/1.0.12/equality-explorer-two-variables_es.html	Math
31far	expression-exchange/1.1.14/expression-exchange_es.html	Math
32for	faradays-law/1.1.23/faradays-law_es.html	Physics
33fra	forces-and-motion-basics/2.3.16/forces-and-motion-basics_es.html	Physics
34fra	fractions-equality/1.1.1/fractions-equality_es.html	Math
35fra	fraction-matcher/1.2.1/fraction-matcher_es.html	Math
36fra	fractions-intro/1.0.12/fractions-intro_es.html	Math
37fri	fractions-mixed-numbers/1.0.12/fractions-mixed-numbers_es.html	Math
38fun	friction/1.5.10/friction_es.html	Physics
39fun	function-builder/1.0.23/function-builder_es.html	Math
40gas	function-builder-basics/1.0.14/function-builder-basics_es.html	Math
41gas	gases-intro/1.0.5/gases-intro_es.html	Earth science
42gen	gas-properties/1.0.4/gas-properties_es.html	Earth science
43gra	gene-expression-essentials/1.0.16/gene-expression-essentials_es.html	Biology
44gra	graphing-lines/1.3.10/graphing-lines_es.html	Math
45gra	graphing-quadratics/1.1.5/graphing-quadratics_es.html	Math
46gra	graphing-slope-intercept/1.1.9/graphing-slope-intercept_es.html	Math
47gra	gravity-and-orbits/1.1.15/gravity-and-orbits_es.html	Physics
48gra	gravity-force-lab/2.2.0/gravity-force-lab_es.html	Physics
49hoo	gravity-force-lab-basics/1.0.0/gravity-force-lab-basics_es.html	Physics
50iso	hookes-law/1.0.23/hookes-law_es.html	Chemistry
51joh	isotopes-and-atomic-mass/1.1.9/isotopes-and-atomic-mass_es.html	Chemistry
52lea	john-travoltage/1.5.12/john-travoltage_es.html	Physics
53mak	least-squares-regression/1.1.20/least-squares-regression_es.html	Math
54mas	make-a-ten/1.0.16/make-a-ten_es.html	Math
55mas	masses-and-springs/1.0.10/masses-and-springs_es.html	Math
56mol	masses-and-springs-basics/1.0.9/masses-and-springs-basics_es.html	Physics
57mol	molarity/1.5.1/molarity_es.html	Chemistry
58mol	molecules-and-light/1.4.14/molecules-and-light_es.html	Earth science
59mol	molecule-shapes/1.2.8/molecule-shapes_es.html	Chemistry
60mol	molecule-shapes-basics/1.2.8/molecule-shapes-basics_es.html	Chemistry
61neu	neuron/1.1.18/neuron_es.html	Biology
62ohm	ohms-law/1.4.7/ohms-law_es.html	Math
63pen	pendulum-lab/1.0.15/pendulum-lab_es.html	Math
64ph	ph-scale/1.3.4/ph-scale_es.html	Earth science
65ph	ph-scale-basics/1.3.4/ph-scale-basics_es.html	Biology
66pli	plinko-probability/1.1.18/plinko-probability_es.html	Math
67pro	projectile-motion/1.0.15/projectile-motion_es.html	Math
68pro	proportion-playground/1.0.15/proportion-playground_es.html	Math
69rea	reactants-products-and-leftovers/1.2.11/reactants-products-and-leftovers_es.html	Chemistry
70res	resistance-in-a-wire/1.6.9/resistance-in-a-wire_es.html	Math
71rut	rutherford-scattering/1.1.9/rutherford-scattering_es.html	Chemistry
72sta	states-of-matter-basics/1.1.8/states-of-matter-basics_es.html	Physics
73sta	states-of-matter/1.1.10/states-of-matter_es.html	Physics

Table 1. *Cont.*

ID	URL	Subject
74tri	trig-tour/1.0.22/trig-tour_es.html	Math
75und	under-pressure/1.1.18/under-pressure_es.html	Earth science
76uni	unit-rates/1.0.17/unit-rates_es.html	Math
77vec	vector-addition/1.0.0/vector-addition_es.html	Math
78vec	vector-addition-equations/1.0.0/vector-addition-equations_es.html	Math
79wav	wave-interference/2.0.2/wave-interference_es.html	Earth science
80wav	waves-intro/1.0.2/waves-intro_es.html	Earth science
81wav	wave-on-a-string/1.1.22/wave-on-a-string_es.html	Earth science
82bui	build-a-molecule/latest/build-a-molecule_en.html	Chemistry

Phase 2: Define the user's type. Two experts in software application accessibility carried out the evaluation, in this case, on the serious games. This study defined the WCAG 2.1 for users with low vision [31]. According to the WHO [32], blindness and vision impairment affect at least 2.2 billion people around the world. Of those, 1 billion have a preventable vision impairment or one that has yet to be addressed. Reduced vision can have long-lasting effects on various aspects of life, and with increasing age, older people tend to decrease their presbyopia-related visual ability [33]. Based on these definitions, accessibility experts evaluated serious games by applying WCAG 2.1 to identify accessibility barriers. The experts have experience in the evaluation of mobile applications, web accessibility, and accessibility of educational resources since 2015 and have published several articles in high impact journals related to the topic.

Phase 3: Define the test scenario. In this phase, the authors define the scenarios to navigate and interact in serious games and reach the goal. The task is to (1) enter serious games, (2) review the functionality of each serious game, and (3) check if there are barriers that prevent accessibility for serious games. In this case study, an accessibility barrier for a person with low vision [34] means that the person cannot effectively move from one point to another within serious games due to visual acuity problems.

Phase 4: Explore each serious game to evaluate. In the fourth phase, the user explores and becomes familiar with the interaction mechanisms of serious games. In this phase, the evaluators identify (1) the functionalities of serious gaming; (2) if the content is adjustable with the zoom and the appearance of the game; and (3) the change of behavior according to the device, the context, and the applied configuration.

Figure 2 presents a screenshot of one of the evaluated games; in this example, it is a serious game used in Physics to explain the topic of the projectile launch.

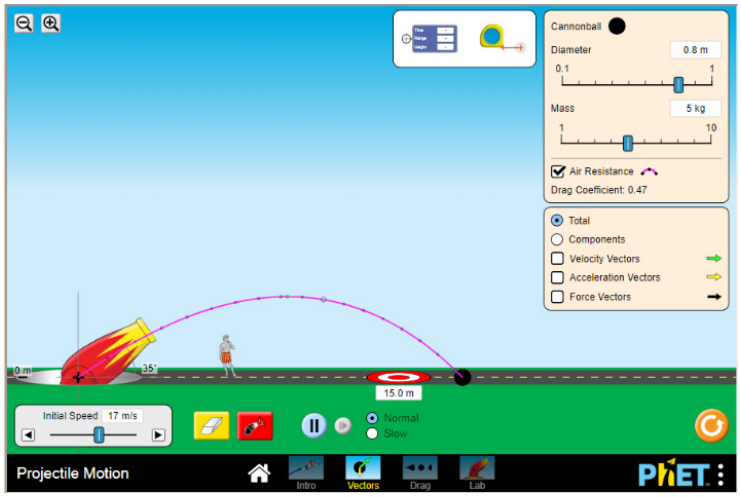


Figure 2. Screenshot Projectile Motion—PHET.

Phase 5: List the barriers based on WCAG. This phase is essential, in which we list the barriers related to WCAG 2.1 for the evaluation of serious games. The barriers are listed in Table 2, which contains 29 guidelines considered in the manual evaluation of each serious game. Table 2 shows the guideline, the barrier, the WCAG 2.1 principle, the success criteria, and the level.

Table 2. Guidelines for evaluating accessibility in serious games.

Guideline	Barrier	WCAG 2.1	Success Criteria	Level
G01	Accessible keyboard	Operable	2.1.1	A
G02	Luminance flash failures	Operable	2.3.1	A
G03	Animation from Interactions	Operable	2.3.3	AAA
G04	Content hovering over focus	Perceivable	1.4.13	AA
G05	Easy to read font	Perceivable	1.1.1	A
G06	Text alternatives	Perceivable	1.1.1	A
G07	Subtitled	Perceivable	1.2.4	AA
G08	Automatic transcripts	Perceivable	1.2.5	AA
G09	Sign language	Perceivable	1.2.6	AAA
G10	Information and relationships	Perceivable	1.3.1	A
G11	Sensory characteristics	Perceivable	1.3.1	A
G12	Adjust display settings	Perceivable	1.3.4	AA
G13	Interface rearrangement	Perceivable	1.3.5	AA
G14	Use of color	Perceivable	1.4.1	A
G15	Contrast without text	Perceivable	1.4.11	AA
G16	Well-spaced elements	Perceivable	1.4.12	A
G17	Good audio techniques	Perceivable	1.4.2	A
G18	Contrast (Minimum)	Perceivable	1.4.3	AA
G19	Images as sharp as possible	Perceivable	1.4.5	AA
G20	Visual presentation	Perceivable	1.4.8	AAA
G21	Pause, stop, hide	Perceivable	2.2.2	A
G22	Contrast (Enhanced)	Perceivable	1.4.6	AAA
G23	Screen reader support	Robust	4.1.2	A
G24	Status messages	Robust	4.1.3	AA
G25	Language	Understandable	3.1.1	A
G26	Consistent navigation	Understandable	3.2.3	AA
G27	Labels or instructions	Understandable	3.3.2	A
G28	Help	Understandable	3.3.5	AAA
G29	On Focus	Understandable	3.2.1	A

Phase 6: Evaluate with automatic tools and manually. In this phase, we evaluated the 82 serious games detailed in Table 1. We applied a combined evaluation using two automatic tools: (1) Colour Contrast Analyser (CCA), version 3.0.1 [35], a tool used to analyze some WCAG 2.1 to set the input colors of plain text. It also allows support for alpha transparency in foreground colors, includes a color blindness simulator. This tool allows a foreground and background color swatch to be taken to measure the contrast against which a report is output with WCAG 2.1. (2) Photosensitive Epilepsy Analysis Tool (PEAT), version 1.6 [36], allows evaluation in serious games or animations whether the content presents flickering or rapid transitions between light and dark background colors that can generate photosensitive seizures caused by certain types of flashing in serious gameplay, including mouse-overs that cause large areas of the screen to turn on and off quickly. The tool applies some of the WCAG 2.1 and 2.2, including restrictions related to frequency, luminance, area, and color of any flicker. Before analyzing the serious games with PEAT, the games were transformed into format Audio Video Interleave (.AVI) using a batch processing program to take a sample of the video.

Phase 7: Record evaluation data. In this phase, we present the registration of the data obtained from the evaluation of the accessibility of serious games with CCA and PEAT tools; the evaluation dataset [37] can be found at https://data.mendeley.com/datasets/t2tr35ww4c/5. The codes assigned to each column, which correspond to the WCAG success criteria, where C1 = 1.4.3 Contrast (Minimum)

AA, Regular Text, C2 = 1.4.3 Contrast (Minimum) AA, Large Text, C3 = 1.4.6 Contrast (Enhanced) AA, Regular Text, C4 = 1. 4.6 Contrast (Enhanced) AAA, Large Text, C5 = 1.4.11 Contrast without text AA (Button Reset), C6 = 1.4.11 Contrast without text AA (Others), P1 = State, P2 = Luminosity flash failures, P3 = Red flash failures, P4 = Extended flash alerts. The number one (1) indicates that the barrier has been exceeded, and the number zero (0) indicates that it has not been exceeded. Figure 3 presents the data recorded in the manual evaluation of the serious games with WCAG 2.1, contains the identifier assigned to each serious game with the 29 guidelines. We place the value of one (1) if the barrier is exceeded and zero (0) when the barrier was not exceeded. In Figure 3, the darkest color represents that the barrier was exceeded and the lightest color that the barrier was not exceeded.

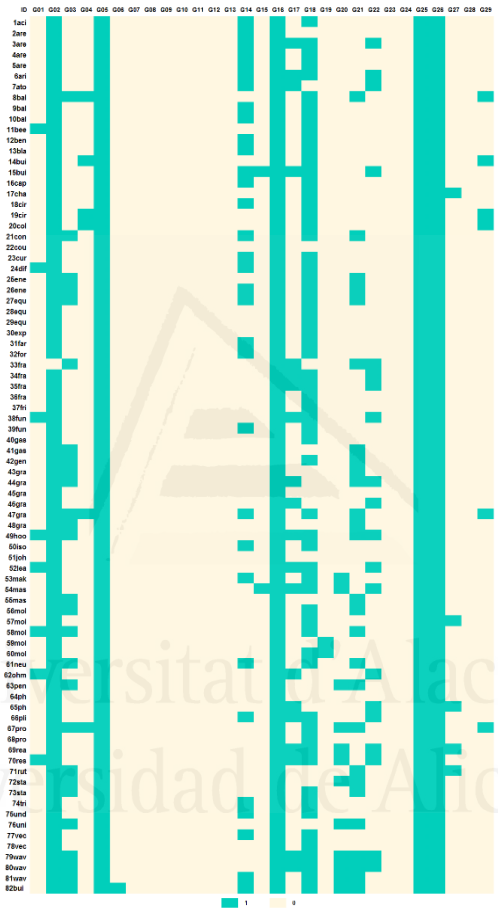


Figure 3. Manual evaluation of serious games.

Phase 8: Classify and analyze data. In this phase, the data of serious games were classified, considering the four principles of web accessibility proposed in WCAG 2.1. We grouped the data obtained with the automatic CCA and PEAT tools with which the contrast and photosensitivity that affects users with epilepsy were analyzed. The data obtained in the manual evaluation were grouped to identify the presence of each of the accessibility principles, the success criteria, and the level of accessibility, which will be detailed in the results analysis section. This process takes a long time and is therefore very demanding. Recorded data and analysis are available at Mendeley (https://data.mendeley.com/datasets/t2tr35ww4c/5) so that the assessment can be replicated [37].

4. Results and Discussion

In this phase, we analyze the results with automatic and manual evaluation tools. Applying descriptive statistics to the evaluation data with the CCA and PEAT tools, we have that the mean value is 3.9, the standard error is 0.21; the median is 5.0, the mode is 5.0, the standard deviation is 1.9,

the variance of the sample is 3.64, the minimum value is 1.0, the maximum is 7.0. Figure 4 shows the evaluation with the CCA and PEAT tools; we found that 24 serious games meet from 1 to 2.5 in the evaluated contrast and photosensitivity parameters, 10 serious games meet from 2.5 to 4, the next 30 from 4 to 5.5, and 18 serious games meet of 5.5 to 7 points. From the data in Table 3, we find that the 82 serious games passed the photosensitivity test.

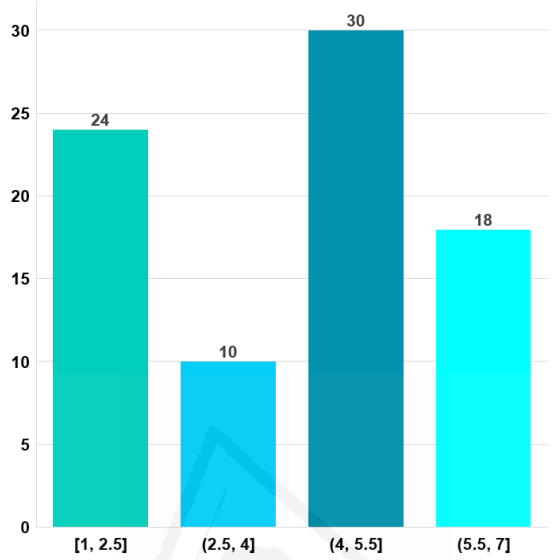


Figure 4. Evaluation of serious games with CCA and PEAT.

Table 3. Summary of Accessibility Evaluation in Serious Games with the Manual Method.

Guideline	Barrier	WCAG 2.1 (Principle)	Success Criteria	Level	Total	%
G01	Accessible keyboard	Operable	2.1.1	A	8	1.3
G02	Luminance flash failures	Operable	2.3.1	A	81	13
G03	Animation from Interactions	Operable	2.3.3	AAA	27	4.2
G04	Content hovering over focus	Perceivable	1.4.13	AA	6	0.9
G05	Easy to read font	Perceivable	1.1.1	A	82	13
G06	Text alternatives	Perceivable	1.1.1	A	1	0.2
G07	Subtitled	Perceivable	1.2.4	AA	0	0
G08	Automatic transcripts	Perceivable	1.2.5	AA	0	0
G09	Sign language	Perceivable	1.2.6	AAA	0	0
G10	Information and relationships	Perceivable	1.3.1	A	0	0
G11	Sensory characteristics	Perceivable	1.3.1	A	0	0
G12	Adjust display settings	Perceivable	1.3.4	AA	0	0
G13	Interface rearrangement	Perceivable	1.3.5	AA	0	0
G14	Use of color	Perceivable	1.4.1	A	32	5
G15	Contrast without text	Perceivable	1.4.11	AA	2	0.3
G16	Well-spaced elements	Perceivable	1.4.12	A	82	13
G17	Good audio techniques	Perceivable	1.4.2	A	20	3.1
G18	Contrast (Minimum)	Perceivable	1.4.3	AA	62	9.7
G19	Images as sharp as possible	Perceivable	1.4.5	AA	2	0.3
G20	Visual presentation	Perceivable	1.4.8	AAA	12	1.9
G21	Pause, stop, hide	Perceivable	2.2.2	A	27	4.2
G22	Contrast (Enhanced)	Perceivable	1.4.6	AAA	20	3.1
G23	Screen reader support	Robust	4.1.2	A	0	0
G24	Status messages	Robust	4.1.3	AA	0	0
G25	Language	Understandable	3.1.1	A	82	13
G26	Consistent navigation	Understandable	3.2.3	AA	82	13
G27	Labels or instructions	Understandable	3.3.2	A	5	0.8
G28	Help	Understandable	3.3.5	AAA	0	0
G29	On Focus	Understandable	3.2.1	A	6	0.9

Table 3 shows a summary of the manual evaluation of 82 serious games; it contains the guideline, barrier, accessibility principle, success criteria, level, total, and percentage of accessibility evaluation in serious games with the manual method. The total column shows the value of the guidelines that exceed the barrier. We found that the 82 serious games compliance the following guidelines: (1) G05 related to easy to read font, (2) G16 related to well-spaced elements, (3) G25 related to language, (4) G26 related to consistent navigation.

Figure 5 shows the percentage of compliance with accessibility principles of the 82 serious games evaluated. We found that the perceptible principle is fulfilled in 54.4% of the total, the comprehensible one registers 27.4% of fulfillment, the operable one registers 18.2%, and the robust one registers 0.0%. We can conclude that in the evaluation of the accessibility of the 82 serious games, the most violated principle is the robust one.

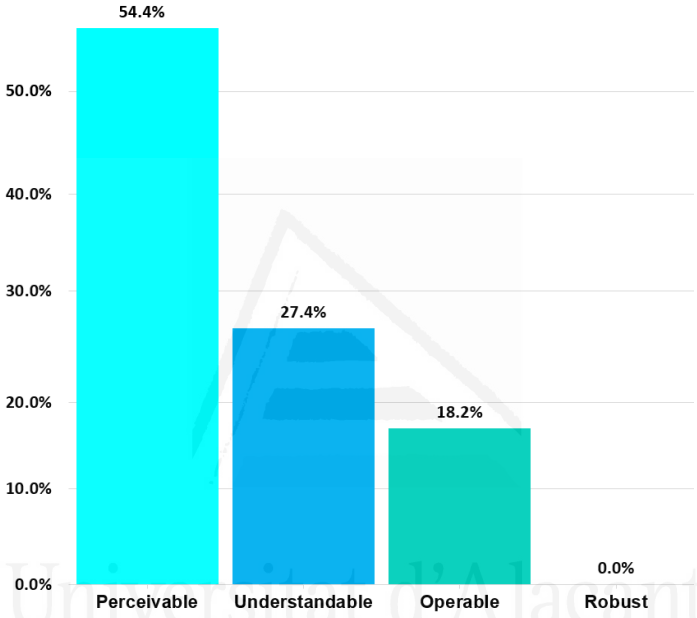


Figure 5. Successes of the WCAG principles in manual evaluation.

Figure 6 shows the manual evaluation of the accessibility in 82 serious games; we obtained the following success criteria that overcome the barriers in the manual evaluation: (1) the success criteria representing 64% of the total are 1.1.1 for easy to read font, 1.4.12 for well-spaced elements, 3.1.1 for language, 3.2.3 for consistent navigation and 2.3.1 for luminance flash failures; (2) the success criteria representing 9.7% of the total is 1.4.3 for enhanced contrast; (3) the success criteria representing 5% of the total is 1.4.1 for the use of color; (4) the success criteria representing 8.4% of the total are 2.3.3 for animation from interactions, and 2.2.2 for pause, stop, hide; (5) the rest of the success criteria representing 12.8% of the total.

Figure 7 shows the evaluation of accessibility in serious games with the following results: (1) the guidelines G05, G16, G25, G02, G14, G21, G17, G01, G29, G27, G06, G10, G11, and G23 represent 66.6% of total compliance concerning Level A; (2) G26, G18, G04, G15, G19, G07, G08, G12, G13, and G24 guidelines represent 24.3% of total compliance for Level AA; (3) G03, G20, G22, G09, and G28 guidelines represent 9.1% of total compliance for Level AAA. For a serious game to have an acceptable level of accessibility, WCAG 2.1 suggests considering level AA [14].

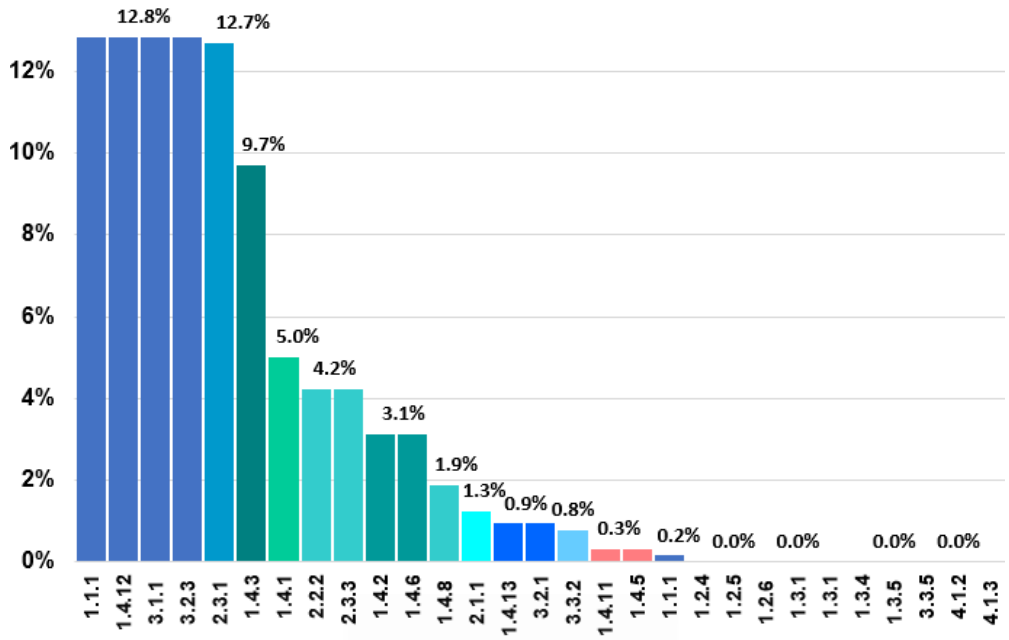


Figure 6. Success criteria in manual evaluation that exceed the barriers.

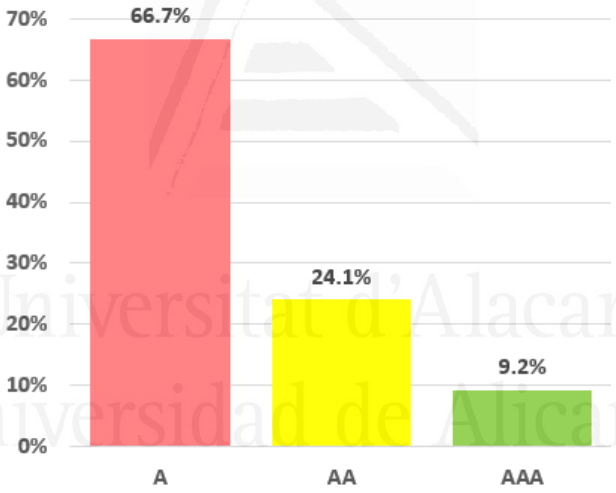


Figure 7. WCAG levels in manual evaluation that exceed the barriers.

5. Conclusions and Future Work

During the literature review, we found that there is no solid work focused on accessibility with WCAG 2.1. Therefore, this work proposes the application of a combined method of evaluating accessibility in serious games and establishes 29 guidelines based on WCAG. From the case study, we can conclude that the most neglected accessibility principles are operable and robust; the operable principle refers to how people interact and have control during interaction with serious games. On the other hand, "robust" barriers related to related ones can be addressed by including assistive technology that allows better compatibility with current and future tools.

This combined approach can be replicated for other serious games that include users with different types of disabilities. To improve accessibility in serious gaming, we propose to include (1) automatic transcriptions or a bot to transcribe the audio or video to text without human intervention, so that the user can review the transcriptions while playing; (2) sign language to establish a communication channel with the social environment, this option is useful for users with hearing disabilities; (3) photosensitivity control, to configure the excess of light and brightness useful in users with epilepsy problems;

(4) external devices to allow virtual and augmented reality, for example, with the oculus quest the user can achieve greater immersion in the learning process; and (5) a contextual help option so that users can operate without losing sight of what they are doing. The authors can conclude that no serious games among those selected have reached an acceptable level of accessibility. Therefore, serious game developers should make significant efforts to improve accessibility.

This study has its limitations because it is a combined method that includes a manual part where accessibility experts intervene; the evaluation results depend on the experience and ability to evaluate serious games. From the theoretical point of view, we present a new method to evaluate accessibility in serious games based on a combined method. On the other hand, in practical terms, this study tries to wake up and motivate serious game developers to apply WCAG 2.1 guidelines to make serious games more accessible and inclusive that consider diversity. Additionally, this method can serve as a reference for future studies related to accessibility in simulations and serious games.

As future work, we suggest (1) testing this method with users with different types of disabilities and applying the corresponding disability-related guidelines; (2) generating a heuristic accessibility evaluation focused on serious games, based on the accessibility issues identified in WCAG 2.1; (3) expanding the serious games database with some applications other than serious games to deepen the analysis and evaluation, and (4) developing a software application that includes the WCAG 2.1 guidelines to assist in the evaluation of serious games.

Author Contributions: Conceptualization, L.S.-U. and P.A.-V.; methodology, L.S.-U.; investigation, L.S.-U.; M.G. and P.A.-V.; writing—original draft preparation, L.S.-U. and P.A.-V.; writing—review and editing L.S.-U., S.L.-M., M.G. and P.A.-V.; supervision, S.L.-M.; project administration, P.A.-V. and L.S.-U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidad de Las Américas-Ecuador, as part of an internal research project FGE.PAV.19.11.

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

References

1. Belitski, M.; Heron, K. Expanding entrepreneurship education ecosystems. *J. Manag. Dev.* **2017**, *36*, 163–177. [CrossRef]
2. Martin, F.; Betrus, A.K. Instructional simulations and games. In *Digital Media for Learning*; Springer: Cham, Germany, 2019; pp. 85–110.
3. Cheng, M.T.; Chen, J.H.; Chu, S.J.; Chen, S.Y. The use of serious games in science education: A review of selected empirical research from 2002 to 2013. *J. Comput. Educ.* **2015**, *2*, 353–375. [CrossRef]
4. He, W.; Xu, G.; Kruck, S.E. Online IS education for the 21st century. *J. Inf Syst. Educ.* **2019**, *25*, 1.
5. Kazimoglu, C.; Kiernan, M.; Bacon, L.; Mackinnon, L. A serious game for developing computational thinking and learning introductory computer programming. *Proc. Soc. Behav. Sci.* **2012**, *47*, 1991–1999. [CrossRef]
6. De Freitas, S.; Liarokapis, F. Serious games: A new paradigm for education? In *Serious Games and Edutainment Applications*; Springer: London, UK, 2011; pp. 9–23.
7. Assaf, M.; van Hillegersberg, J.; Spil, T.; Arikat, N. Teachers' perceptions about using serious games in formal education in Jordan: Possibilities and limitations. In Proceedings of the Engineering Education Conference, IEEE, Dubai, United Arab Emirates, 8–11 April 2019; pp. 436–441.
8. Egenfeldt-Nielsen, S.; Heide Smith, J.; Pajares Tosca, S. Serious Games and gamification—When entertainment is not enough. In *Understanding Video Games*; Routledge: Abingdon, UK, 2015; pp. 247–280.
9. Larson, K. Serious games and gamification in the corporate training environment: A literature review. *Tech. Trends* **2020**, *64*, 319–328. [CrossRef]
10. World Health Organization (WHO). World Report on Disability. Available online: https://www.who.int/disabilities/world_report/2011/report/en/ (accessed on 10 May 2020).
11. Meadows, M.L.; Caniglia, J.C. Using PhET simulations in the mathematics classroom. *Math Teach* **2019**, *112*, 386–389. [CrossRef]

12. Interactive Simulations. PhET: Free Online Physics, Chemistry, Biology, Earth Science and Math Simulations. Available online: https://phet.colorado.edu/ (accessed on 25 April 2020).
13. Acosta-Vargas, P.; Salvador-Ullauri, L.; Luján-Mora, S. A heuristic method to evaluate web accessibility for users with low vision. *IEEE Access* **2019**, *7*, 125634–125648. [CrossRef]
14. World Wide Web Consortium. Web Content Accessibility Guidelines (WCAG) 2.1. Available online: https://www.w3.org/TR/WCAG21/ (accessed on 7 July 2020).
15. World Wide Web Consortium (W3C). Web Content Accessibility Guidelines (WCAG) 2.2. Available online: https://www.w3.org/TR/2020/WD-WCAG22-20200227/ (accessed on 10 May 2020).
16. Statista. Game-based Learning Market Revenue Worldwide in 2018 and 2024. Available online: https://www.statista.com/statistics/733616/game-based-learning-industry-revenue-world/ (accessed on 10 May 2020).
17. Ainslie, K.E.; Walters, C.E.; Fu, H.; Bhatia, S.; Wang, H.; Xi, X.; Cattarino, L. Evidence of initial success for China exiting COVID-19 social distancing policy after achieving containment. *Wellcome Open Res.* **2020**, *5*, 81. [CrossRef] [PubMed]
18. Schell, J. *The Art of Game Design: A Book of Lenses*; CRC Press: Boka Raton, FL, USA, 2019.
19. Abt, C. *Serious Games*; University Press of America: Millburn, NJ, USA, 1987; p. 196.
20. López, J.M.; Medina, N.M.; de Lope, R.P. Interaction in video games for people with impaired visual function: Improving accessibility. In Proceedings of the International Conference on Human Computer Interaction, ACM, Salamanca, Spain, 13–16 September 2016; pp. 1–2.
21. Jaramillo-Alcázar, A.; Luján-Mora, S.; Salvador-Ullauri, L. Accessibility assessment of mobile serious games for people with cognitive impairments. In Proceedings of the International Conference on Information Systems and Computer Science, IEEE, Quito, Ecuador, 23–25 November 2017; pp. 323–328.
22. Salvador-Ullauri, L.; Acosta-Vargas, P.; Luján-Mora, S. *Accessibility Evaluation of Video Games for Users with Cognitive Disabilities*; Springer: Cham, Germany, 2020; pp. 853–859.
23. World Wide Web Consortium (W3C). Web Content Accessibility Guidelines (WCAG) 2.0. Available online: https://www.w3.org/TR/WCAG20/ (accessed on 3 August 2020).
24. Park, H.J.; Kim, S.B. Guidelines of serious game accessibility for the disabled. In Proceedings of the International Conference on Information Science and Applications, IEEE, Suwon, South Korea, 24–26 June 2013; pp. 1–3.
25. Araújo, M.C.; Façanha, A.R.; Darin, T.G.; Sánchez, J.; Andrade, R.M.; Viana, W. *Mobile Audio Games Accessibility Evaluation for Users Who are Blind*; Springer: Cham, Germany, 2017; pp. 242–259.
26. Cairns, P.; Power, C.; Barlet, M.; Haynes, G. Future design of accessibility in games: A design vocabulary. *Int. J. Hum. Comput. Stud.* **2019**, *131*, 64–71. [CrossRef]
27. Waki, A.L.; Fujiyoshi, G.S.; Almeida, L.D. *Games Accessibility for Deaf People: Evaluating Integrated Guidelines*; Springer: Cham, Germany, 2015; pp. 493–504.
28. Westin, T.; Ku, J.J.; Dupire, J.; Hamilton, I. *Game Accessibility Guidelines and WCAG 2.0–A Gap Analysis*; Springer: Cham, Germany, 2018; pp. 270–279.
29. Wilson, A.; Crabb, M. W3C Accessibility guidelines for mobile games. *Comput. Games J.* **2018**, *7*, 49–61.
30. Spyridonis, F.; Daylamani-Zad, D. A serious game to improve engagement with web accessibility guidelines. *Behav. Inf. Technol.* **2020**, 1–19. [CrossRef]
31. Moreno, L.; Valencia, X.; Pérez, J.; Arrue, M. Exploring the Web navigation strategies of people with low vision. In Proceedings of the International Conference on Human Computer Interaction, ACM, Palma, Spain, 12–14 September 2018; p. 13.
32. World Health Organization (WHO). Blindness and Vision Impairment. Available online: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment (accessed on 3 September 2020).
33. Bourne, R.R.; Flaxman, S.R.; Braithwaite, T.; Cicinelli, M.V.; das, A.; Jonas, J.B.; Naidoo, K. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: A systematic review and meta-analysis. *Lancet. Glob. Heal.* **2019**, *5*, e888–e897. Available online: https://linkinghub.elsevier.com/retrieve/pii/S2214109X17302930 (accessed on 26 January 2019). [CrossRef]
34. Brajnik, G. *Beyond Conformance: The Role of Accessibility Evaluation Methods*; Springer: Berlin, Germany, 2008; pp. 63–80.

35. The Paciello Group. Colour Contrast Analyser. Available online: https://developer.paciellogroup.com/resources/contrastanalyser/ (accessed on 20 June 2020).
36. University of Maryland. Photosensitive Epilepsy Analysis Tool. Available online: https://trace.umd.edu/peat (accessed on 20 June 2020).
37. Acosta-Vargas, P.; Salvador-Ullauri, L. Dataset Evaluation in Serious Games. Mendeley Data. Available online: https://data.mendeley.com/datasets/t2tr35ww4c/5 (accessed on 3 September 2020).

11 Web-Based Serious Games and Accessibility: A Systematic Literature Review

Referencia:
Salvador-Ullauri L., Acosta-Vargas P., and Luján-Mora S. (2020). Web-Based Serious Games and Accessibility: A Systematic Literature Review. Applied Sciences, 10(21), 7859; 125634–125648 (Salvador-Ullauri, Acosta-Vargas, y Luján-Mora, 2020)

Disponible en:

- https://www.mdpi.com/2076-3417/10/21/7859
- https://doi.org/10.3390/app10217859

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad web en los juegos serios educativos.
2. Recopilación del estado de la cuestión en juegos serios basados en la Web y accesibilidad.
3. Identificación de la accesibiidad en juegos serios con los tipos de discapacidad.

Review

Web-Based Serious Games and Accessibility: A Systematic Literature Review

Luis Salvador-Ullauri [1], Patricia Acosta-Vargas [2,*] and Sergio Luján-Mora [1]

[1] Department of Software and Computing Systems, University of Alicante, 03690 Alicante, Spain; lasu1@alu.ua.es (L.S.-U.); sergio.lujan@ua.es (S.L.-M.)
[2] Intelligent and Interactive Systems Laboratory, Universidad de Las Américas, Quito 170125, Ecuador
* Correspondence: patricia.acosta@udla.edu.ec

Received: 11 September 2020; Accepted: 23 October 2020; Published: 6 November 2020

Abstract: Nowadays, serious games, called training or learning games, have been incorporated into teaching and learning processes. Due to the increase of their use, the need to guarantee their accessibility arises in order to include people with disabilities in the educational environments in an integral way. There are reviews of the literature on video games but not on web-based serious games. Serious games are different from the previous ones because their educational processes allow reinforcing learning. This literature review was conducted using the recommendations for systematic reviews proposed by Kitchenham and Petersen. Three independent reviewers searched the ACM Digital Library, IEEE Xplore, Scopus, and Web of Science databases for the most relevant articles published between 2000 and 2020. Review selection and extraction were made using an interactive team approach. We applied the study selection process's flowchart adapted from the PRISMA statement to filter in three stages. This systematic literature review provides researchers and practitioners with the current state of web-based serious games and accessibility, considering cognitive, motor, and sensory disabilities.

Keywords: accessibility; games; literature; review; serious; systematic; Web Content Accessibility Guideline 2.1

1. Introduction

The Web has changed the way people communicate and relate to each other. Technology has generated a continuous impact on society and individuals' behavior. The increasing access to the Web and the variety of devices that allow us to interact with it have made it possible for students to choose the tools and services that best suit their needs, and thus to personalize the learning experience [1].

Figure 1 shows the Google Trends search related to web applications, serious games, and mobile applications made on the Web in the last five years. We found that the term serious games and web applications began to intensify from 2019.

Serious games are "games that do not have entertainment, enjoyment, or fun as their main objective" (p. 21, [3]). The main objectives of serious games can be, among others, education, training, human resources management, and health improvement [4]. Web-based serious games constitute an area growing thanks to the improvement of browsers and technologies used on the Web [1], which have reduced the gap between desktop and web applications.

According to Statista [5], the game-based learning market revenue worldwide between 2018 and 2024 indicates the serious games market is expected to grow from 3.5 billion U.S. dollars to 24 billion in 2024. The trend of serious web-based games has several benefits: (1) Reinforce learning in educational processes virtually and at a distance [1]. (2) Use the applications without the need to download, install, and configure. (3) Interact with the applications at any time and space. (4) Update the application

automatically with the latest version. (5) Use the applications with fewer technical problems due to software or hardware conflicts with other applications.

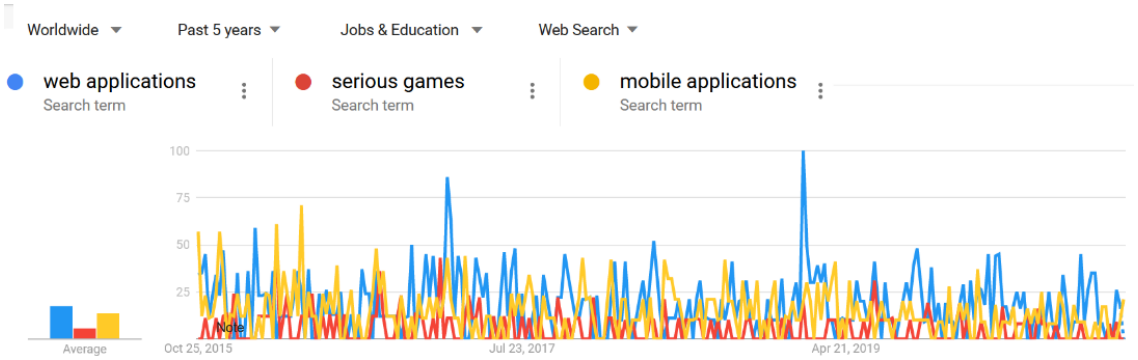


Figure 1. Trend of web-based serious games [2].

Nowadays, there are many web-based serious games, but developers are not usually worried about making them accessible. The accessibility [6] aims to ensure that applications can be used by the maximum number of people, regardless of their abilities and regardless of the technical characteristics of the equipment used to access the application. According to the Web Content Accessibility Guidelines (WCAG) 2.1, some guidelines help validate web pages, applications including serious games, making them more accessible to everyone, including people with disabilities.

This study compares articles related to accessibility in serious web-based games. In this research, we present a systematic literature review (SLR) [7,8] that allows examining serious games' accessibility. We start from the following research question: What accessibility evaluation standards have been used by developers to create serious web-based games? This study defines the query strings that allow finding the most significant research related to accessibility in serious games [9]. To determine the query string, we apply the structure in terms of population, intervention, comparison, and outcome (PICO) [10].

This SLR allowed us to (1) outline the issues relevant to serious web-based gaming and accessibility studies; (2) identify how accessibility is involved in serious gaming; (3) determine accessibility guidelines based on the WCAG, and (4) identify the assistive technologies and devices used to achieve accessibility in serious gaming according to disability. After an extraction process of 476 studies, a collection of 47 primary studies was selected using the Preferred Reporting Elements for Systematic Reviews (PRISMA) [11,12], the flowchart in the selection process.

This article is organized as follows. Section 2 introduces readers to the topic of accessibility and serious games. Section 3 describes the research method used for the systematic review of the literature. Section 4 includes the bibliometric analysis results and the literature review. Section 5 presents discussions of the results, along with limitations for research. Finally, Section 6 presents conclusions and future research work.

2. Background and Motivation

The formal description given by [13] indicates that "serious games" have an explicit and carefully thought out educational purpose and are not intended to be played primarily for fun [14]. Serious games are educational or training games [14], while video games [15] provide a cultural outlet where more players can be included and interacted to perform activities between different users.

This study identified video game SRL publications but not on serious games, so we justify this study's need to: (1) identify information on the most relevant research on web-based serious games and accessibility; (2) identify accessibility guidelines that apply to web-based serious games; (3) detect the different approaches to web-based serious games for cognitive, motor, and sensory disabilities; (4) identify the WCAG-based accessibility guidelines applied to serious games to determine trends and gaps in serious games development; (5) identify authors conducting accessibility studies on serious games.

Serious Games and Accessibility

Accessibility in serious games [16] aims to ensure that serious games can be used by the maximum number of people to access serious games. The authors suggest applying the four principles of WCAG 2.1.

Several studies [9,17] show a lack of commitment by designers to implement accessibility. For this reason, there is a low percentage of accessible serious games. Currently, serious games have been incorporated into the teaching-learning processes. Therefore, it is essential to guarantee accessibility [18] so that the largest number of people can use them.

The authors [19] present an analysis of the accessibility guidelines for the development of videogames; the study is oriented to cognitive disabilities. It also proposes categorizing the guidelines that should be used to analyze a video game's accessibility, especially serious games. The authors present an evaluation tool for the development of serious games for mobile devices.

Following the article, the authors [20] indicate that it is a great challenge to implement serious games to support the learning processes of people with cognitive disabilities. The authors evaluated ten serious video games using the design principles established by WCAG 2.0 [21]. The results revealed that applications do not reach an adequate level of accessibility to be used by people with cognitive problems. However, they do meet some of the accessibility requirements.

3. Method Applied for Systematic Literature Review

This SRL [7,8] began defining a review protocol, the research question, and the methods. In this SLR, we apply the PRISMA Statement, which consists of a list of 27 elements and a four-phase flow diagram. The PRISMA method is frequently used in health issues [22]; this method was adapted to identify studies related to accessibility and serious games. We attached a checklist (Appendix A); in PRISMA Checklist, we record the page number or pages in which compliance or non-compliance with the 27 items detailed in the seven sections can be evidenced: (1) Title, (2) Summary, (3) Introduction, (4) Methods, (5) Results, (6) Discussion, and (7) Funding.

Figure 2 shows the review process consisting of five phases: (1) definition of the research questions to review the scope; (2) search strategy to obtain all documents; (3) screening of the documents to extract the most relevant documents; (4) keywording using abstracts for the classification scheme, and (5) data extraction and revision process to obtain the results of the systematic review.

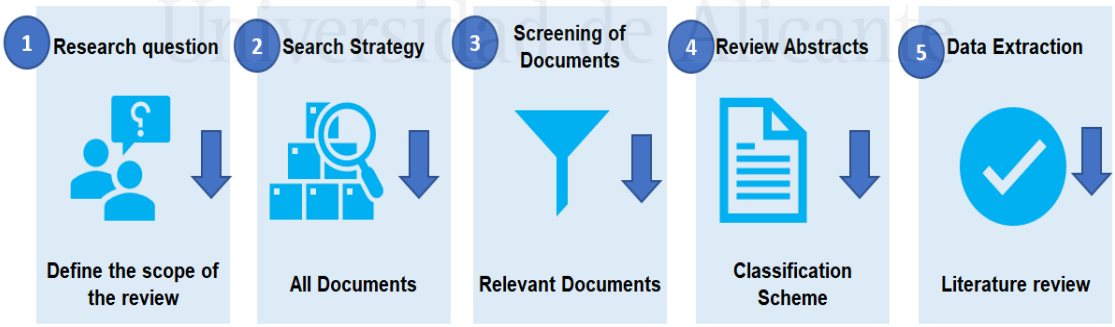


Figure 2. Review process.

3.1. Research Objectives and Questions

This study's first objective is to present information about the most relevant research on published web-based serious games and accessibility. This SLR contains a series of articles from the digital libraries and details the authors, the year of publication, and the Scimago Journal Rank (SJR) impact factor.

The second objective is to detect the different approaches to serious web-based games for cognitive, motor, and sensory disabilities.

The third objective is to identify the WCAG-based accessibility guidelines applied to serious gaming to determine trends and gaps in serious game development.

The research questions were raised because serious games have been extensively incorporated into the teaching-learning processes [23,24]. Due to the increase in their use, the need arises to fully guarantee their accessibility to people with disabilities in educational environments.

Our study examines the results of existing primary studies published on accessibility and serious games to identify current trends and open issues in the domain: our research questions and each question's purpose.

RQ1. Are the web-based serious games being developed today accessible? To investigate the accessibility of web-based serious games that have been developed from 2000 to the present.

RQ2. What are the proposals to increase accessibility by disability in web-based serious games? To identify the accessibility proposals by the disability that are applied in web-based serious games.

RQ3. What are the accessibility solutions by disability for web-based serious games? To identify existing by disability solutions that are used to achieve accessibility in web-based serious games.

RQ4. What methods are applied in the design of web-based serious games? To classify the methods applied in the design of web-based serious games by disability.

RQ5. What kind of research and contributions are used in web-based serious games and accessibility? To identify the types of research and contribution used in web-based serious games and accessibility considering the disability.

3.2. Search Strategy

Primary studies were identified by a query string derived from the research questions. Based on the research questions in Table 1, PICO was implemented as follows:

- Population: published studies.
- Intervention: accessibility, web-based serious games.
- Comparison: selected studies by disability, accessibility standard-based, type of research, assistive technologies, and use of external devices.
- Outcome: published studies on accessibility and web-based serious games.

Built on PICO, we created the query string, as presented in Table 2. The search was conducted on 6 June 2020, and the authors selected four academic research databases used in engineering to retrieve primary information: (1) ACM Digital Library; (2) IEEE Xplore; (3) Scopus, and (4) Web of Science (WOS). The query strings for each chosen source were defined from the search terms connected by Boolean AND/OR operators. Additionally, the asterisk (*) wildcard was used to include both the singular and plural form of each term. Table 1 shows the selected database, the query string, and the number of studies extracted. The query string was applied to the title of the publication with the keywords: "serious", "game*", and "accessi*". Similar search syntax was applied across the four selected sources for consistency; the period under review included studies published between 2000 and 2020. We used equivalent strings that seek to locate the same articles, but each database has its specific syntax.

Table 1. Query string applied.

Database	String Search	Number of Studies
ACM Digital Library	[Publication Title: accessi*] AND [Publication Title: serious] AND [Publication Date: (01/01/2000 TO 05/31/2020)] [Publication Title: accessi*] AND [Publication Title: game*] AND [Publication Date: (01/01/2000 TO 05/31/2020)]	92
IEEE Xplore	(("Document Title": accessi* serious) OR "Document Title": accessi* game*)	25
Scopus	TITLE (accessi*) AND (TITLE (serious) OR TITLE (game*))	190
Web of Science	TI = (accessi* serious) OR TI = (accessi* game*)	169
	Total studies number	**476**

Table 2. Article quality evaluation checklist.

N°	Quality Assessment Questions	Answer
QA1	Is serious games accessibility detailed in the paper?	(+1) Yes/(+0) No
QA2	Is the serious games accessibility evaluation method specified in the paper?	(+1) Yes/(+0) No
QA3	Does the paper discuss any findings of serious games accessibility evaluation?	(+1) Yes/(+0) No
QA4	Are standard serious games accessibility errors described in the results?	(+1) Yes/(+0) No
QA5	Is the journal or the conference where the paper was published indexed in SJR?	(+1) if it is ranked Q1, (+0.75) if it is ranked Q2, (+0.50) if it is ranked Q3, (+0.25) if it is ranked Q4, (+0.0) if it is not indexed.

3.3. Screening of Documents

Based on the guidelines of the literature review [7], the application of the inclusion and exclusion criteria is essential to filter the results. The inclusion and exclusion criteria aim to obtain relevant primary studies to answer the defined research questions. Selection discrepancies were resolved by consensus between the authors.

Inclusion criteria: The primary study must be related to (1) the type of publication in journals, conferences, books, and book chapters on accessibility in web-based serious games published from 2000 to 2020; (2) primary peer-reviewed studies; (3) written in English language.

Exclusion criteria: The primary study: (1) summarizes a keynote, a workshop introduction, or only an abstract; (2) duplicate articles from the same study from different sources.

In this phase, to describe the process, we apply PRISMA [11,12,25], as shown in Figure 2. PRISMA applies to all types of systematic reviews and is not limited to clinical trials. PRISMA has been conceived as a tool to help improve clarity and transparency in systematic reviews. The search and selection process is placed on a flow chart; the process phases serve as a literature reviewer's guide. This process includes: (1) the databases consulted, indicating the number of documents obtained from each of them; (2) the number of documents that are duplicates; (3) the number of papers eliminated in each stage of the process and the reasons for elimination, and (4) the number of documents included in the study. Figure 3 shows the PRISMA flow diagram with the four phases of the selection process of the articles, which are described below:

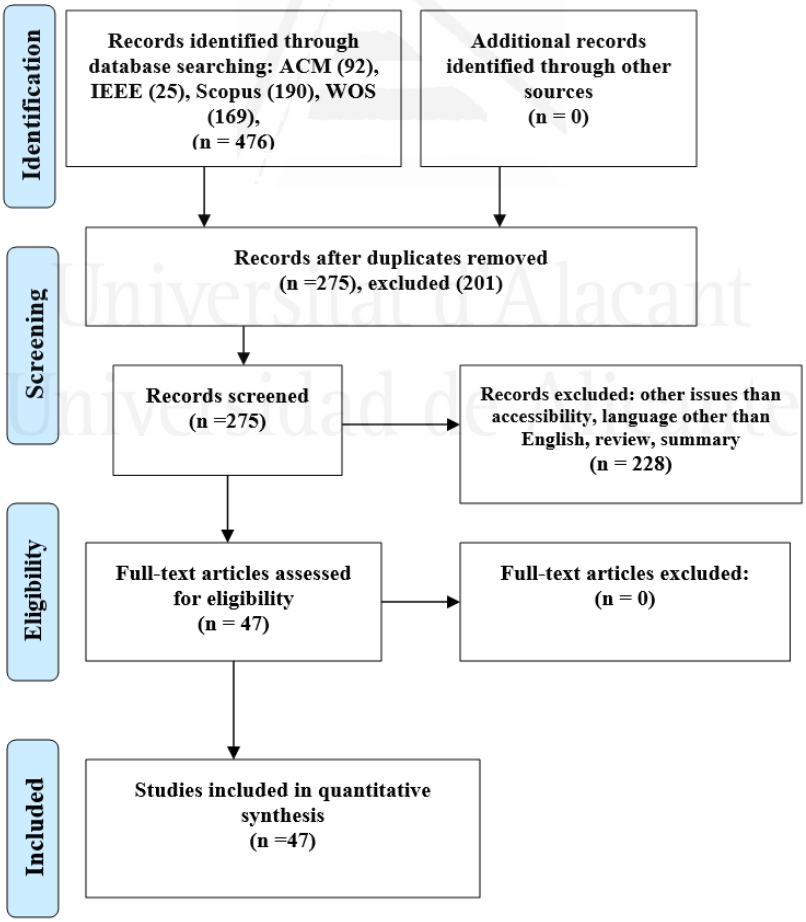


Figure 3. PRISMA flow diagram.

Phase 1: Identification. Here, we include the records obtained from database searches: ACM with 92 documents, IEEE Xplore with 25 articles, Scopus with 190 articles, and WOS with 169, a total of 476 articles were extracted.

Phase 2: Screening. Here, we apply the inclusion and exclusion criteria. Of the 476 articles, 201 articles were excluded because they were duplicated in different databases, 275 articles were included. Then, in the following filter, we excluded studies written in a language other than English, review studies, abstracts, workshops, and studies on topics other than accessibility in serious games; we excluded a total of 228 studies; finally, a total of 47 reviews passed to the next phase.

Phase 3: Eligibility. Three authors conducted an in-depth review of the full text of the 47 articles that focused explicitly on primary studies on accessibility and web-based serious games; we did not exclude any full-text articles. Furthermore, we evaluate the quality of the research articles that respond to accessibility in serious games; we apply a "quality assessment" of the selected articles. The purpose of this quality assessment (QA) is to weigh the importance of each of the papers chosen when the results are discussed and to guide the interpretation of findings [8]. Each QA obtains a score of one for the fulfillment of each clause (1) Is web-based serious games accessibility detailed in the paper? (2) Is the method of evaluating the accessibility of web-based games specified in the article? (3) Does the article discuss the accessibility assessment results in serious web-based games? (4) Are the accessibility issues of the web-based serious games described? (5) Is the journal where the paper was published indexed in SCImago Journal Rank (SJR)? Table 2 presents a checklist of quality evaluation.

Phase 4: Included. We recorded 47 articles full-text articles in the quantitative synthesis. Figure 3 shows that we have not added any additional records.

3.4. Keywording and Classification

For keywording and classification, we apply the concepts: (1) Classification scheme, which consists of a process of reading abstracts, searching for keywords and concepts that reflect the contribution of the primary study to ensure that the desired results are covered in the literature review, providing in the introduction a set of categories representing the study population. (2) Keywords that are used to apply the classification scheme in the literature review system. We consider abstract reading, keyword search, and context-related study objective. (3) The technique that allows for the classification of relevant articles for actual data extraction. In this phase, we use the keywords to group and form categories. The categories have been grouped. We review all the selected documents. After reading them, we update the categories or create a new category if the document reveals something. The keywords grouped by category, and the frequency are Key1 = Accessibility, Accessibility assessment, Accessibility, Design with a frequency of 37. Key2 = Assistive technology with 3. Key3 = Computer, aided, instruction with 10. Key4 = Disability with 5. Key5 = Games, Game, serious games, videogames with 44. Key6 = Guidelines, Accessibility guidelines with 14. Key7 = Human factors, Systems interaction with 5. Key8 = People disabilities with 25. Key9 = Visually impaired with 13. Key10 = Web with a frequency of 6.

3.5. Data Extraction

Data extraction was iterative; it was divided into several stages in which different activities were carried out. To extract the information from the ACM Digital Library, we exported it to BibTeX (BIB) format. In contrast, the IEEE Xplore, Scopus, and WOS information were exported in Research Information Systems (RIS) format. We then imported the data from the four files to the StartLapes tool version 2.3.4.2 [25], which automatically eliminates duplicate studies. We applied the process detailed in the PRISMA flowchart. Finally, we imported the data into a Microsoft Excel spreadsheet to continue the analysis. Table 3 presents the 47 primary studies selected, ordered by the most current year of publication. It contains the article number, the assigned indicator (it was created with the first letters of the surnames of the first two authors and the year of publication), the title of the article, the first author with the reference, and the year of publication.

In this phase, we apply the quality evaluation to the selected papers. Table 4 presents a list of the chosen works, together with the results of the quality control. Furthermore, a standardization column has been created to use a standard scale from 0 to 1.

Table 3. List of papers selected in this review.

#	ID	Title	Authors	Year
1	RS20	Be Active! Participatory Design of Accessible Movement-Based Games	Regal G [26]	2020
2	SD20	A serious game to improve engagement with web accessibility guidelines	Spyridonis F [27]	2020
3	SA20a	Development of an accessible video game to improve the understanding of the test of Honey-Alonso	Salvador-Ullauri L [28]	2020
4	KO20	Game accessibility and advocacy for participation of the Japanese disability community	Kaigo M [29]	2020
5	SA20b	Accessibility evaluation of video games for users with cognitive disabilities	Salvador-Ullauri L [20]	2020
6	KT19	A Study on Accessibility in Games for the Visually Impaired	Khaliq I [30]	2019
7	DF19	Startup Workplace, Mobile Games, and Older Adults: A Practical Guide on UX, Usability, and Accessibility Evaluation	De Lima Salgado A[31]	2019
8	OZ19	Accessibility Requirements in Serious Games for Low Vision Children	Othman N [32]	2019
9	CP19a	Future design of accessibility in games: A design vocabulary	Cairns P [15]	2019
10	CM19	A guide for making video games accessible to users with cerebral palsy	Compañ-Rosique P [33]	2019
11	SD19	A Serious Game for Raising Designer Awareness of Web Accessibility Guidelines	Spyridonis F [34]	2019
12	CP19b	Enabled Players: The Value of Accessible Digital Games	Cairns P [35]	2019
13	MD19	Problem-Based Learning applied to the development of accessible serious games	Martins V [36]	2019
14	JG18	Towards an Accessible Mobile Serious Game for Electronic Engineering Students with Hearing Impairments	Jaramillo-Alcázar A [37]	2018
15	KK18	Bonk: Accessible programming for accessible audio games	Kane S [38]	2018
16	JL18a	Accessibility assessment of serious mobile games for people with cognitive impairments	Jaramillo-Alcázar A [19]	2018
17	JL18b	An approach to mobile serious games accessibility assessment for people with hearing impairments	Jaramillo-Alcázar A [39]	2018
18	YC18	Design of a game community based support system for cognitive game accessibility	Yildiz S [40]	2018
19	WK18	Game Accessibility Guidelines and WCAG 2.0-A Gap Analysis	Westin T [41]	2018
20	WC18	W3C accessibility guidelines for mobile games	Wilson A [42]	2018
21	LP17a	A Mobile Educational Game Accessible to All, Including Screen Reading Users on a Touch-Screen Device	Leporini B [43]	2017
22	SJ17	A Serious Game Accessible to People with Visual Impairments	Salvador-Ullauri L [44]	2017
23	JL17	Mobile Serious Games: An Accessibility Assessment for People with Visual Impairments	Jaramillo-Alcázar A [17]	2017
24	LP17b	An Inclusive Educational Game Usable via Screen Reader on a Touch-Screen	Leporini B [45]	2017
25	PC17	Game Accessibility Guidelines for People with Sequelae from Macular Chorioretinitis	Pereira A [46]	2017
26	AF17	Mobile audio games accessibility evaluation for users who are blind	Araújo M [47]	2017
27	LM16	Interaction in Video Games for People with Impaired Visual Function: Improving Accessibility	López J [18]	2016

Table 3. *Cont.*

#	ID	Title	Authors	Year
28	HS16	Using video game patterns to raise the intrinsic motivation to conduct accessibility evaluations	Henka A [48]	2016
29	DZ15	Accessible Games for Blind Children, Empowered by Binaural Sound	Drossos K [49]	2015
30	WF15	Games accessibility for deaf people: Evaluating integrated guidelines	Waki A [50]	2015
31	Po14	Understanding and Addressing Real-World Accessibility Issues in Mainstream Video Games	Porter J R [51]	2014
32	MB14	BraillePlay: Educational Smartphone Games for Blind Children	Milne L [52]	2014
33	TS14	Development of a game engine for accessible web-based games	Torrente J [53]	2014
34	PK13	Guidelines of Serious Game Accessibility for the Disabled	Park H [54]	2013
35	Ga13	Game Accessibility: Enabling Everyone to Play	Garber L [55]	2013
36	WW13	Return on investment in game accessibility for cognition impairments	Westin T [56]	2013
37	MM12	Assessment of Universal Design Principles for Analyzing Computer Games' Accessibility	Mustaquim M [57]	2012
38	TV11	Introducing accessibility features in an educational game authoring tool: The <e-adventure> experience	Torrente J [58]	2011
39	OM10	Accessibility of a Social Network Game	Ossmann R [59]	2010
40	GS09	Designing Universally Accessible Games	Grammenos D [60]	2009
41	MH08	Accessibility Challenge—a Game Show Investigating the Accessibility of Computer Systems for Disabled People	Morgan M [61]	2008
42	MO08	More than just a game: Accessibility in computer games	Miesenberger K [62]	2008
43	MP07	Finger Dance: A Sound Game for Blind People	Miller D [63]	2007
44	OM06	Guidelines for the development of accessible computer games	Ossmann R [64]	2006
45	GS06	Access invaders: Developing a universally accessible action game	Grammenos D [65]	2006
46	OA06	Computer Game Accessibility: From Specific Games to Accessible Games	Ossmann R [66]	2006
47	CL03	The TiM game engine: Development of computer games accessible to blind and partially sighted children	Callaos N [67]	2003

Table 4. Selected papers and quality assessment outcomes.

ID	Publication Name	Quality Assessment						
		QA1	QA2	QA3	QA4	QA5	Score	Normalization
RS20	International Conference on Tangible, Embedded, and Embodied Interaction	1	1	1	1	0	4	0.8
SD20	Behaviour & Information Technology	1	1	1	1	0.75	4.75	0.95
SA20a	International Conference on Applied Human Factors and Ergonomics	1	1	1	1	0.5	4.5	0.9
KO20	Information	1	1	1	1	0.5	4.5	0.9
SA20b	International Conference on Intelligent Human Systems Integration	1	1	1	1	0.5	4.5	0.9
KT19	International Conference on Smart Objects and Technologies for Social Good	1	1	1	1	0	4	0.8
DF19	International Conference on Smart Objects and Technologies for Social Good	1	1	1	1	0	4	0.8
OZ19	International Conference on the Design of Communication	1	1	1	1	0	4	0.8
CP19a	International Journal of Human Computer Studies	1	1	1	1	1	5	1
CM19	Universal Access in the Information Society	1	1	1	1	0.75	4.75	0.95
SD19	Conference on Human-Computer Interaction	1	1	1	1	0	4	0.8
CP19b	Games and Culture	1	1	1	1	1	5	1
MD19	Iberian Conference on Information Systems and Technologies	1	1	1	1	0.5	4.5	0.9
JG18	World Engineering Education Conference	1	1	1	1	0	4	0.8
KK18	Conference on Interaction Design and Children	1	1	1	1	0	4	0.8
JL18a	International Conference on Information Systems and Computer Science	1	1	1	1	0	4	0.8
JL18b	International Conference on Information Theoretic Security	1	1	1	1	0.5	4.5	0.9
YC18	International Conference on ArtsIT	1	1	1	1	0.25	4.25	0.85
WK18	International Conference on Computers Helping People with Special Needs	1	1	1	1	0.75	4.75	0.95
WC18	The Computer Games Journal	1	1	1	1	0	4	0.8
LP17a	World Conference on Mobile and Contextual Learning	1	1	1	1	0	4	0.8
SJ17	International Conference on Education Technology and Computers	1	1	1	1	0	4	0.8
JL17	International Conference on Technological Ecosystems for Enhancing Multiculturality	1	1	1	1	0	4	0.8
LP17b	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
PC17	Entertainment Computing	1	1	1	1	0.75	4.75	0.95
AF17	International Conference on Universal Access in Human-Computer Interaction	1	1	1	1	0	4	0.8
LM16	International Conference on Human Computer Interaction	1	1	1	1	0	4	0.8

Table 4. *Cont.*

ID	Publication Name	Quality Assessment						
		QA1	QA2	QA3	QA4	QA5	Score	Normalization
HS16	International Conference on Applied Human Factors and Ergonomics	1	1	1	1	0.5	4.5	0.9
DZ15	International Conference on PErvasive Technologies Related to Assistive Environments	1	1	1	1	0	4	0.8
WF15	International Conference on Universal Access in Human-Computer Interaction	1	1	1	1	0	4	0.8
Po14	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
MB14	International ACM SIGACCESS Conference on Computers & Accessibility	1	1	1	1	0	4	0.8
TS14	International Conference on Games and Learning Alliance	1	1	1	1	0.75	4.75	0.95
PK13	International Conference on Information Science and Applications	1	1	1	1	0	4	0.8
Ga13	Computer	1	1	1	1	1	5	1
WW13	European Conference of the Association for the Advancement of Assistive Technology in Europe	1	1	1	1	0	4	0.8
MM12	International Conference on Computers for Handicapped Persons	1	1	1	1	0.75	4.75	0.95
TV11	International Conference on Advanced Learning Technologies	1	1	1	1	0	4	0.8
OM10	International Conference on Computers for Handicapped Persons	1	1	1	1	0.75	4.75	0.95
GS09	Computers in Entertainment	1	1	1	1	0.5	4.5	0.9
MH08	ACM SIGACCESS Accessibility and Computing	1	1	1	1	0	4	0.8
MO08	Symposium of the Austrian HCI and usability engineering group	1	1	1	1	0	4	0.8
MP07	International ACM SIGACCESS Conference on Computers and Accessibility	1	1	1	1	0	4	0.8
OM06	International Conference on Computers for Handicapped Persons	1	1	1	1	0	4	0.8
GS06	International Conference on Computers for Handicapped Persons	1	1	1	1	0	4	0.8
OA06	International Conference on Computer Games (CGAMES)	1	1	1	1	0	4	0.8
CL03	World Multiconference on Systemics, Cybernetics and Informatics	1	1	1	1	0	4	0.8

Normalization [68] was used, which preserves the relationship between the original data values. The values in this column are transformed using the following Equation (1):

$$Normalization = \frac{\text{Score} - \min(\text{Score})}{[\max(\text{Score}) - \min(\text{Score})]} \quad (1)$$

where the min(Score) is equal to 0, the max(Score) is equal to 5, and the Score is the value calculated in Table 4.

4. Results

In this section, we answer the research questions by:

(1) A bibliometric analysis to collect information about the authors and publication data of research growth over time, journals, conferences, books, and book chapters published on serious games and accessibility.
(2) A literature review to map the studies according to serious games' concepts and the five research questions.

4.1. Bibliometric Analysis

This analysis aims to respond to RQ1; Figure 4 shows the evolution of scientific production, presenting the number of documents each year. The years of most scientific output in accessibility in the serious games are 2018 and 2019. We found eight papers for 2019, which corresponds to 17%, seven documents for 2018, which corresponds to 14.9%. In 2017, we found six articles, corresponding to 12.8%. In 2020, we found five documents, which corresponds to 10.6%. It is expected that this number tends to increase because it was done until July 2020. In 2006, 2013, and 2014, there were three documents each year that add up to 19.1%. In 2008, 2015, and 2016, there were two items each year that add up to 12.8%. Finally, in 2003, 2007, 2009, 2010, 2011, and 2012, one document added up to 12.8% each year. The annual growth rate of the published articles follows the polynomial Equation (2).

$$y = 0.0216x2 - 0.1639x + 0.6421 \quad (2)$$

Figure 5 presents 35 conference studies representing 74.5% of the total and 12 journal articles representing 25.5%. In this review of the literature, the most significant number of studies found are concentrated in conferences. The largest number of documents are indexed in Scopus.

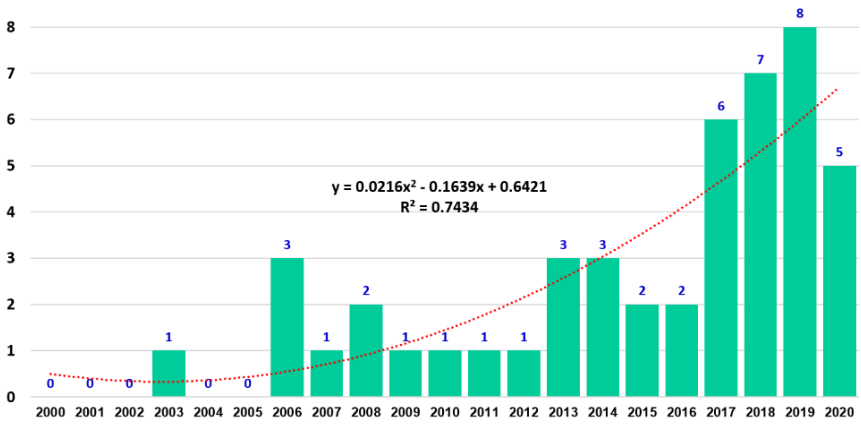


Figure 4. Documents published from 2000 to 2020.

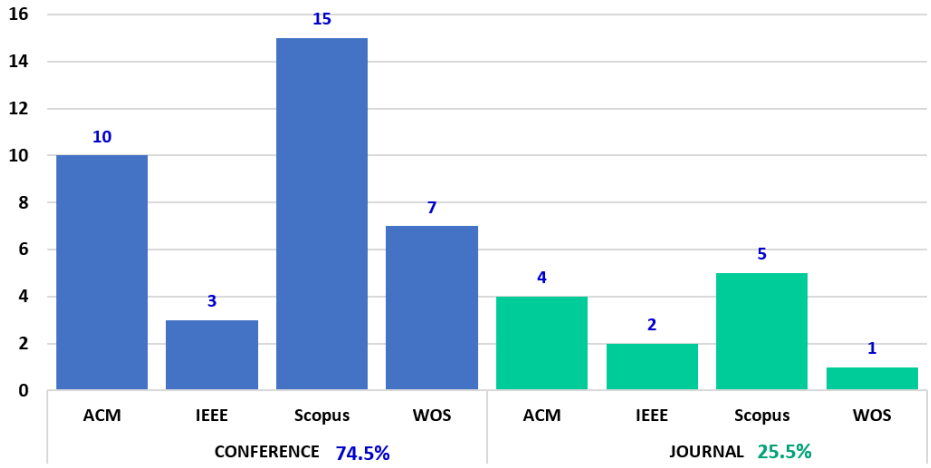


Figure 5. Documents by type.

4.2. Review of the Literature to Map the Studies

In this section, we presented a classification scheme using keywords; we performed the following: (1) we read the abstracts of the 47 primary studies selected and searched for keywords;(2) we read the introduction and conclusion sections of each of the primary studies chosen to elaborate the classification scheme; (3) we presented the classification in five aspects that were defined as follows: (1) The disability accessibility guidelines which aim to provide a standard of easy access to serious games that meets people's needs. (2) The applied solutions that involve the methods used to make serious games accessible. (3) The disability accessibility guidelines that provide input for serious play. (4) The types of disability contributions [5] include the formal study, method, system, or experience, and (5) The type of research that includes validation, solution, evaluation, feedback, and experience [7].

Then, we present and discuss the answers to the research questions in this study; the dataset and analysis are available for replication in the Mendeley repository [69].

4.2.1. RQ1. Are the Serious Games Being Developed Today Accessible?

In this research, we have selected the primary studies that apply accessibility to serious games. The web has numerous limitations, but if the design is considered accessible to all people, including people with some type of disability, the application will be more accessible and inclusive for many users.

Table 5 presents the primary studies that use accessibility by type of disability. In the review of the documents, we applied the following definitions:

- Cognitive or intellectual disability is a problem characterized by a delay in mental development that disrupts the learning process.
- Motor coordination, or physical disability, is a problem related to significant impairment of one or more parts of the body's movement abilities.
- Sensory: this type of disability is related to (1) vision, which includes users with low vision and deafness; (2) hearing disability, which provides deafness and hearing loss.

Table 5 shows the accessibility related to the type of disability. We found 33 primary studies on sensory disability that represent 72% of the total, then 11 studies apply accessibility for cognitive disability with 22%. Finally, three studies on motor coordination that correspond to 6% of the total.

Table 5. Studies by disability.

Type of Disability	ID
Cognitive (11 studies)	CL03, CM19, HS16, JL18a, LP17a, MD19, OM06, SA20a, SA20b, WW13, YC18
Motor coordination (3 studies)	KO20, DF19, SD19
Sensory: visually impaired, hearing (33 studies)	JL17, JG18, RS20, SD20, KT19, OZ19, CP19a, CP19b, KK18, JL18b, WK18, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, Ga13, MM12, TV11, OM10, GS09, MH08, MO08, MP07, GS06, OA06

4.2.2. RQ2. What Are the Proposals to Increase Accessibility in Serious Games?

Table 6 presents the proposals to increase accessibility by type of disability; in the review of the documents, we applied the following definitions:

- WCAG 2.0: includes the primary studies that applied the Web Content Accessibility Guidelines with version 2.0 to increase serious games accessibility.
- WCAG 2.1: includes the primary studies that applied the Web Content Accessibility Guidelines with version 2.1 to increase serious games accessibility. WCAG 2.1 is the most advanced and accepted mechanism for creating accessible content, and it is not limited exclusively to web content [70].
- Other guidelines contain the primary studies that help increase accessibility in serious games by applying guidelines without specifying the standard.
- External devices: contains the primary studies that help to increase accessibility use some form of support appropriate to the motor, cognitive, and sensory characteristics of people who find it easy to access serious play, including the use of assistive technology.

We found: (1) 24 studies that refer to the guidelines for achieving accessibility in serious games but do not specify a standard, representing 51.1% of the total; (2) 14 studies that indicate external devices' application to achieve a higher level of accessibility in serious games, representing 29.8%; (3) seven studies that focused on the guidelines suggested by WCAG 2.0, representing 14.9%; (4) two studies focused on WCAG 2.1, representing 4.3% of the total.

Table 6. Guidelines by disability.

Guidelines	Cognitive	Motor Coordination	Sensory (Visually Impaired, Hearing)
WCAG 2.0 (7 studies)	SA20a.		SD20, CP19a, WK18, AF17, WF15, PK13.
WCAG 2.1 (2 studies)	SA20b.		WC18.
Other guidelines (24 studies)	CL03, CM19, LP17a, MD19, OM06.	KO20, DF19, SD19.	JG18, RS20, KT19, OZ19, CP19b, KK18, PC17, DZ15, MB14, MM12, TV11, GS09, MH08, MP07, GS06, OA06.
External devices (14 studies)	HS16, JL18a, WW13, YC18.		JL17, JL18b, SJ17, LP17b, LM16, Po14, TS14, Ga13, OM10, MO08.

4.2.3. RQ3. What Are the Accessibility Solutions Proposed for Serious Games?

Table 7 presents seven accessibility solutions for serious games by disability; it contains the type of solution applied and references; in the review of the documents, we used the following definitions:

- Accessibility guidelines: contains the primary studies that give solutions to accessibility problems by applying some norm or standard.
- Accessibility requirements: includes primary studies that provide solutions to accessibility problems by suggesting examining the state of serious games.
- Apply assistive technologies contains studies in which they apply assistive technology to achieve accessibility in serious games.

- Apply the concept of parallel game: has primary studies in which they give accessibility solutions by applying the parallel game, parallel universes, or alternative realities that improve the experience by taking the player out of the reality they are used to, and helps them improve their concentration.
- Apply external devices: contain studies of adaptation of external devices to provide accessibility solutions for serious games.
- Companies games: include primary studies where accessibility depends on the company's standards that develop serious games.
- Creative design: contains studies where applying innovative design addresses some of the accessibility issues.

The solution by type of disability has: (1) 22 studies and corresponds to 46.8% of the total consists of accessibility guidelines; (2) external devices apply with 14 primary reviews, corresponding to 29.8% of the total; (3) the solution proposed consists of accessibility requirements, with four studies representing 8.5%; (4) the proposal to apply creative design, with three primary studies, represents 6.4%; (5) the solution consists of applying the concept of the parallel game with two studies, representing 4.3%. (6) the proposal indicates the application of assistive technologies, has one study, corresponding to 2.1%; (7) the solution that shows to interact with companies games, with one review, representing 2.1% of the total.

Table 7. The solution to accessibility by type of disability.

Solution	Cognitive	Motor Coordination	Sensory (Visually Impaired, Hearing)
Accessibility guidelines (22 studies)	SA20a, SA20b, MD19, LP17a, CL03.	DF19, SD19.	JG18, KT19, CP19b, WK18, WC18, PC17, DZ15, WF15, MB14, PK13, MM12, TV11, MH08, MP07, OA06.
Accessibility requirements (4 studies)	CM19		OZ19, CP19a, AF17.
Apply assistive technologies (1 study)	OM06		
Apply the concept of Parallel Game (2 studies)			GS09, GS06.
Apply external devices (14 studies)	JL18a, YC18, HS16, WW13.		JL17, JL18b, SJ17, LP17b, LM16, Po14, TS14, Ga13, OM10, MO08.
Companies Games (1 study)		KO20	
Creative design (3 studies)			RS20, SD20, KK18.

4.2.4. RQ4. What Methods Are Applied in the Design of Serious Games?

Table 8 presents a summary of the methods by disability applied in the design of serious games with the references of the selected studies; in the review of the documents, we used the following definitions:

- Qualitative: The qualitative method is inductive and follows a flexible design, and records are made through narration, participant observation, and unstructured interviews. This method is manifested in the facts, processes, observations, case studies, interviews, analysis, and opinions of the authors are very subjective because there is no measurement of the elements. This method includes small-scale studies, emphasizes the validity of research through proximity to empirical reality, and does not usually test theories or hypotheses. The basis of this method is intuition; in general, it does not allow statistical analysis.
- Quantitative: The quantitative method produces numerical data, which allows the data to be collected and analyzed. In this method, objectivity is the way to reach knowledge; it uses specific and controlled measurements, looking for certainty. It includes descriptive studies under the

objective conception through a deductive strategy. This method contains studies that apply mixed methods and surveys for data collection.

Table 8 contains 41 studies that apply the qualitative method, representing 87.2%, and six studies use the quantitative approach, corresponding to 12.8% of the total. Figure 6 presents a classification of the studies by the method applied. The qualitative studies include (1) two analytical studies, corresponding to 4.3% of the total; (2) four case studies, representing 8.5%; (3) one interview corresponds to 2.1%; (4) 28 observation studies, corresponding to 59.6% of the total, are the most significant number of studies in this literature review; (5) three opinion studies compared to 6.4%. Quantitative studies include (1) two studies applying mixed methods represent 4.3% and (2) seven studies based on surveys, corresponding to 14.9% of the total.

Table 8. Methods applied to the design of serious games by disability.

Method	Cognitive	Motor Coordination	Sensory (Visually Impaired, Hearing)
Qualitative (41 studies)	OM06, SA20b, CM19, MD19, JL18a, YC18, LP17a, WW13, CL03.	KO20, DF19, SD19.	JL17, JG18, RS20, KT19, CP19a, KK18, JL18b, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, Ga13, MM12, TV11, OM10, GS09, MH08, MO08, MP07, GS06, OA06.
Quantitative (6 studies)	SA20a, HS16		SD20, OZ19, CP19b, WK18.

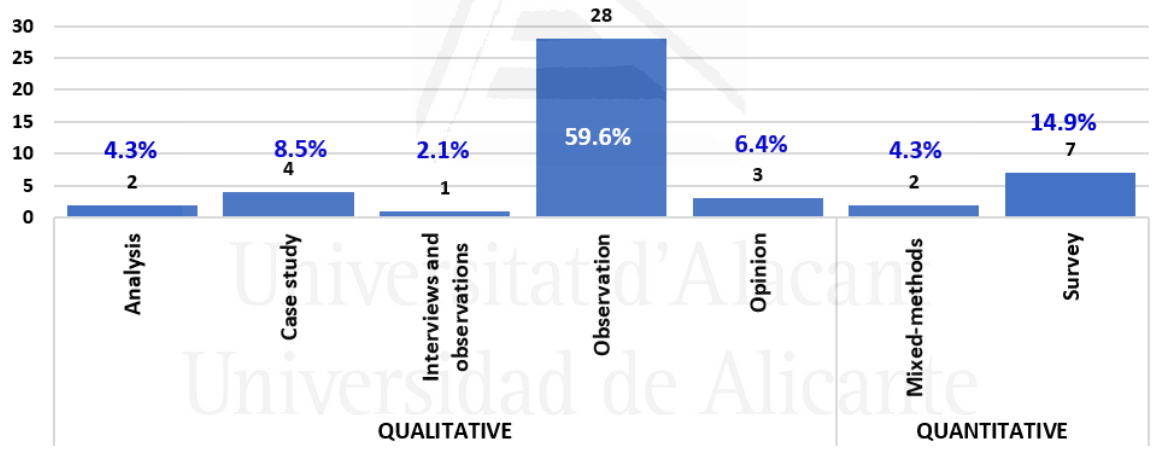


Figure 6. Methods and techniques applied in the design of serious games.

4.2.5. RQ5. What Kind of Research and Contribution Are Used in Accessibility in Serious Games?

To answer this question, we reviewed the documents by type of research by disability, as shown in Table 9. In the review of the papers, we applied the following definitions [7]:

- Evaluation research: provides the implemented solution, and investigates a practical problem, applies math test, survey, case study, field experiment to validate knowledge affirmation.
- Experience: contains case studies, projects, or reports on experiences, provides lessons learned.
- Opinion paper: provides the author's opinion on how something should be done.
- Solution proposal: offers a novel technique, or at least a relevant improvement.
- Validation research: presents researched techniques that have not yet been implemented in practice and are novel. It is methodologically sound and comprehensive, including experiments, prototyping, property testing, and simulation.

We found (1) 37 studies that apply "Experience", representing 78.7% of the total. (2) Five studies involve "Opinion paper" with 10.6%. (3) Two studies use "Evaluation research" corresponding to 4.3%.

(4) Two studies use "Validation research" with 4.3%. (5) One study applies a "Solution proposal" that represents 2.1% of the total. In this study, we conducted a systematic review of the literature with the following: (1) The question most answered corresponds to RQ1 with 47 studies, representing 28%. (2) The question RQ4, with 38 studies, represents 22.6%. (3) Question RQ5 has 37 studies, corresponding to 22%. (4) Questions RQ2 and RQ3 have 23 studies each, accounting for 27.4% of the total.

Table 9. Studies according to the type of research by disability.

Research Type	Cognitive	Motor Coordination	Sensory (Visually Impaired, Hearing)
Evaluation research (2 studies)			CP19b, WK18.
Experience (37 studies)	OM06, SA20b, CM19, MD19, JL18a, YC18, LP17a, WW13, CL03.	DF19, SD19.	JL17, JG18, RS20, SD20, KT19, OZ19, CP19a, KK18, JL18b, WC18, SJ17, LP17b, PC17, AF17, LM16, DZ15, WF15, Po14, MB14, TS14, PK13, TV11, OM10, GS09, MP07, GS06.
Opinion paper (5 studies)			Ga13, MM12, MH08, MO08, OA06.
Solution proposal (1 study)	SA20a.		
Validation research (2 studies)	HS16.	KO20.	

Figure 7 shows (1) The question that contributes most to this study are RQ1, RQ2, and RQ3. (2) The type of research that contributes the most to this study is the experience, which contributes to the five research questions, corresponding to 27.8% of the total. (3) Evaluation research, solution proposal, and validation research contribute to RQ1, RQ2, and RQ3, representing 50%. (4) Opinion paper contributes to questions RQ1, RQ2, RQ3, and RQ4, corresponding to 22.2% of the total.

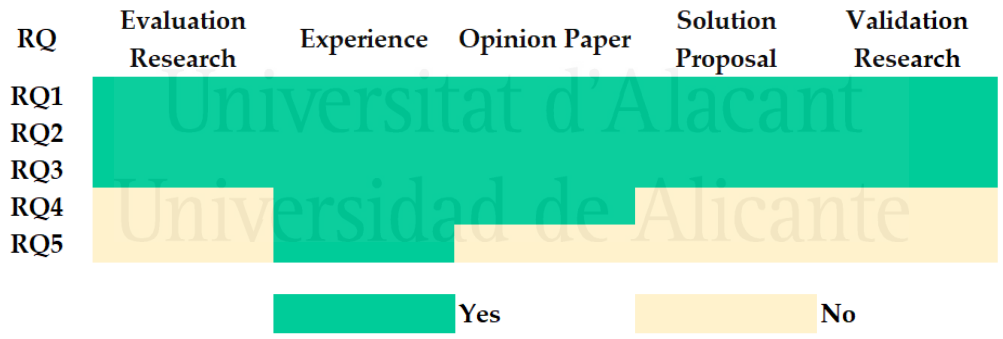


Figure 7. Contribution of research questions to the study.

Figure 8 shows: (1) A summary of the ten most frequently repeated keywords in the primary studies examined. The most repeated keyword is "game and serious games" with 27.2%, followed by "accessibility" corresponding 22.8%, "people disabilities" representing 15.4%, "guidelines" with 8.6%, "visually impaired" reaching 8%, and the rest representing 17.9%. (2) A summary of the answers to the questions posed in this research, and we found 17 studies that respond to the five questions and are AF17, CP19a, JL18a, JL18b, JL17, LP17b, LM16, OM10, PK13, Po14, KO20, SJ17, TS14, WF15, WW13, WC18, YC18.

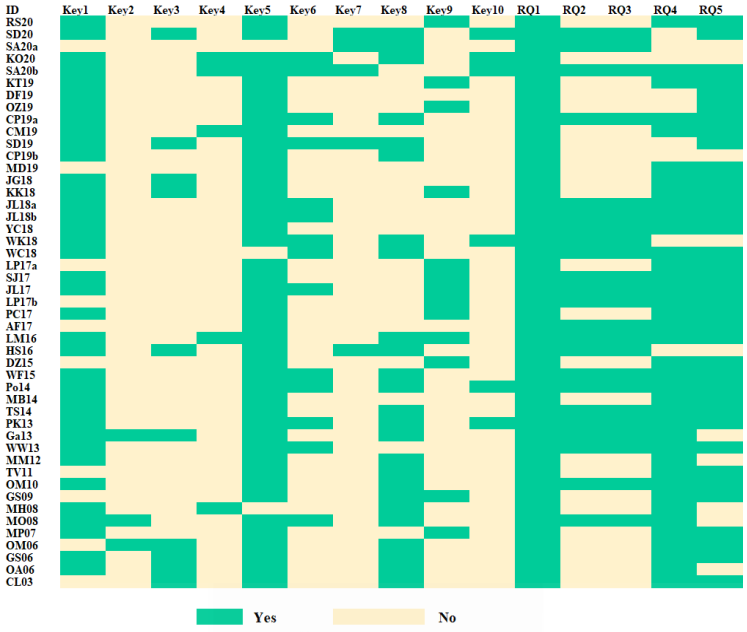


Figure 8. Primary studies answered keywords and research questions.

5. Discussion

In this study, we conducted a systematic review of the literature with five research questions. Excel spreadsheets can be downloaded from the Mendeley repository [69]. In this section, we summarize the main findings.

(1) The current accessibility situation shows that few developers apply it to serious games that consider disabilities. This literature review found that 72% of the primary studies selected are related to visual and hearing impairment accessibility. On the other hand, 22% of studies apply accessibility guidelines to solve some cognitive and learning problems. Few studies, about 6%, are concerned with using accessibility to serious games for motor disabilities.

(2) This study's statistics related to proposals to increase accessibility by type of disability in serious games reveal that 70.2% apply the accessibility guidelines. However, no guidelines are specified; we found studies that use their guidelines or modifications based on the International Game Developers Association (IGDA) [71] ideas on games' accessibility. Others apply the GA-SIG guidelines to create something like the WCAG [6]. We also find studies that involve the IBM [72] and Section 508 [73] guidelines. Of the selected primary studies, 14.9% use the WCAG 2.0, and 4.3% apply the WCAG 2.1. They apply the GA-SIG guidelines to create something like the W3C/WAI [74].

(3) The solutions to increase accessibility in serious games considering disability are few; we found that 2.1% of assistive technologies are applied, especially for cognitive disabilities. Moreover, 29.8% use external devices to make games more accessible, especially for motor and sensory disabilities. According to the studies found, we can conclude no inclusive development culture in software development companies.

(4) The methods applied to the design of serious disability games show that 87.2% of the primary studies selected use the qualitative approach, relying on observation to collect non-numerical data through focus groups and observation techniques. In contrast, the quantitative method received 12.8% of the selected primary studies, based on systematic empirical research of observable phenomena using statistical, mathematical, or computer techniques.

(5) The SLR results by type of disability-related documents reveal that experience-based research models received the most attention in 78.7% of the selected primary studies. This research model includes case studies, projects, and experience reports that provide lessons learned.

Besides, 10.6% of the selected primary studies rely on the author's opinion to apply accessibility in serious games. 4.3% of selected primary studies rely on evaluation research to provide solutions to practical problems and surveys. Also, 4.3% of the primary studies apply validation research by presenting researched techniques that have not yet been implemented and are novel. Finally, 2.3% of the selected primary studies use solution proposals to offer new approaches and improvements.

The selected studies' quality was determined by applying the quality assessment based on five additional questions (see Table 5). This SLR process has its limitations; it is not foolproof as any other secondary research method.

In this study, attention was paid to choosing the most useful query strings adapted according to each database's query structure. To mitigate this limitation, we applied the PICO criteria to our query strings [5]. The selection of the databases, the ACM Digital Library, IEEE Xplore, Scopus, and WOS, is adequate because out of 476 articles, 201 were duplicates, which means that the coverage of the four databases is high, so much so that some of them could have been excluded. The criteria emerged from discussions with the researchers involved. However, primary research search terms, such as accessibility and serious games, are traditional, well-defined, and accepted terms, which should decrease the number of ignored studies. Moreover, as the study focuses on identifying primary research on accessibility and web-based serious games, there is less concern about capturing vaguely domain-related research.

6. Conclusions

Accessibility is an essential research area that emerges from the web. In recent years, many studies have been published with a growing interest in this topic. This study highlighted current trends and outstanding issues in accessibility and applied guidelines for designing serious inclusive games using the results of existing primary studies published between 2000 and 2020.

In this study, an SLR was conducted with a set of five research questions and five questions to validate the quality of the selected studies. We extracted a total of 476 studies, and after a screening process with the help of the PRISMA flowchart, we chose a group of 47 primary studies. As a result, the limitations and problems of serious games regarding accessibility and possible solutions to generate more inclusive serious games were demonstrated.

Furthermore, we identified the status of serious gaming and accessibility related to disability. We identified research and contribution types that apply to serious gaming in cognitive, motor, and sensory disabilities. This study identified that developers rely on assistive technologies through software and hardware to achieve greater accessibility in serious games. This study shows the need for research on issues related to accessibility policies, guidelines, and practices for serious games and the threats of accessibility violations. Moreover, this study shows open research issues in applying accessibility guidelines in serious games by companies and developers. Finally, this study provides researchers and professionals with the status of serious games related to cognitive, motor, and sensory disabilities. For future work, we suggest: (1) building a software tool that applies WCAG 2.1 guidelines to support serious game developers; (2) defining anti-rules to increase the accessibility of serious games; (3) conducting a literature review on the accessibility of serious games for mobile and computer applications for users with disabilities.

Author Contributions: Conceptualization, L.S.-U., and P.A.-V.; methodology, L.S.-U.; investigation, L.S.-U., and P.A.-V.; writing—original draft preparation, L.S.-U., and P.A.-V.; writing—review and editing L.S.-U., S.L.-M., and P.A.-V.; supervision, S.L.-M.; project administration, P.A.-V., and L.S.-U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidad de Las Américas-Ecuador, as part of an internal research project FGE.PAV.19.11.

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

Appendix A

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1,2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	1
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	1, 3
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	3
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up), and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search, and date last searched.	4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe the data extraction method from reports (e.g., piloted forms, independently, duplicate) and any processes for obtaining and confirming data from investigators.	6,7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	3
Risk of bias in individual studies	12	Describe methods used for assessing the risk of bias of individual studies (including specification of whether this was done at the study or outcome level) and how it is used in any data synthesis.	3
Summary measures	13	State the principal summary measures (e.g., risk ratio, the difference in means).	13,14
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	9,10
Risk of bias across studies	15	Specify any assessment of the risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	16
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	3-15

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7,8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	9
Risk of bias within studies	19	Present data on the risk of bias of each study and, if available, any outcome level assessment (see item 12).	17,18
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	4-15
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	14,15
Risk of bias across studies	22	Present results of any assessment of the risk of bias across studies (see Item 15).	16
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	17
DISCUSSION			
Summary of evidence	24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policymakers).	13-15
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias) and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16,17
Conclusions	26	Provide a general interpretation of the results in the context of other evidence and implications for future research.	16,17
FUNDING			
Funding	27	Describe funding sources for the systematic review and other support (e.g., a supply of data) and funders' role for the systematic review.	17

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097
For more information, visit: www.prisma-statement.org

References

1. Kompen, R.T.; Edirisingha, P.; Canaleta, X.; Alsina, M.; Monguet, J.M. Personal learning Environments based on Web 2.0 services in higher education. *Telemat. Informatics.* **2019**, *38*, 194–206. [CrossRef]
2. Google. Google Trends. Available online: https://trends.google.com/trends/explore?cat=958&date=today5-y&q=webapplications,seriousgames,mobileapplications (accessed on 22 October 2020).
3. Michael, D.R.; Chen, S.L. *Serious Games: Games that Educate, Train, and Inform*; Muska & Lipman/Premier-Trade: USA, 2005.
4. Lau, H.M.; Smit, J.H.; Fleming, T.M.; Riper, H. Serious games for mental health: Are they accessible, feasible, and effective? A systematic review and meta-analysis. *Front. Psychiatry* **2017**, *7*. [CrossRef] [PubMed]
5. Statista. Game-Based Learning Market Revenue Worldwide in 2018 and 2024. 2020. Available online: https://www.statista.com/statistics/733616/game-based-learning-industry-revenue-world/ (accessed on 22 October 2020).
6. World Wide Web Consortium (W3C). Web Content Accessibility Guidelines (WCAG) 2.1. 2018. Available online: https://www.w3.org/TR/WCAG21/ (accessed on 21 October 2020).
7. Petersen, K.; Feldt, R.; Mujtaba, S.; Mattsson, M. Systematic mapping studies in software engineering. *Int. Conf. Eval. Assess Softw. Eng.* **2008**, *12*, 1–10. [CrossRef]
8. Kitchenham, B. *Procedures for Performing Systematic Reviews*; Keele University: Keele, UK, 2004; Volume 33, p. 28.
9. Aguado-Delgado, J.; Gutiérrez-Martínez, J.M.; Hilera, J.R.; de-Marcos, L.; Otón, S. Accessibility in video games: A systematic review. *Univers Access Inf. Soc.* **2020**, *19*, 169–193. [CrossRef]
10. Eriksen, M.B.; Frandsen, T.F. The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: A systematic review. *J. Med. Libr. Assoc.* **2018**, *106*, 420. [CrossRef] [PubMed]
11. Prisma-Statement. PRISMA. 2015. Available online: http://www.prisma-statement.org/ (accessed on 22 October 2020).
12. García-Holgado, A.; García-Peñalvo, F.J. Mapping the systematic literature studies about software ecosystems. In Proceedings of the International Conference on Technological Ecosystems for Enhancing Multiculturality, Salamanca, Spain, 24–26 October 2018; ACM: New York, NY, USA, 2018; pp. 910–918.
13. Schell, J. *The Art of Game Design: A Book of Lenses*; CRC Press: Boca Raton, FL, USA, 2008.
14. Pendleton, A.; Okolica, J. Creating Serious Games with the Game Design Matrix. In Proceedings of the International Conference on Games and Learning Alliance, Athens, Greece, 27–29 November 2019; Springer: Cham, Switzerland, 2019; pp. 530–539.
15. Cairns, P.; Power, C.; Barlet, M.; Haynes, G. Future design of accessibility in games: A design vocabulary. *Int. J. Hum. Comput. Stud.* **2019**, *131*, 64–71. [CrossRef]
16. Salvador-Ullauri, L.; Acosta-Vargas, P.; Gonzalez, M.; Luján-Mora, S. Combined Method for Evaluating Accessibility in Serious Games. *Appl. Sci.* **2020**, *10*, 6324. [CrossRef]
17. Jaramillo-Alcázar, A.; Luján-Mora, S. Mobile serious games: An accessibility assessment for people with visual impairments. In Proceedings of the International Conference on Technological Ecosystems for Enhancing Multiculturality, Cádiz, Spain, 18–20 October 2017; ACM: New York, NY, USA, 2017; pp. 1–6.
18. López, J.M.; Medina, N.M.; de Lope, R.P. Interaction in video games for people with impaired visual function: Improving accessibility. In Proceedings of the International Conference on Human Computer Interaction, Salamanca, Spain, 13–16 September 2016; ACM: New York, NY, USA, 2016; pp. 1–2.
19. Jaramillo-Alcázar, A.; Luján-Mora, S.; Salvador-Ullauri, L. Accessibility assessment of mobile serious games for people with cognitive impairments. In Proceedings of the International Conference on Information Systems and Computer Science, Quito, Ecuador, 23–25 November 2017; IEEE: New York, NY, USA, 2017; pp. 323–328.
20. Salvador-Ullauri, L.; Acosta-Vargas, P.; Luján-Mora, S. Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. In Proceedings of the International Conference on Intelligent Human Systems Integration, Modena, Italy, 19–21 February 2020; Springer: Cham, Switzerland, 2020; pp. 853–859.
21. World Wide Web Consortium (W3C). Web Content Accessibility Guidelines 2.0. 2018. Available online: https://www.w3.org/TR/WCAG20/ (accessed on 10 October 2020).
22. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Prisma Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]

23. Hersh, M.; Leporini, B. Serious games, education and inclusion for disabled people editorial. *Br. J. Educ. Technol.* **2018**, *49*, 587–595. [CrossRef]
24. Fuster-Guilló, A.; Pertegal-Felices, M.L.; Jimeno-Morenilla, A.; Azorín-López, J.; Rico-Soliveres, M.L.; Restrepo-Calle, F. Evaluating Impact on Motivation and Academic Performance of a Game-Based Learning Experience Using Kahoot. *Front. Psychol.* **2019**, *10*, 2843.
25. Budgen, D.; Turner, M.; Brereton, O.P.; Kitchenham, B.A. *Using Mapping Studies in Software Engineering*; Psychology of Programming Interest Group: Salford, UK, 2008; pp. 195–204.
26. Regal, G.; Sellitsch, D.; Kriglstein, S.; Kollienz, S.; Tscheligi, M. Be Active! Participatory Design of Accessible Movement-Based Games. In Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction, Sydney, NSW, Australia, 9–12 February 2020; ACM: New York, NY, USA, 2020; pp. 179–192.
27. Spyridonis, F.; Daylamani-Zad, D. A serious game to improve engagement with web accessibility guidelines. *Behav. Inf. Technol.* **2020**, 1–19. [CrossRef]
28. Salvador-Ullauri, L.; Acosta-Vargas, P.; Jadán-Guerrero, J.; Guevara, C.; Sanchez-Gordon, S.; Calle-Jimenez, T.; Lara-Alvarez, P. Development of an Accessible Video Game to Improve the Understanding of the Test of Honey-Alonso. In Proceedings of the International Conference on Applied Human Factors and Ergonomics, Washington, DC, USA, 24–28 July 2019; Isabel, L.N., Ed.; Springer: Cham, Switzerland, 2020; pp. 289–298.
29. Kaigo, M.; Okura, S. Game Accessibility and Advocacy for Participation of the Japanese Disability Community. *Information* **2020**, *11*, 162. [CrossRef]
30. Khaliq, I.; Torre, I.D. A Study on Accessibility in Games for the Visually Impaired. In Proceedings of the International Conference on Smart Objects and Technologies for Social Good, Valencia, Spain, 25–27 September 2019; ACM: New York, NY, USA, 2019; pp. 142–148.
31. de Lima Salgado, A.; Federici, F.M.; de Mattos Fortes, R.P.; Motti, V.G. Startup workplace, mobile games, and older adults: A practical guide on UX, usability, and accessibility evaluation. In Proceedings of the International Conference on the Design of Communication, Portland, ON, USA, 4–6 October 2019; ACM: New York, NY, USA, 2019; pp. 1–9.
32. Othman, N.I.; Zin, N.A.; Mohamed, H. Accessibility Requirements in Serious Games for Low Vision Children. In Proceedings of the International Conference on Electrical Engineering and Informatics, Bandung, Indonesia, 9–10 July 2019; IEEE: New York, NY, USA, 2019; pp. 624–630.
33. Compañ-Rosique, P.; Molina-Carmona, R.; Gallego-Durán, F.; Satorre-Cuerda, R.; Villagrá-Arnedo, C.; Llorens-Largo, F. A guide for making video games accessible to users with cerebral palsy. *Univers. Access Inf. Soc.* **2019**, *18*, 565–581. [CrossRef]
34. Spyridonis, F.; Daylamani-Zad, D. A Serious Game for Raising Designer Awareness of Web Accessibility Guidelines. In Proceedings of the Conference on Human-Computer Interaction, Paphos, Cyprus, 2–6 September 2019; Springer: Cham, Switzerland, 2019; pp. 3–12.
35. Cairns, P.; Power, C.; Barlet, M.; Haynes, G.; Kaufman, C.; Beeston, J. Enabled Players: The value of accessible digital games. *Games Cult.* **2019**, 1555412019893877. [CrossRef]
36. Martins, V.F.; De la Higuera, C.A.; Frango Silveira, I.; Amelia Eliseo, M. Problem-Based Learning applied to the development of accessible serious games. In Proceedings of the Iberian Conference on Information Systems and Technologies, Coimbra, Portugal, 19–22 June 2019; IEEE: New York, NY, USA, 2019; pp. 1–6.
37. Jaramillo-Alcázar, A.; Guaita, C.; Rosero, J.L.; Luján-Mora, S. Towards an accessible mobile serious game for electronic engineering students with hearing impairments. In Proceedings of the World Engineering Education Conference, Buenos Aires, Argentina, 11–14 March 2018; IEEE: New York, NY, USA, 2018; pp. 1–5.
38. Kane, S.K.; Koushik, V.; Muehlbradt, A. Bonk: Accessible programming for accessible audio games. In Proceedings of the Conference on Interaction Design and Children, Trondheim, Norway, 19–22 June 2018; ACM: New York, NY, USA, 2018; pp. 132–142.
39. Jaramillo-Alcázar, A.; Luján-Mora, S. An approach to mobile serious games accessibility assessment for people with hearing impairments. In Proceedings of the International Conference on Information Technology & Systems, Libertad City, Ecuador, 10–12 January 2018; Springer: Cham, Switzerland, 2018; pp. 552–562.
40. Yildiz, S.; Carlsson, A.; Järnbrand, H.; Sandberg, T.; Westin, T. Design of a game community based support system for cognitive game accessibility. In Proceedings of the International Conference on ArtsIT, Heraklion, Greece, 30–31 October 2017; Springer: Cham, Switzerland, 2017; pp. 238–247.

41. Westin, T.; Ku, J.J.; Dupire, J.; Hamilton, I. Game accessibility guidelines and wcag 2.0—A gap analysis. In Proceedings of the International Conference on Computers Helping People with Special Needs, Linz, Austria, 11–13 July 2018; Miesenberger, K., Kouroupetroglou, G., Eds.; Springer: Cham, Switzerland, 2018; pp. 270–279.
42. Wilson, A.; Crabb, M. W3C Accessibility Guidelines for Mobile Games. *Comput. Games J.* **2018**, *7*, 49–61. [CrossRef]
43. Leporini, B.; Palmucci, E. A mobile educational game accessible to all, including screen reading users on a touch-screen device. In Proceedings of the World Conference on Mobile and Contextual Learning, Larnaca, Cyprus, 30 October–1 November 2017; ACM: New York, NY, USA, 2017; pp. 1–4.
44. Salvador-Ullauri, L.; Jaramillo-Alcázar, A.; Luján-Mora, S. A Serious Game Accessible to People with Visual Impairments. In Proceedings of the International Conference on Education Technology and Computers, Barcelona, Spain, 20–22 December 2017; ACM: New York, NY, USA, 2017; pp. 84–88.
45. Leporini, B.; Palmucci, E. An inclusive educational game usable via screen reader on a touch-screen. In *SIGACCESS Accessibility and Computing*; ACM: New York, NY, USA, 2017; pp. 3–9.
46. Pereira, A.F.; Silva, J.; Hideki, H.; Rodrigues, M.; Souza, L.; Martins, M.; SilvaMichel, I.S.; Barbosa, G.A.; Coutinho, F.R. Game accessibility guidelines for people with sequelae from macular chorioretinitis. *Entertain. Comput.* **2018**, *28*, 49–58. [CrossRef]
47. Araújo, M.C.C.; Façanha, A.R.; Darin, T.G.R.; Sánchez, J.; Andrade, R.M.C.; Viana, W. Mobile audio games accessibility evaluation for users who are blind. In Proceedings of the International Conference on Universal Access in Human-Computer Interaction, Vancouver, Canada, 9–14 July 2017; Antona, M.S.C., Ed.; Springer: Cham, Switzerland, 2017; pp. 242–259.
48. Henka, A.; Stiegler, A.; Zimmermann, G. Using video game patterns to raise the intrinsic motivation to conduct accessibility evaluations. In Proceedings of the International Conference on Applied Human Factors and Ergonomics, Walt Disney World, FL, USA, 27–31 July 2016; Springer: Cham, Switzerland, 2016; pp. 65–78.
49. Drossos, K.; Zormpas, N.; Giannakopoulos, G.; Floros, A. Accessible games for blind children, empowered by binaural sound. In Proceedings of the National Conference on PErvasive Technologies Related to Assistive Environments, Corfu, Greece, 1–3 July 2015; ACM: New York, NY, USA, 2015; pp. 1–8.
50. Waki, A.L.; Fujiyoshi, G.S.; Almeida, L.D. Games accessibility for deaf people: Evaluating integrated guidelines. In Proceedings of the International Conference on Universal Access in Human-Computer Interaction, Los Angeles, CA, USA, 2–7 August 2015; Springer: Cham, Switzerland, 2015; pp. 493–504.
51. Porter, J.R. Understanding and addressing real-world accessibility issues in mainstream video games. *SIGACCESS Access Comput.* **2014**, *108*, 42–45. [CrossRef]
52. Milne, L.R.; Bennett, C.L.; Ladner, R.E.; Azenkot, S. BraillePlay: Educational smartphone games for blind children. In Proceedings of the SIGACCESS Conference on Computers & Accessibility, Rochester, NY, USA, 26–28 October 2014; ACM: New York, NY, USA, 2014; pp. 137–144.
53. Torrente, J.; Serrano-Laguna, Á.; del Blanco Aguado, Á.; Moreno-Ger, P.; Fernandez-Manjon, B. Development of a game engine for accessible web-based games. In Proceedings of the International Conference on Games and Learning Alliance, Paris, France, 23–25 October 2013; Springer: Cham, Switzerland, 2013; pp. 107–115.
54. Park, H.J.; Kim, S.B. Guidelines of serious game accessibility for the disabled. In Proceedings of the International Conference on Information Science and Applications, Suwon, Korea, 24–26 June 2013; IEEE: New York, NY, USA, 2013; pp. 1–3.
55. Garber, L. Game accessibility: Enabling everyone to play. *Comput. (Long Beach Calif.)* **2003**, *6*, 14–18. [CrossRef]
56. Westin, T.; Wiklund, M. Return on Investment in Game Accessibility for Cognition Impairments. In Proceedings of the European Conference of the Association for the Advancement of Assistive Technology in Europe, Vilamoura, Portugal, 19–22 September 2013; IOS Press: Amsterdam, Netherlands, 2013; pp. 577–582.
57. Mustaquim, M.M. Assessment of universal design principles for analyzing computer games' accessibility. In Proceedings of the International Conference on Computers for Handicapped Persons, Linz, Austria, 11–13 July 2012; Miesenberger, K., Karshmer, A., Penaz, P., Zagler, W., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; pp. 428–435.
58. Torrente, J.; Vallejo-Pinto, J.A.; Moreno-Ger, P.; Fern, B. Introducing accessibility features in an educational game authoring tool: The <e-Adventure> experience. In Proceedings of the International Conference on Advanced Learning Technologies, Athens, GA, USA, 6–8 July 2011; IEEE: New York, NY, USA, 2011; pp. 341–343.

59. Ossmann, R.; Miesenberger, K. Accessibility of a social network game. In Proceedings of the Computers for Handicapped Persons, Vienna, Austria, 14–16 July 2010; Springer: Berlin/Heidelberg, Germany, 2010; pp. 243–246.
60. Grammenos, D.; Savidis, A.; Stephanidis, C. Designing universally accessible games. *Comput. Entertain.* **2009**, *7*, 1–29.
61. Morgan, M.; Hanson, V.; Martin, C.; Hughes, J.; Newell, A. Accessibility Challenge—A Game Show Investigating the Accessibility of Computer Systems for Disabled People. In Proceedings of the CHI'08 Extended Abstracts on Human Factors in Computing Systems, Florence, Italy, 10–15 April 2008; ACM: New York, NY, USA, 2008; pp. 2609–2610.
62. Miesenberger, K.; Ossmann, R.; Archambault, D.; Searle, G.; Holzinger, A. More than just a game: Accessibility in computer games. In Proceedings of the Symposium of the Austrian HCI and Usability Engineering Group, Graz, Austria, 20–21 November 2008; Springer: Berlin/Heidelberg, Germany, 2008; pp. 247–260.
63. Miller, D.; Parecki, A.; Douglas, S.A. Finger dance: A sound game for blind people. In Proceedings of the SIGACCESS Conference on Computers and Accessibility, Tempe, AZ, USA, October 2007; ACM: New York, NY, USA, 2007; pp. 253–254.
64. Ossmann, R.; Miesenberger, K. Guidelines for the development of accessible computer games. In Proceedings of the International Conference on Computers for Handicapped Persons, Linz, Austria, 11–13 July 2006; Springer: Berlin/Heidelberg, Germany, 2006; pp. 403–406.
65. Grammenos, D.; Savidis, A.; Georgalis, Y.; Stephanidis, C. Access invaders: Developing a universally accessible action game. In Proceedings of the International Conference on Computers for Handicapped Persons, Linz, Austria, 11–13 July 2006; Springer: Berlin/Heidelberg, Germany, 2006; pp. 388–395.
66. Ossmann, R.; Archambault, D.; Miesenberger, K. Computer game accessibility: From specific games to accessible games. In Proceedings of the International Conference on Computer Games (CGAMES), Dublin, Ireland, 22–24 November 2006; Mehdi, Q., Mtenzi, F., Duggan, B., McAtamney, H., Eds.; pp. 104–108.
67. Callaos, N.; Lesso, W.; Schewe, K.D.; Atlam, E.; Archambault, D. The TiM game engine: Development of computer games accessible to blind and partially sighted children. In Proceedings of the World Multiconference on Systemics, Cybernetics and Informatics, Orlando, FL, USA, 27–30 July 2003; pp. 179–184.
68. Jain, Y.K.; Bha, S.K. Min max normalization based data perturbation method for privacy protection. *Int. J. Comput. Commun. Technol.* **2011**, *2*, 45–50.
69. Acosta-Vargas, P.; Salvador-Ullauri, L. Dataset Accessibility and Web-based Serious Games. 2020. Available online: https://data.mendeley.com/datasets/9x45s74ww5/3 (accessed on 25 October 2020).
70. W3C. WCAG2ICT Overview. 2019. Available online: https://www.w3.org/WAI/standards-guidelines/wcag/non-web-ict/ (accessed on 22 October 2020).
71. IGDA. SIG guidelines. 2020. Available online: https://igda-gasig.org/get-involved/sig-initiatives/resources-for-game-developers/sig-guidelines/. (accessed on 22 October 2020).
72. IBM. IBM Accessibility Checklist. 2020. Available online: https://www.ibm.com/able/guidelines/ci162/accessibility_checklist.html (accessed on 22 October 2020).
73. General Services Administration Section 508 of the Rehabilitation Act of 1973. 2018. Available online: https://www.section508.gov/manage/laws-and-policies (accessed on 22 October 2020).
74. W3C Making the Web Accessible. Available online: https://www.w3.org/WAI/ (accessed on 22 October 2020).

12 A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision

Referencia:
Salvador-Ullauri, L., Acosta-Vargas, P., Gonzalez, M., Luján-Mora, S. (2020). A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision. Applied Sciences, 10 (24), 8803 (Salvador-Ullauri, Acosta-Vargas, Gonzalez, y Luján-Mora, 2020b)

Disponible en:

- https://www.mdpi.com/2076-3417/10/24/8803
- https://doi.org/10.3390/app10248803

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en los juegos serios basados en la Web.
2. Recopilación del estado de la cuestión en heurísticas para la accesibilidad en juegos serios.
3. Identificación de los requisitos de accesibilidad de los juegos serios basados en la Web para usuarios con baja visión.
4. Evaluación del nivel de accesibilidad de los juegos serios con un método heurístico.

Article

A Heuristic Method for Evaluating Accessibility in Web-Based Serious Games for Users with Low Vision

Luis Salvador-Ullauri [1], Patricia Acosta-Vargas [2,*], Mario Gonzalez [2] and Sergio Luján-Mora [1]

[1] Department of Software and Computing Systems, University of Alicante, 03690 Alicante, Spain; lasu1@alu.ua.es (L.S.-U.); sergio.lujan@ua.es (S.L.-M.)
[2] Intelligent and Interactive Systems Laboratory, Universidad de Las Américas, Quito 170125, Ecuador; mario.gonzalez.rodriguez@udla.edu.ec
* Correspondence: patricia.acosta@udla.edu.ec

Received: 31 October 2020; Accepted: 25 November 2020; Published: 9 December 2020

Abstract: Nowadays, serious games have become a beneficial resource in the learning process; they are part of our culture and promote social inclusion. Designing accessible serious games is a complete challenge, even more for non-experts. Most existing serious games do not meet accessibility standards because of a lack of methods that include standards and help create more accessible serious games. For this reason, our research presents a heuristic method with three modifications to Giorgio Brajnik's barrier walkthrough method and based on the Web Content Accessibility Guidelines 2.1 (WCAG 2.1). We defined 28 barriers for the users with low vision and the related impact and persistence variables by defining severity ranges to evaluate accessibility. This method allows measuring the accessibility of web-based serious games; the method proposed in this article can be a good help for non-experts. As a case study, this heuristic method was applied to 40 web-based serious games. The evaluators concluded that serious games should apply WCAG 2.1 to achieve an adequate and inclusive accessibility level. However, this study has limitations; the heuristic method depends on the evaluators' experience. This work can contribute to studies related to accessibility heuristics in serious games; it can also help construct a software tool that applies WCAG 2.1 and helps experts and non-experts evaluate accessibility in serious games.

Keywords: accessibility; assessment; barrier walkthrough; heuristic; method; serious games; Web Content Accessibility Guidelines (WCAG) 2.1

1. Introduction

At present, web-based serious games significantly contribute to our culture and can promote social inclusion. Additionally, students' participation and motivation in the classroom are of great importance in the learning process, so the concept of gamification [1] has taken on great importance. Gamification allows (1) stimulation and support of creativity; (2) player motivation through modifications and new levels of play; (3) use as a teaching aid; (4) inclusion as a trendy means of recreation; and (5) mind training [2].

The International Game Developers Association (IGDA), according to its survey of 1116 developers in 2019, has revealed that 85% of developers considered diversity in the games industry to be essential [3]. On the other hand, the Game Accessibility Special Interest Group (SIG) aims to support the design of universally accessible games [4]. This group has worked since 2003 to aid the game industry to develop more accessible video games.

The accessibility requirements themselves are described in the comprehensive legislation, specifically section 14.21 of the Century Communications and Video Accessibility Act (CAVAA) [5]. Similarly, Microsoft [6–8], and Sony [9] are committed to ensuring that products and services are

designed for everyone, including the one billion people with disabilities, and therefore apply sets of guidelines to design and evaluate the accessibility of software and hardware developed by companies.

According to the World Health Organization (WHO), more than one billion people have some disability; this corresponds to the fact that there is 15% disability worldwide [10]. Therefore, accessibility in serious games is essential to improving the interaction between users and serious games. The primary motivation for building serious accessible games is to offer easy access to many users, including people with disabilities.

Therefore, accessibility in the context of serious games [11] aims to make applications usable by the maximum number of people, regardless of their knowledge or personal abilities and technical characteristics of the equipment used to access the serious games. Accessibility implies the way users perceive, navigate, understand, and interact with serious games.

This study considered the four principles of accessibility of the Web Content Accessibility Guidelines (WCAG) 2.1 [12]; we used a heuristic method to assess accessibility in serious games. The proposed method is based on the barrier walkthrough (BW) suggested by Brajnik [13–15] and WCAG 2.1 [12]. Therefore, a barrier is an impediment that hinders the interaction between the serious game and the user.

The barriers found through the assessment can produce obstacles in interacting with serious games, especially for people with disabilities. In this study, the authors considered the impact and persistence of each barrier faced by users with disabilities. After establishing scales for impact and persistence, the authors determined the severity of each barrier.

This study was developed from previous works [15–17]; in the current work, the authors apply three modifications to the BW method. The first modification comprises widening the scale to examine the persistence and impact between zero (0) and three (3). The second modification is applied to persistence, which depends on the number of barriers presented in the assessment. The third applies the scales defined to evaluate effectiveness, productivity, satisfaction, security, and impact.

The heuristic method proposed has eight phases: (1) choose the web-based serious games; (2) describe the category of user; (3) determine user activities; (4) investigate the serious games; (5) make a list of the barriers; (6) evaluate with the heuristic method; (7) record the data; and (8) interpret and analyze the data.

As a case study, this method was applied to a total of 40 web-based serious games selected with simple random probability sampling from various websites for educational and learning purposes. During the evaluation of the serious games with the heuristic method, two evaluators participated, with accessibility experience in serious games from 2015. In this case study, the authors applied the 28 guidelines for users with low vision. This heuristic method can be replicated for other categories of disabilities by considering the appropriate barriers with the type of disability. However, this heuristic method is manual and requires experience and training in web accessibility by the evaluators. This investigation can provide a beginning step for future studies associated with accessibility heuristics in web-based serious games.

The rest of the document is structured as follows: Section 2 defines the background and work related to accessibility in serious games; Section 3 defines the heuristic method; Section 4 presents the case study; Section 5 explains the results; Section 6 presents the discussion of the results. Finally, Section 7 describes the perspectives and future work.

2. Background

In this section, we explain serious games, considered as a resource to support learning [18]. Some authors maintain that serious games improve the comprehension capacity of students when they learn [19]. Accessibility in serious games implies that users can perceive, understand, navigate, and interact [12] without the application's problems. The evaluation methods of the accessibility in serious games, several previous studies about the subject, are presented and introduced to our study. The heuristic method addresses several studies and concepts applied in this research.

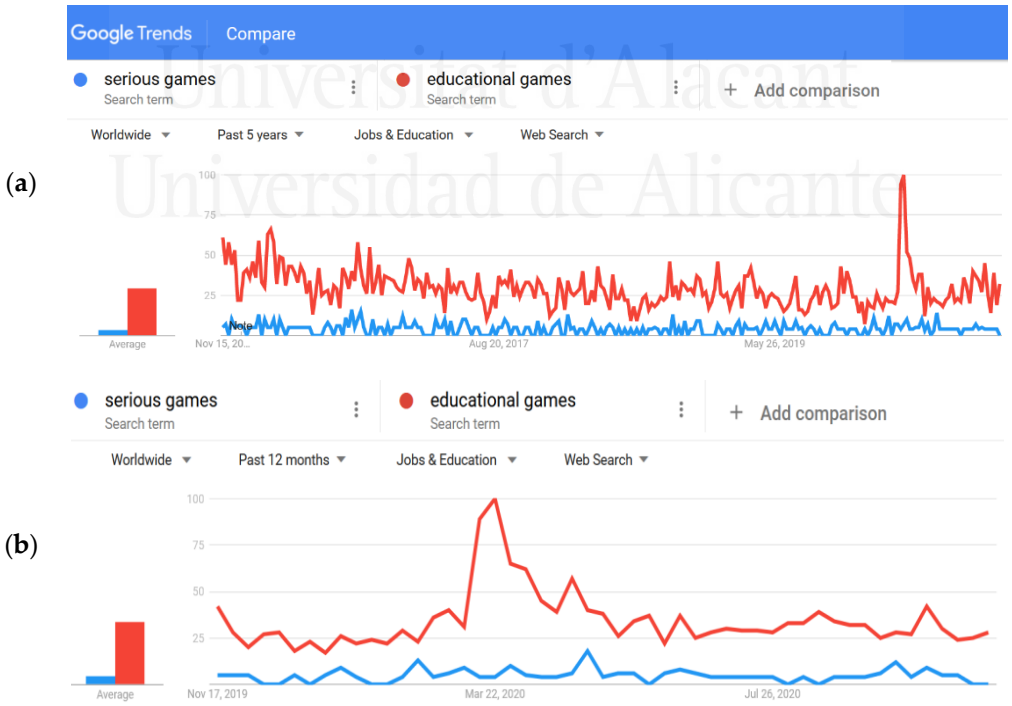
2.1. Serious Games

Serious games [20] or training games have a different primary purpose than entertainment; they must also link the real and virtual world. They promote [21] the construction of knowledge and skills through exposure to different situations, cases, or problems. They allow simulations of a real situation to interact in the environment in the same way they would in a real environment. They are aimed at different audiences and can be of any kind, uses different technologies, and are designed for different platforms, computers, consoles, virtual worlds, and social networks. According to its final objective, [22], three categories are identified:

(1) Edutainment, or educational games so that the game takes part in the education, the game provides an ideal environment for training by transmitting information and testing the knowledge.
(2) Advergaming, a game to promote a product, one of the most popular applications of serious games is advertising communication.
(3) Simulation facilitates learning represents a simplified model of reality, either with group games of physical or intellectual skills that reproduce the study's process.

The video gaming industry is vast; in 2015, there were almost two billion video players worldwide; it is estimated that this number will increase to more than three billion gamers by 2023 [23]. According to statistics [24], the educational serious games market's income will grow from 3.5 billion USD in 2018 to 24 billion USD in 2024.

According to Google Trends [25] trend on "serious games" and "educational games" in the last five years worldwide, taken from 15 November 2015 to 15 November 2020, in Figure 1a, we observe that "educational games" tend to grow from 2019. Figure 1b shows that the peak corresponds to 22 March 2020, coinciding with the coronavirus pandemic's confinement in many countries. Because teachers, parents, and students were looking for "educational games" to reinforce students' learning processes and compensate for the fact that they could not use face-to-face classes.



(a)

(b)

Figure 1. (**a**) Google Trends about serious games and educational games in the last five years. (**b**) Google Trends about serious games and educational games in the 12 months.

2.2. Accessibility in Serious Games

As we have mentioned, accessibility [12] is the inclusive practice of ensuring that serious games and technologies are designed and developed so that people with disabilities can use them. In the context of serious games, accessibility includes aids such as high-contrast or large font size, screen magnifiers, screen readers and reviewers, voice recognition software, keyboards, and adapted devices according to user needs.

The study [26] argues that application designers face a significant challenge in applying accessibility guidelines because they are complex and ambiguous. For this reason, the authors propose following the WCAG with a user-centered approach. They offer designers an innovative and engaging solution for broader adoption of accessibility guidelines that can create accessible games.

The study [27] indicates that games offer a traditional channel where all people can be involved; however, this only happens when creating inclusive design environments to achieve this challenge. Therefore, they suggest developing an accessibility vocabulary and language for games. The authors recommend including the terminology used, showing the controls that enable the play's tasks and skills.

The investigation [28] indicates that play accessibility is about removing barriers for users with disabilities. Besides which, the authors argue that the challenge is that web-based games can better access the WCAG 2.1 and achieve an adequate accessibility level in the construct of more accessible games.

Previous studies by the study [29] indicate that it is essential to evaluate the users' learning styles, for which they applied the Honey-Alonso test [30] for the development of serious games. The Honey-Alonso test includes active, reflective, theoretical, and practical techniques. The authors proposed constructing an educational video game with a Honey-Alonso test script and applied the WCAG.

The research [31] argues that making serious games universal and accessible are a challenge for interface creators and game designers. The authors indicate that more effort is needed and propose research with recommendations for accessibility in serious games. Consequently, the authors recommend ten strategies for designing games for visually impaired users. The results indicated that only three out of ten games were accessible.

Concerning accessibility, in June 2018, the World Wide Web Consortium (W3C) [32] established the WCAG 2.1 recommendations for making web content more accessible; furthermore, this proposal can be applied to achieve accessibility in serious games. WCAG 2.1 covers a wide range of recommendations to make web content more accessible. Applying [12] these guidelines will make serious game content more accessible to people with disabilities, including adaptations for blindness and low vision, deafness and hearing loss, limited movement, speech disabilities, photosensitivity, and combinations, and some adaptations for learning disabilities and cognitive limitations. WCAG 2.1 comprises four principles, 13 guidelines, 78 compliance criteria, combined with an undefined number of sufficient techniques and advisory techniques. The four principles are described below:

(1) Perceivable, users must distinguish content in audio, video, and text.
(2) Operable; users must be able to use and interact with the interface modules.
(3) Understandable, users must be able to recognize self-controls of the interface.
(4) Robust, users must be able to access comfortably and understand consistently in any case of the present and potential technologies.

Therefore, the compliance criteria include three levels. Level A offers a minimum of accessibility; not achieving implies that users cannot access the content. Level AA allows an intermediate level of accessibility; it satisfies the levels A and AA; it indicates that the users cannot access all the content. Furthermore, Level AAA is the highest level of accessibility. Achieving this level means that users can easily access the content.

2.3. Accessibility Evaluation Methods

Serious games and gamification approaches in the educational context [33] allows for greater student participation in skill development. Due to the growing multidisciplinary interest in learning, serious games are considered a useful pedagogical tool. Therefore, the need arises to build serious games accessible and inclusive to access these learning resources. This section describes several of the accessibility evaluation works, which contribute with tools that guide the design of web-based serious games.

The research [34] evaluates accessibility related to visual impairments in educational video games to suggest improvements in this type of application's design. A second study by the authors indicates that the evaluation of mobile serious games' accessibility for people with hearing disabilities argue that accessibility has not been considered in the development of serious games. As a case study, they evaluated a mobile game's accessibility, where they proposed an analysis tool. In a third study, the investigation [35] argues that accessibility is a feature that is not considered in the design of serious games, so they are not easily accessible. The study shares a compilation of accessibility guidelines for developing video games; they propose categorizing the existing guidelines to evaluate a video game's accessibility for people with motor disabilities.

A previous study by the authors [36] proposes a method to motivate software developers to improve accessibility. The authors present a technique for evaluating the accessibility of serious games applying WCAG 2.1, which incorporates barriers for users with cognitive disabilities. The proposed approach can be replicated for people with other disabilities and can be used throughout the game to create a cycle to guarantee more inclusive and accessible applications. A second study [37] proposes to apply a combined method to evaluate accessibility in serious games, taking into account the WCAG 2.1. As a case study, the accessibility of 82 serious games developed by Physical Education Technology Interactive Simulations at the University of Colorado was evaluated. The authors suggest replicating the combined approach for users with various disabilities, considering the accessibility barriers. As future work, they suggest generating a heuristic accessibility evaluation focused on serious games to develop applications more inclusive.

2.4. Heuristic Method

In the literature review for this research, we did not find any automatic review methods or heuristics applied to serious games, so we started from the existing information on evaluating the heuristics of accessibility for websites; we have the following studies. The study [38] argued that accessibility heuristics are created as a complement to accessibility guidelines. Additionally, heuristics allow evaluators to identify which sections of an application have accessibility issues effectively. The results revealed that using accessibility heuristics can locate a broader range of barriers to solving accessibility problems. However, heuristics do not provide evaluators with compliance information, so heuristics studies are not a substitute for user experience.

The research [39] argued that accessibility evaluation methods help user-centered accessibility. The author notes that accessibility evaluation methods can find accessibility issues, for instance, guideline infringements, modes of failure, defects, or user implementation rates. An evaluation method can prescribe how to rank and rate topics in conditions of severity and priority. It presents a discussion of several evaluation methods, one of which is the BW method, which has the following advantages: low complication, validates knowledge, more excellent correction than conformance review, and produces severity indices.

A study by the authors [17] argues that determining whether interfaces are accessible is essential, and it requires accessibility evaluation. One form of assessment uses automated tools, which are not sufficient; human testing with experts and users with disabilities is already necessary. The authors present a study to evaluate accessibility and barriers present on the application for Banco do Brazil employing the BW method, which records and defines a sequence of barriers that are susceptible to each classification of the user. This survey's objective was to examine whether this approach can be treated as a supplement to automatic assessment when observations involving users cannot be made—the method allowed for rapid and timely evaluation, decreasing the assessment's complication.

With the suggested study, they detected usability problems associated with accessibility, for which they presented some suggestions.

The study [40] argued that accessibility assessment methodologies assume that all guidelines must be met to achieve universal accessibility. The authors noted that the BW approach addresses issues of applying the guidelines to diverse groups of users. The process allows evaluators to assess the severity of the barrier being inspected. They determined that barriers could be combined with the BW method to evaluate the impact of an application on users and effectively relate to the subject.

A previous study by the authors [16] indicated that there are qualitative and quantitative methods for checking whether an application is accessible. The authors presented a modification to the BW method offered by Giorgio Brajnik based on WCAG 2.1. The change involved incorporating persistence to work out the severity of an accessibility barrier. With the process used in the experiment, the evaluators found that the method allows for (1) measuring the accessibility of applications; (2) testing a heuristic process; (3) assisting in manual evaluations, and (4) contributing to studies associated with accessibility heuristics.

Therefore, the heuristic method based on the BW suggested in the studies [13–15] can assist in supplementing accessibility assessment in serious games. The heuristic method is a systematic method built on testing and error inspections in which an evaluator thinks of some potential accessibility barriers corresponding to the WCAG 2.1 accessibility principles. Barriers incorporate characteristics according to user type, purpose, the perspective of use, and serious gaming site to draw appropriate conclusions related to effectiveness, productivity, satisfaction, and security [13,14], with severity scores designated to each accessibility barrier.

In this study, the barriers are defined in the conditions of the next parameters: (1) Effectiveness indicates the degree of compliance to accomplish the user's aim accurately; (2) Productivity is associated with the time, effort, and cognitive load prerequisite to achieving a specific level of effectiveness; (3) Satisfaction characterizes the contentment and acceptance by the user; it implies the capacity to acclimate, and (4) Security represents the established weakness in the serious game assessed. The BW method [13,15] is an accessibility inspection technique created from accessibility designed principles, taking into account the user group, the type of assistive technology, the influence of users, the types of serious games, and the effects caused.

The study [41] considers that inspection-based evaluation techniques are standard, as they involve less formal instruction. It applies a method that combines task-oriented heuristic assessments that are easy to understand and use. Sears recommends methods for checking the authenticity and consistency of the assessment techniques. The results of heuristic assessments allow for more significant problems to be identified than in cognitive reviews.

The severity of a barrier, according to the BW method [13,15], is related to the physical and cognitive characteristics of the user and the context in which the activities are performed; in this way, it is possible to reach conclusions with effectiveness, productivity, satisfaction, and security, to achieve the applicable parameters of severity. This method recommends utilizing two factors to assess the severity of a barrier: the impact of the barrier on satisfaction and productivity user and the persistence with which the barrier is present [15].

The BW method states that the evaluator can measure the severity of the barrier on a scale between one (1) and three (3), where the value of one (1) corresponds to a "minor problem," implying that the user can overcome and avoid the barrier [13,42]. An identified barrier may affect productivity or user satisfaction but not effectiveness and security. A barrier that seriously affects a task's execution is assigned the value of two (2) and corresponds to a "significant problem." Finally, when it is difficult to avoid the barrier, security and effectiveness are reduced. The value of three (3) is assigned, implying a "critical problem," in which context users often fail to achieve the objectives. Therefore, the barrier causes a negative effect that could affect (1) productivity and effectiveness; and (2) security and user satisfaction.

For this research, we start with the authors' previous studies of authors [16] on websites' heuristic methods. The authors apply the heuristic method based on the barrier path using ranges and severity

scales to evaluate websites. In this research for the heuristic evaluation of accessibility in serious games, we apply the concept of heuristics suggested by the authors [43], which involves a method of inspection that supports an interactive evaluation of the system; three modifications to the BW heuristic method [13] are proposed by Giorgio Brajnik.

3. Method

The authors tested an initial part of this method in previous studies, the authors [16] related to evaluating accessibility heuristics in websites. Therefore, in this study, we applied a method that considers three variations used for the first time in the heuristic evaluation of accessibility in serious games. This method consists of prioritizing the impacts of the barriers corresponding to the applied perspective. With this heuristic method, we can identify a more significant number of accessibility barriers that prevent interaction between serious games and users.

Once these barriers are identified, they can be corrected by the developers of serious games. Using the detailed scale in Table 1, we applied three modifications to the BW method in this investigation; this contains the scale and the meaning of the severity with the first modification of the BW [14–16]; it consisted of expanding the scale to evaluate the efficiency, productivity, satisfaction, security, and impact.

Table 1. Enlarged Scale.

Scale	Meaning
0	Null
1	Minor
2	Significant
3	Critical

The second modification affects persistence, which depends on the number of barriers presented in the evaluation; we apply the persistence scale detailed in Table 2. The third modification was to apply the severity according to the value of impact and persistence, shown in Table 3.

Table 2. Barrier–Persistence.

Barriers Number	Persistence
0 and 1	0
2 and 3	1
4 and 5	2
Greater than 5	3

Table 3. Impact, Persistence, and Severity value.

Impact	Persistence	Severity
0	0	Null
1	0	Null
2	0	Null
3	0	Null
1	1	Minor
1	2	Minor
1	3	Significant
2	1	Significant
2	2	Significant
2	3	Critical
3	1	Critical
3	2	Critical
3	3	Critical

The heuristic method to evaluate web-based serious games is condensed into eight phases, corresponding to Figure 2; each phase of the method is detailed in the case study.

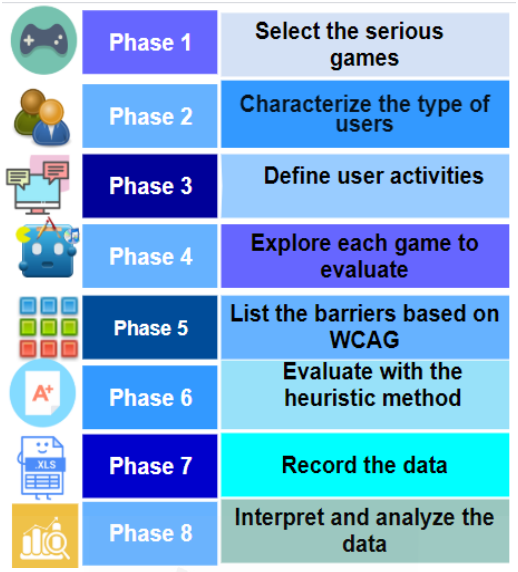


Figure 2. A heuristic method for accessibility evaluation method.

4. Case Study

This method was applied to 40 web-based serious games, selected with a simple random probability sampling, from several websites for educational and learning purposes. The websites that contain the web-based serious games are shown in Table 4.

In this research, we applied accessibility barriers for low vision users; the evaluators specified heuristics associated with impact and severity involving serious games. The evaluators previously raised the accessibility barriers based on the WCAG 2.1, applied according to the disability and user impact, characteristics, and effects of the serious games evaluated.

Table 4. Websites where serious games have been obtained.

URL	Description
https://phet.colorado.edu/sims/html/	The site created by Physical Education Technology (PhET) Interactive Simulations at the University of Colorado [18], which contains several free serious games for educational use in different subjects
https://www.vascak.cz/	The simulations and animations of physics, electromagnetism, mechanics, gravitational field, molecular physics and thermodynamics, and particular relativity theory.
https://www.freeriderhd.com/ http://www.raptjs.com/play/ http://www.sinuousgame.com https://worldsbiggestpacman.com/ https://ludominga-aff09.firebaseapp.com/ https://funhtml5games.com/	The random selection of various websites that contain serious learning games, including some of the most popular game lists.

Phase 1: Select the serious games; in this phase, we used the formula for calculating the sample size when the population size is unknown. Before calculating the sample size, we need to determine: (1) the size of the population defined as a collection of objects or individuals that have similar characteristics;

(2) the margin of error or confidence interval, which is a statistic that expresses the amount of random sampling error in the results; (3) the confidence level that refers to the random intervals that are used to constrain a value with a given high probability. For our case, we applied Equation (1).

$$n = \frac{Z_a^2 * p * q}{d^2} \quad (1)$$

where: n = size of the desired sample, Z = confidence level = 0.631, p = probability of success = 50%, q = $(1 - p)$ probability of failure = 50%, d = accuracy, accepted estimation error = 5%.

When applying the calculations, we obtained a value of 39.8; therefore, a total of 40 serious games listed in Table 5 should be evaluated, containing the ID that is the identifier assigned to the web-based serious game, the URL, and the subject of the serious game.

Phase 2: Characterize the type of users; in this experiment, the guide for low vision users [44] was applied, who are characterized as those who have a situation in which the user's vision cannot be rectified with glasses, affecting everyday events, reading, and driving. Low vision is most frequent among the elderly but can occur in people of any age because of degenerative diseases.

The WHO defines low vision [45] as a visual abnormality that restricts the ability to perform everyday visual tasks. The leading causes of visual impairment are uncorrected refractive errors, cataracts, age-related macular degeneration, glaucoma, diabetic retinopathy, corneal opacity, and trachoma. The fundamental principle of accessibility for users with low vision is "perceivable" [12].

Phase 3: Define user activities; the evaluators define scenarios to analyze the serious game and how users interact with the game to achieve the objective. The task was to enter each serious game, review each game's functionality, check the menus, images, messages, and help options to see any accessibility barriers for low vision users. Additionally, in this phase, we describe the level of accessibility (A, AA, AAA) that would be assessed; in this situation, we operate up to the level AA. It was also necessary to detect accessibility support with a listing of web browsers that must be friendly. In this investigation, the evaluators used Google Chrome version 84.0.4147.125, Mozilla Firefox version 77.0.1, and Opera version 70.0.3728.106.

Table 5. List of selected serious games.

ID	URL	Subject
SG01	https://phet.colorado.edu/sims/html/acid-base-solutions/latest/acid-base-solutions_en.html	Chemistry
SG02	https://phet.colorado.edu/sims/html/area-builder/latest/area-builder_en.html	Math
SG03	https://phet.colorado.edu/sims/html/area-model-algebra/1.2.1/area-model-algebra_en.html	Math
SG04	https://phet.colorado.edu/sims/html/coulombs-law/1.0.9/coulombs-law_en.html	Physics
SG05	https://phet.colorado.edu/sims/html/energy-skate-park-basics/1.1.19/energy-skate-park-basics_en.html	Physics
SG06	https://phet.colorado.edu/sims/html/expression-exchange/1.1.14/expression-exchange_en.html	Math
SG07	https://phet.colorado.edu/sims/html/fractions-intro/1.0.12/fractions-intro_en.html	Math
SG08	https://phet.colorado.edu/sims/html/function-builder-basics/1.0.14/function-builder-basics_en.html	Math
SG09	https://phet.colorado.edu/sims/html/gravity-and-orbits/1.1.15/gravity-and-orbits_en.html	Physics
SG10	https://phet.colorado.edu/sims/html/masses-and-springs-basics/1.0.9/masses-and-springs-basics_en.html	Physics
SG11	https://phet.colorado.edu/sims/html/ph-scale/1.3.4/ph-scale_en.html	Earth science
SG12	https://phet.colorado.edu/sims/html/rutherford-scattering/1.1.9/rutherford-scattering_en.html	Chemistry
SG13	https://phet.colorado.edu/sims/html/vector-addition/1.0.0/vector-addition_en.html	Math
SG14	https://phet.colorado.edu/sims/html/waves-intro/1.0.2/waves-intro_en.html	Earth science
SG15	https://phet.colorado.edu/sims/html/build-a-molecule/latest/build-a-molecule_en.html	Chemistry
SG16	https://phet.colorado.edu/sims/html/density/latest/density_en.html	Chemistry
SG17	https://phet.colorado.edu/sims/html/energy-skate-park/latest/energy-skate-park_en.html	Physics
SG18	https://phet.colorado.edu/sims/html/number-line-integers/1.0.1/number-line-integers_en.html	Math
SG19	https://phet.colorado.edu/sims/html/molecule-polarity/1.0.15/molecule-polarity_en.html	Chemistry
SG20	https://phet.colorado.edu/sims/html/graphing-lines/1.3.10/graphing-lines_en.html	Math
SG21	http://www.raptjs.com/play/#/rapt/Bomberland/	Skills
SG22	https://funhtml5games.com/?play=angrybirds	Strategy
SG23	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mech_sily&l=en	Physics
SG24	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mech_pohyb&l=en	Physics
SG25	https://sumonhtml5.ludei.com/	Math
SG26	http://arcade.lostdecadegames.com/onslaught-arena/	Skills
SG27	https://worldsbiggestpacman.com/play/#-1,1	Skills

Table 5. *Cont.*

ID	URL	Subject
SG28	https://www.freeriderhd.com/t/727781-the-great-oak	Racing
SG29	http://www.sinuousgame.com/	Skills
SG30	https://ludominga-aff09.firebaseapp.com/boingBoingGame	Skills
SG31	https://ludominga-aff09.firebaseapp.com/facesAndGesturesGame	Skills
SG32	https://ludominga-aff09.firebaseapp.com/huntingFiguresGame	Skills
SG33	https://ludominga-aff09.firebaseapp.com/puzzleGame	Skills
SG34	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mech_rovnobeznik&l=en	Physics
SG35	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mech_pruzna&l=en	Physics
SG36	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mech_maxwell&l=en	Physics
SG37	https://www.vascak.cz/data/android/physicsatschool/template.php?s=gp_newton_zakon&l=en	Physics
SG38	https://www.vascak.cz/data/android/physicsatschool/template.php?s=gp_sourad_geol&l=en	Physics
SG39	https://www.vascak.cz/data/android/physicsatschool/template.php?s=mf_parnistroj&l=en	Physics
SG40	https://www.vascak.cz/data/android/physicsatschool/template.php?s=opt_newtonkotouc&l=en	Physics

In this case study, a barrier for a user with low vision means that he or she cannot interact effectively with the serious game, implying that it is difficult for him or her to move precisely over the content of the serious game due to the complexity of his or her visual perception. The two evaluators identified the scenarios made up of users with low vision, the aims, and the activities that users must complete in the testing to apply the approach suggested in this investigation. A list of accessibility barriers for low vision users based on WCAG 2.1 [12] is listed in Table 6. The evaluators recommended this method to accomplish the aim, considering effectiveness, productivity, security, and user satisfaction. It was essential to recognize the scale of severity and range of persistence of each barrier that characterizes the low vision user's impediment to achieve the aim.

Table 6. Barrier vs. Web Content Accessibility Guidelines 2.1 (WCAG 2.1.)

ID	Barrier	WCAG 2.1	Success Criteria	Level
G01	Accessible keyboard	Operable	2.1.1	A
G02	No luminance flash failures	Operable	2.3.1	A
G03	Animation from Interactions	Operable	2.3.3	AAA
G04	Content hovering over focus	Perceivable	1.4.13	AA
G05	Easy to read font	Perceivable	1.4.4	AA
G06	Text alternatives	Perceivable	1.1.1	A
G07	Subtitled	Perceivable	1.2.4	AA
G08	Automatic transcripts	Perceivable	1.2.5	AA
G09	Sign language	Perceivable	1.2.6	AAA
G10	Information and relationships	Perceivable	1.3.1	A
G11	Adjust display settings	Perceivable	1.3.4	AA
G12	Interface rearrangement	Perceivable	1.3.5	AA
G13	Use of color	Perceivable	1.4.1	A
G14	Contrast without text	Perceivable	1.4.11	AA
G15	Well-spaced elements	Perceivable	1.4.12	A
G16	Good audio techniques	Perceivable	1.4.2	A
G17	Contrast	Perceivable	1.4.3	AA
G18	Images as sharp as possible	Perceivable	1.4.5	AA
G19	Visual presentation	Perceivable	1.4.8	AAA
G20	Pause, stop, hide	Perceivable	2.2.2	A
G21	Sensory Characteristics	Perceivable	1.3.3	A
G22	Screen reader support	Robust	4.1.2	A
G23	Status messages	Robust	4.1.3	AA
G24	Language	Understandable	3.1.1	A
G25	Consistent navigation	Understandable	3.2.3	AA
G26	Labels or instructions	Understandable	3.3.2	A
G27	Help	Understandable	3.3.5	AAA
G28	On Focus	Understandable	3.2.1	A

Phase 4: Explore the serious games; the expert explores each serious game with the instructions defined in phase 3. The tasks that the user had to perform were: (1) interact with the first interface of the serious game; (2) review the functionality of each round; (3) identify whether the games have a screen magnifier; (4) review whether the games have the option to adjust the game parameters; (5) determine whether the game has the opportunity to help the user; (6) identify whether the user can read each message of the serious game; (7) review whether the images have adequate clarity and are apparent to the user; and (8) check whether the serious game has the option to change the language.

At this stage, the evaluators navigate all the serious game features to detect potential accessibility barriers. Finally, in this phase, the evaluators review the behaviors agreeing to the device used, the browser, and the structure applied.

Phase 5: List the barriers; we selected 28 barriers based on WCAG 2.1 for low vision users to apply this BW-based heuristic method. Table 6 contains the guideline identifier, the barrier, the WCAG 2.1 principle, the success criteria, and the level of accessibility.

Phase 6: Evaluate with the heuristic method, the evaluators carried out the following process: (1) run the serious game; (2) carefully examine whether each barrier meets the parameters of effectiveness, productivity, security, and satisfaction; we applied Table 1. (3) Find the impact related to the parameters defined in Table 1; (4) record the persistence of each barrier according to the parameters defined in Table 2; (5) apply the persistence scale defined in Table 2; (6) finally, apply the severity scale according to the impact and resulting persistence defined in Table 3.

To analyze the severity of a barrier, we need two parameters: (1) the impact of the barrier as a result of the effectiveness, productivity, security, and satisfaction of the user performing an activity; (2) the value of persistence, denoted by the number of times the barrier is repeated, is essential when evaluating a serious game.

For example, when checking the barrier "Accessible keyboard" in the game SG01 "Acid-base solutions", we apply the following process: First, for the efficiency parameters, we register the value zero (0), in productivity the value of one (1), in satisfaction zero (0) and security the value of one (1). Second, we analyze whether the barrier affects productivity, satisfaction, effectiveness, or safety. In that case, the impact was minimal; when analyzing these parameters, the impact's value is two (2). Thirdly, we evaluate the number of times the barrier corresponding to the persistence parameter presented by the barrier "Accessible keyboard" is presented. Fourth, we apply the persistence scale defined in Table 2. Fifth, we determine the severity defined in Table 3 for impact and persistence; for the barrier "Accessible keyboard" we have in the impact the value of two (2) and for the persistence the value of two (2), therefore the severity for the barrier "Accessible keyboard" is significant.

Phase 7: Record the data; the data from each serious game evaluated was documented in a spreadsheet. Table 7 is an example since it collects the data of only one set; it contains the identifier assigned to the pattern, the barrier, the effectiveness, the productivity, the satisfaction, the safety, the impact, the range of persistence, the total persistence, the result of persistence and the severity of the serious set with the code SG01 that corresponds to "acid-based solutions" of the PhET project of the University of Colorado. For the G01 "Accessible keyboard" barrier, we applied Table 1 and obtained the following results: in effectiveness we recorded zero (0), in productivity one (1), in satisfaction zero (0), and in safety one (1). Then we analyzed the impact; if the barrier affects productivity or satisfaction marginally, but not effectiveness or safety, the impact is minimal; when analyzing these parameters, we found impact equal to two (2) according to the scale of Table 1 this corresponds to significant. To evaluate persistence, we apply Table 2; we find that the barrier is present for more than four times; therefore, persistence is equal to two (2). Finally, we applied Table 3 to find severity, with the impact value equal to two (2) and persistence equal to (2); therefore, this barrier presents significant severity.

The recorded data are available in the repository [46] so that the assessment can be reproduced. Data recording is essential; the data allow evaluators to manage and condense information by diverse categories.

Phase 8: Interpret and analyze the data; the evaluators offer the analysis of the severities taken when applying the heuristic method; First, we organize and group the information by categories. To manage each serious game's severity information, we use the dendrogram shown in Figure 3; it contains the distances between each serious web-based game evaluated consecutively. In the results section and the discussion section, a more in-depth analysis of the results related to the severity of the barriers, the accessibility principles, the levels, and the success criteria of the WCAG 2.1 is carried out.

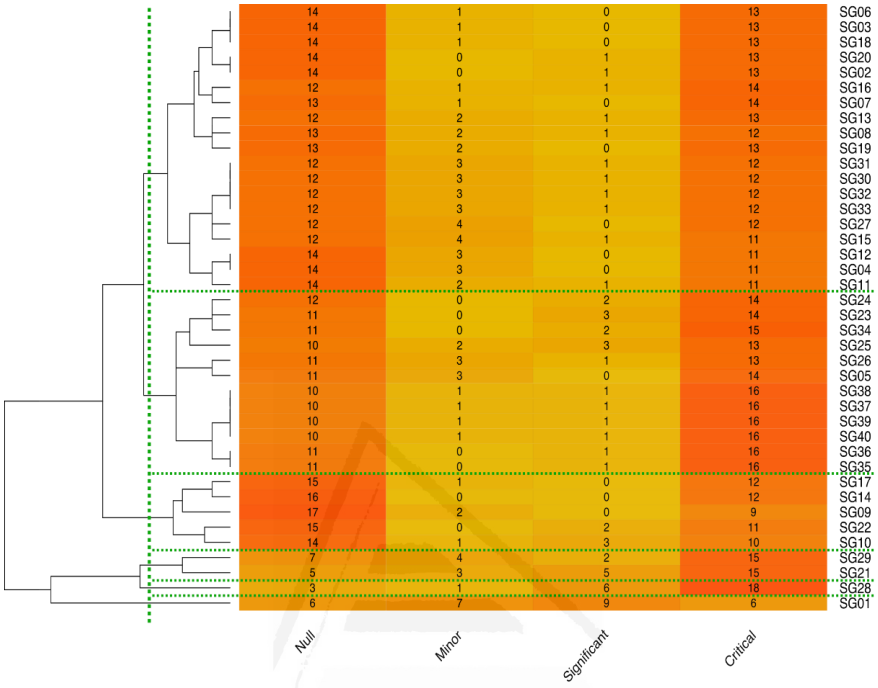


Figure 3. Dendrogram with six clusters of the evaluated serious games with the heuristic method.

Table 7. Evaluation with the BW heuristic method for the serious game SG01 "acid-base-solutions".

ID	Barrier	E	P	St	Sc	I	P1	P2	P3	P4	Pt	P	Severity
G01	Accessible keyboard	0	1	0	1	2			4		4	2	Significant
G02	No luminance flash failures	1	0	1	2	1		2			2	1	Minor
G03	Animation from Interactions	1	0	1	2	1		3			3	1	Minor
G04	Content hovering over focus	0	0	0	0	3				6	6	3	Critical
G05	Easy to read font	1	0	1	2	1		2			2	1	Minor
G06	Text alternatives	0	1	0	1	2			5		5	2	Significant
G07	Subtitled	0	1	0	1	2			4		4	2	Significant
G08	Automatic transcripts	0	1	0	1	2			4		4	2	Significant
G09	Sign language	0	1	0	1	2			5		5	2	Significant
G10	Information and relationships	1	0	1	2	1		3			3	1	Minor
G11	Adjust display settings	1	1	1	3	0	0				0	0	Null
G12	Interface rearrangement	1	1	1	3	0	1				1	0	Null
G13	Use of color	1	0	1	2	1		2			2	1	Minor
G14	Contrast without text	1	0	1	2	1		2			2	1	Minor
G15	Well-spaced elements	1	1	1	3	0	0				0	0	Null
G16	Good audio techniques	0	1	0	1	2			5		5	2	Significant
G17	Contrast	0	1	1	2	1		2			2	1	Minor
G18	Images as sharp as possible	1	1	1	3	0	0				0	0	Null
G19	Visual presentation	1	1	1	3	0	0				0	0	Null
G20	Pause, stop, hide	0	1	1	2	1				6	6	3	Significant
G21	Sensory characteristics	1	0	1	2	1				6	6	3	Significant
G22	Screen reader support	1	0	1	2	1				6	6	3	Significant
G23	Status messages	0	0	1	1	2				6	6	3	Critical
G24	Language	0	0	1	1	2				6	6	3	Critical

Table 7. *Cont.*

ID	Barrier	E	P	St	Sc	I	P1	P2	P3	P4	Pt	P	Severity
G25	Consistent navigation	1	1	1	3	0	0				0	0	Null
G26	Labels or instructions	0	0	0	0	3				6	6	3	Critical
G27	Help	0	0	0	0	3				6	6	3	Critical
G28	On focus	0	0	0	0	3				6	6	3	Critical

Where: E = Effectiveness, P = Productivity, St = Satisfaction, Sc = Security, I = Impact, P1 = 0 and 1, P2 = 2 and 3, P3 = 4 and 5, P4 > 5, Pt = Persistence total, P = Persistence.

5. Results

Table 8 summarizes the 40 serious games evaluated; it contains the serious games' code, the severity of null, minor, significant, and critical.

Table 8. Summary of the severities of the serious games evaluated.

ID	Null	Minor	Significant	Critical
SG01	6	7	9	6
SG02	14	0	1	13
SG03	14	1	0	13
SG04	14	3	0	11
SG05	11	3	0	14
SG06	14	1	0	13
SG07	13	1	0	14
SG08	13	2	1	12
SG09	17	2	0	9
SG10	14	1	3	10
SG11	14	2	1	11
SG12	14	3	0	11
SG13	12	2	1	13
SG14	16	0	0	12
SG15	12	4	1	11
SG16	12	1	1	14
SG17	15	1	0	12
SG18	14	1	0	13
SG19	13	2	0	13
SG20	14	0	1	13
SG21	5	3	5	15
SG22	15	0	2	11
SG23	11	0	3	14
SG24	12	0	2	14
SG25	10	2	3	13
SG26	11	3	1	13
SG27	12	4	0	12
SG28	3	1	6	18
SG29	7	4	2	15
SG30	12	3	1	12
SG31	12	3	1	12
SG32	12	3	1	12
SG33	12	3	1	12
SG34	11	0	2	15
SG35	11	0	1	16
SG36	11	0	1	16
SG37	10	1	1	16
SG38	10	1	1	16
SG39	10	1	1	16
SG40	10	1	1	16
Total	473	70	55	522

The results obtained in this case study show that the total null severity has a value of 473, representing 42.2% of the total. The minor severity corresponds to the amount of 70, representing 6.3%. The significant severity is 55, which corresponds to 4.9%; finally, the critical severity has a value of 522 and represents 46.6%. A summary of WCAG 2.1 principles and the severity of the serious games' barriers are presented in Table 9.

Table 9. Summary of WCAG 2.1 principles and severity of barriers.

Principle	Null	% Null	Minor	% Minor	Significant	% Significant	Critical	% Critical
Perceivable	302	63.8	53	75.7	23	41.8	342	65.5
Operable	57	12.1	14	20.0	12	21.8	37	7.1
Understandable	88	18.6	3	4.3	6	10.9	103	19.7
Robust	26	5.5	0	0.0	14	25.5	40	7.7

6. Discussion

Of the 40 serious games evaluated, we found that:

(1) The SG01 "acid-base solutions" set has a value of six in the critical severity evaluation.
(2) The SG09 "severity-and-orbits" set has nine and corresponds to the group's most accessible serious games with less critical barriers.
(3) The two web-based serious games correspond to the University of Colorado's PhET project.

The serious games with the highest number of critical barriers correspond to SG28 "freeriderhd" with a value of 18, followed by SG35 "physicsatschool" with 16. The results indicate: (1) The most significant number of serious games is in the critical and significant severity rating; (2) For serious games to be accessible at an acceptable level, application programmers must correct the most significant number of accessibility barriers through serious game programming software; and (3) the alternative is to use adaptive hardware by applying assistive technology or digital ramps that allow users to interact with serious games easily.

Furthermore, to find similarities between the serious games evaluated with the heuristic method, we apply the hierarchical grouping that allows the finding of similarities between the serious games accommodated in groups so that the groups are well separated and that the serious games within them are as close as possible. The similarity between the serious games is graphed using a tree called a dendrogram. In this process, we apply the following steps: (1) the number of clusters or groups is formed according to the number of serious games; (2) the serious games are grouped based on a measure of similarity between them; (3) the groups are grouped based on their distance, forming a tree called a dendrogram; (4) they continue to group until only one grouping remains.

Figure 3 shows the dendrogram of the 40 serious games' evaluations with the heuristic method considering the null, minor, significant, and critical variables to know the groups that obtained similar characteristics among the serious games. To measure the similarity between the serious games, we applied the Euclidean distance (2).

$$d(x, y) = \|x - y\| \sqrt{\sum_{i=1}^{n} (xi - yi)^2} \tag{2}$$

The Euclidean distance method allows us to see how similar the evaluation data are for each serious game. The dendrogram in Figure 3 shows the height of the branches that indicates the similarity between the clusters, and contains five horizontal lines in green indicating the number of groups into which they are divided; in this case, it was divided into six groups containing similar values, which are detailed below:

(1) The serious game SG01 is in a single group because it records low values in null, minor, significant, and critical; this implies that SG01 is the most accessible serious game of the 40 evaluated.

(2) The SG28 serious game is in the second group. It is still not as accessible because the critical severity is 18, indicating that it contains some accessibility barriers that must be corrected even though null, minor, and significant are low.
(3) The two serious games, SG21 and SG29, are in the third group are not very accessible because they have a critical severity of 15.
(4) The five serious games, SG10, SG22, SG09, SG14, and SG17, are in the fourth group and are not very accessible because they have a critical severity.
(5) The 12 serious games SG05, SG23, SG24, SG25, SG26, SG34, SG35, SG36, SG37, SG38, SG39, SG40 have a high critical severity and are therefore not accessible.
(6) The 19 serious games SG02, SG03, SG04, SG06, SG07, SG08, SG11, SG12, SG13, SG15, SG16, SG18, SG19, SG20, SG27, SG30, SG31, SG32, SG33 are among the least accessible.

Figure 4a shows that the examined critical games violate some principles of WCAG 2.1.

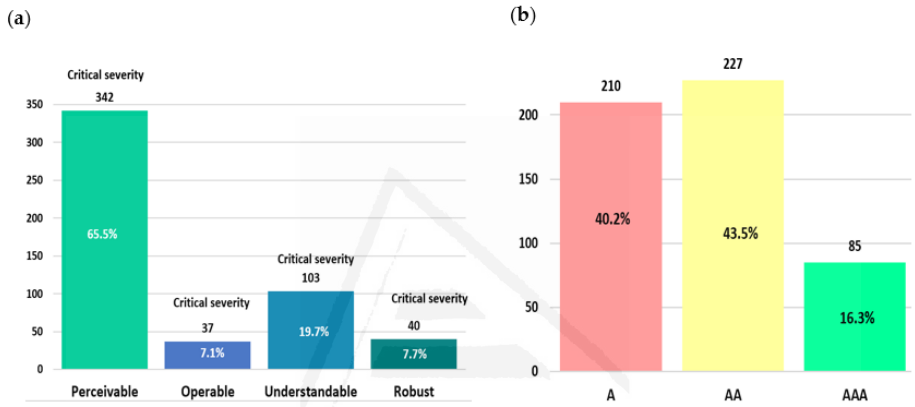


Figure 4. (**a**) WCAG 2.1 vs. critical severity. (**b**) WCAG 2.1 accessibility levels vs. critical severity.

In the 40 evaluated serious games, the evaluators found: (1) 342 barriers with critical severity, where 65.5% characterize the perceptible principle. (2) 37 barriers with critical severity represent 7.1% of the operable. (3) 19.7% corresponding to the understandable, and (4) 7.7% corresponding to the robust. These statistics indicate that accessibility barriers affect web-based serious games and should be corrected.

Figure 4b shows a summary of the accessibility levels corresponding to critical severity; we observe that for level A, 210 barriers representing 40.2%, for level AA, 227 barriers corresponding to 43.5%, and level AAA has 85 barriers corresponding to 16.3% of the total.

Figure 5 presents the success criteria for critical severity; these criteria can be found in Table 7; we observe that:

(1) The on-focus barriers correspond to criterion 3.2.1. The help barrier of the success criterion 3.3.5 is the most critical with a value of 40.
(2) It is followed by the content hovering over the focus barrier of criterion 1.4.13, subtitled criterion 1.2.4, and the automatic transcripts barrier of criterion 1.
(3) With the value of 38, the barriers text alternative is sign language.
(4) Through 37, the criterion status messages.
(5) By 36, interface rearrangement.
(6) With 32, we have adjusted the display settings and pause, stop, hide.
(7) With 30, the criterion accessible keyboard.
(8) Together with 23, the criterion useful audio techniques.
(9) The rest of the criteria have values lower than 12.

We suggest incorporating solutions using digital ramps or software and hardware assistance technologies to have serious games accessible. We propose to include support tools that help users with sensory, motor, and visual disabilities with configuration options to enable an environment controlled by the user of the serious game. We propose that the serious game contains (1) A tool to control the serious game's video, the subtitles, and playback. (2) A tool to support motor, sensory, and cognitive disabilities.

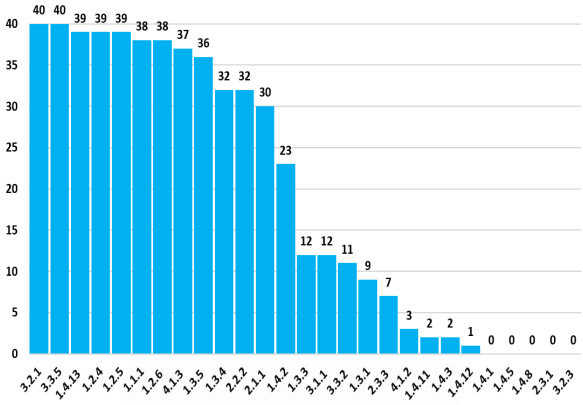


Figure 5. WCAG 2.1 success criteria vs. critical severity.

The tool in Figure 6 suggested should contain (1) an option to control the serious game's execution that allows the configuration of subtitles, descriptions, keyboard, and automatic transcription; (2) the subtitle settings should include options to manage the position, font, font size, text color, background, and opacity; (3) an option to configure the serious game's speed, subtitles, and audio replay in the application. The user must have the control to manage and customize the speed of video, subtitles, and audio according to the user's disability.

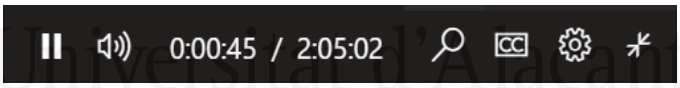


Figure 6. Accessibility suggestion for serious game control.

Figure 7 suggests including a tool to support users with disabilities that allows voice commands, and the option for them to use the VoiceOver application that narrates what happens on the screen of any device; voice assistants are a great help for users with visual or motor disabilities. Another option is to include a chatbot based on artificial intelligence, which feeds the database as the user learns.

Figure 7. A tool to configure the options according to the disability of the users.

A system can be included to transcribe the video into text or sign language and transform the text into sign language for deaf users.

People with motor disabilities usually read the information presented by computer output devices through the monitor or printer without difficulty, but often have difficulty handling input devices such as the keyboard and mouse. For people with motor disabilities, filters can be incorporated to facilitate the use of the keyboard and mouse by a trackball, joystick, buttons, and custom devices.

As additional add-ons, serious games can include changing the language to customize and choose the audio description and subtitles' language. Although sign language is not similar globally, this option should be included to help deaf and dumb users and feed a database with each region's

sign language. Therefore, assistive technologies have become an essential resource to overcome the barriers of access to digital technologies that positively impact people's quality of life with disabilities.

7. Conclusions

This heuristic method can be used to evaluate the accessibility of any serious web-based game. One of these heuristic methods' contributions is to evaluate each barrier by the parameters of effectiveness, productivity, satisfaction, and security related to impact and persistence. We recommend reproducing this heuristic accessibility evaluation method for any serious game considering the accessibility barriers that correspond to the type of motor, cognitive, or sensory disability. The evaluators identified some critical severity barriers, including the following two. The first barrier with the highest critical severity is the focus, and the second barrier is the help, both of which are related to the understandable principle.

These barriers occur when no contextual help is available, and any user interface component receives the focus but does not initiate a context change. Consequently, the evaluators recommend: (1) Applying techniques and tools to reduce the barrier help's critical severity can use clear labels that can act as contextual help. (2) To reduce the on-focus barrier's severity, the user interface components can be implemented as a programmable element to perceive the parts as separate controls. To assess the accessibility of serious games, evaluators recommend fusing automatic assessment tools with heuristic methods. One must remember that no instrument can substitute manual assessment by a serious game accessibility expert. The proposed method can be tested with serious game developers throughout the software development cycle to identify new barriers and correct them as they are built to achieve more inclusive applications.

Future research may propose new methods of evaluating multimedia resources concerning videos and sound recordings; in both cases, a transcript of the dialogues, a description of the sounds, and control of the playback speed should be provided. However, inappropriate use of multimedia elements may create a barrier to user access. To achieve more accessible serious games, we suggest testing with users with sensory, motor, and cognitive disabilities to identify the barriers users face with disabilities.

Future work should continue to refine heuristic methods related to serious games and socialize best accessibility practices, designing software that helps experts evaluate serious games' accessibility by considering this heuristic method and the WCAG 2.1. Furthermore, we propose to survey serious game developers to find out if they know the WCAG 2.1 and if they have tried to apply some of its guidelines to design inclusive products that make an essential contribution in the field of accessible serious games.

Author Contributions: Conceptualization, L.S.-U. and P.A.-V.; methodology, L.S.-U.; investigation, L.S.-U. and P.A.-V.; writing—original draft preparation, L.S.-U., and P.A.-V.; writing—review and editing L.S.-U., S.L.-M., M.G. and P.A.-V.; supervision, S.L.-M.; project administration, P.A.-V. and L.S.-U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidad de Las Américas-Ecuador, as part of an internal research project FGE.PAV.19.11.

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

References

1. García-Iruela, M.; Fonseca, M.J.; Hijón-Neira, R.; Chambel, T. Gamification and Computer Science Students' Activity. *IEEE Access* **2020**, *8*, 96829–96836. [CrossRef]
2. Bonnechère, B.; Bier, J.; Van Hove, O.; Sheldon, S.; Samadoulougou, S.; Kirakoya-Samadoulougou, F.; Klass, M. Age-Associated Capacity to Progress When Playing Cognitive Mobile Games: Ecological Retrospective Observational Study. *J. Med. Internet Res. Serious Games* **2020**, *8*, e17121. [CrossRef] [PubMed]

3. International Game Developers Association (2019) Developer satisfaction survey 2019: Summary report. Available online: https://s3-us-east-2.amazonaws.com/igda-website/wp-content/uploads/2020/01/29093706/IGDA-DSS-2019_Summary-Report_Nov-20-2019.pdf (accessed on 21 October 2020).
4. Bierre, K.; Chetwynd, J.; Ellis, B.; Hinn, D.M.; Ludi, S.; Westin, T. Game not over: Accessibility issues in video games. In Proceedings of the International Conference on Universal Access in Human-Computer Interaction, Las Vegas, NV, USA, 22–27 July 2005; pp. 22–27.
5. Federal Communications Commission 21st Century Communications and Video Accessibility Act (CVAA). Available online: https://www.fcc.gov/consumers/guides/21st-century-communications-and-video-accessibility-act-cvaa (accessed on 21 October 2020).
6. Microsoft Xbox Accessibility Guidelines. 2019. Available online: https://docs.microsoft.com/en-us/gaming/accessibility/guidelines (accessed on 21 October 2020).
7. Micosoft Making Video Games Accessible: Business Justifications and Design Considerations. 2018. Available online: https://docs.microsoft.com/es-es/windows/win32/dxtecharts/accessibility-best-practices?redirectedfrom=MSDN (accessed on 21 October 2020).
8. Microsoft Accessible Gaming with the Xbox Adaptive Controller. 2018. Available online: https://news.xbox.com/en-us/2018/05/16/xbox-adaptive-controller/ (accessed on 21 October 2020).
9. SONY Accessibility and Usability. 2020. Available online: https://www.sony.net/SonyInfo/accessibility/ (accessed on 21 October 2020).
10. World Health Organization (WHO) 10 facts on disability. 2017. Available online: https://www.who.int/features/factfiles/disability/en/ (accessed on 21 October 2020).
11. Salvador-Ullauri, L.; Acosta-Vargas, P.; Luján-Mora, S. Web-Based Serious Games and Accessibility: A Systematic Literature Review. *Appl. Sci.* **2020**, *10*, 7859. [CrossRef]
12. World Wide Web Consortium (W3C) Web Content Accessibility Guidelines (WCAG) 2.1. 2018. Available online: https://www.w3.org/TR/WCAG21/ (accessed on 21 October 2020).
13. Brajnik, G. Web Accessibility Testing: When the Method Is the Culprit. In Proceedings of the International Conference on Computers for Handicapped Persons, Linz, Austria, 11–13 July 2006; Springer: Berlin/Heidelberg, Germany, 2006; pp. 156–163.
14. Brajnik, G. Measuring Web accessibility by estimating severity of barriers. *Int. Conf. Web Inf. Syst. Eng.* **2008**, *5176*, 112–121.
15. Brajnik, G. Barrier Walkthrough. 2011. Available online: https://users.dimi.uniud.it/~{}giorgio.brajnik/projects/bw/bw.html (accessed on 21 October 2020).
16. Acosta-Vargas, P.; Salvador-Ullauri, L.; Luján-Mora, S. A Heuristic Method to Evaluate Web Accessibility for Users With Low Vision. *IEEE Access* **2019**, *7*, 125634–125648. [CrossRef]
17. Braga, H.; Pereira, L.S.; Ferreira, S.B.L.; Da Silveira, D.S. Applying the barrier walkthrough method: Going beyond the automatic evaluation of accessibility. *Procedia Comput. Sci.* **2014**, *27*, 471–480. [CrossRef]
18. Martin, F.; Betrus, A.K. Instructional Simulations and Games. In *Digital Media for Learning*; Springer: Cham, Switzerland, 2019; pp. 85–110.
19. Cheng, M.; Chen, J.; Chu, S.; Chen, S. The use of serious games in science education: A review of selected empirical research from 2002 to 2013. *J. Comput. Educ.* **2015**, *2*, 353–375. [CrossRef]
20. Abt, C. *Serious Games*; The Viking Press Inc.: New York, NY, USA, 1970.
21. Michael, D.R.; Chen, S.L. *Serious Games: Games that Educate, Train, and Inform*; Muska & Lipman/Premier-Trade: Cincinnati, OH, USA, 2005; Available online: https://dl.acm.org/doi/book/10.5555/1051239 (accessed on 28 October 2020).
22. Alvarez, J.; Rampnoux, O.; Jessel, J.-P.; Methel, G. Serious Game: Just a question of posture. *Artif. Ambient Intell. AISB* **2007**, *7*, 420–423.
23. Statista Number of Active Video Gamers Worldwide from 2015 to 2023. In *Surv*; Time Period 2014 to 2020. Release Date June 2020. Available online: https://www.statista.com/statistics/748044/number-video-gamers-world/ (accessed on 15 November 2020).
24. Statista Game-Based Learning Market Revenue Worldwide in 2018 and 2024. In *Surv*; Time Period 2018. Release Date August 2019. Available online: https://www.statista.com/statistics/733616/game-based-learning-industry-revenue-world/ (accessed on 15 November 2020).
25. Google Google Trends. Available online: https://trends.google.com/trends/explore?cat=958&date=today5-y&q=seriousgames,educationalgames (accessed on 15 November 2020).

26. Spyridonis, F.; Daylamani-Zad, D. A serious game to improve engagement with web accessibility guidelines. *Behav. Inf. Technol.* **2020**, 1–19. [CrossRef]
27. Cairns, P.; Power, C.; Barlet, M.; Haynes, G. Future design of accessibility in games: A design vocabulary. *Int. J. Hum. Comput. Stud.* **2019**, *131*, 64–71. [CrossRef]
28. Westin, T.; Ku, J.J.; Dupire, J.; Hamilton, I. Game accessibility guidelines and wcag 2.0–a gap analysis. In *Proceedings of the International Conference on Computers Helping People with Special Needs*; Miesenberger, K.K.G., Ed.; Springer: Cham, Switzerland, 2018; pp. 270–279.
29. Salvador-Ullauri, L.; Acosta-Vargas, P.; Jadán-Guerrero, J.; Guevara, C.; Sanchez-Gordon, S.; Calle-Jimenez, T.; Lara-Alvarez, P. Development of an Accessible Video Game to Improve the Understanding of the Test of Honey-Alonso. In Proceedings of the International Conference on Applied Human Factors and Ergonomics, Washington, DC, USA, 24–28 July 2019; Springer: Cham, Switzerland, 2020; pp. 289–298.
30. Alonso, C.; Gallego, D.; Honey, P. Cuestionarios/Estilos de Aprendizaje. Available online: https://diged.usac.edu.gt/sfpu/cuestionario/chaea (accessed on 21 October 2020).
31. Araújo, M.C.C.; Façanha, A.R.; Darin, T.G.R.; Sánchez, J.; Andrade, R.M.C.; Viana, W. Mobile audio games accessibility evaluation for users who are blind. In Proceedings of the International Conference on Universal Access in Human-Computer Interaction, Toronto, ON, Canada, 17–22 July 2016; Antona, M.S.C., Ed.; Springer: Cham, Switzerland, 2017; pp. 242–259.
32. World Wide Web Consortium (W3C) W3C Issues Improved Accessibility Guidance for Websites and Applications. Available online: https://www.w3.org/2018/06/pressrelease-wcag21.html.en (accessed on 22 October 2020).
33. Almeida, F.; Simoes, J. The role of serious games, gamification and Industry 4.0 tools in the Education 4.0 paradigm. *Contemp. Educ. Technol.* **2019**, *10*, 120–136. [CrossRef]
34. Jaramillo-Alcázar, A.; Luján-Mora, S. An approach to mobile serious games accessibility assessment for people with hearing impairments. In Proceedings of the International Conference on Information Technology & Systems, Libertad City, Ecuador, 10–12 January 2018; Springer: Cham, Switzerland, 2018; pp. 552–562.
35. Jaramillo-Alcázar, A.; Salvador-Ullauri, L.; Luján-Mora, S. A Mobile Serious Games Assessment Tool for People with Motor Impairments. In Proceedings of the International Conference on Education Technology and Computers, Barcelona, Spain, 20–22 December 2017; pp. 172–177.
36. Salvador-Ullauri, L.; Acosta-Vargas, P.; Luján-Mora, S. Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. In Proceedings of the International Conference on Intelligent Human Systems Integration, Modena, Italy, 19–21 February 2020; Springer: Cham, Switzerland, 2020; pp. 853–859.
37. Salvador-Ullauri, L.; Acosta-Vargas, P.; Gonzalez, M.; Luján-Mora, S. Combined Method for Evaluating Accessibility in Serious Games. *Appl. Sci.* **2020**, *10*, 6324. [CrossRef]
38. Paddison, C.; Englefield, P. Applying heuristics to accessibility inspections. *Interact. Comput.* **2004**, *16*, 507–521. [CrossRef]
39. Brajnik, G. Beyond conformance: The role of accessibility evaluation methods. In Proceedings of the International Conference on Web Information Systems Engineering, Dubai, UAE, 12–15 November 2018; Volume 5176, pp. 63–80.
40. Lunn, D.; Yesilada, Y.; Harper, S. Barriers Faced by Older Users On Static Web Pages Criteria Used In The Barrier Walkthrough Method. Available online: http://hcw-eprints.cs.manchester.ac.uk/108/ (accessed on 10 November 2020).
41. Sears, A. Heuristic Walkthroughs: Finding the Problems Without the Noise. *Int. J. Hum. Comput. Interact.* **1997**, *9*, 213–234. [CrossRef]
42. Brajnik, G.; Lomuscio, R. SAMBA: A Semi-Automatic Method for Measuring Barriers of Accessibility. In Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility, Tempe, AZ, USA, 15–17 October 2007; pp. 43–50.
43. Nielsen, J.; Molich, R. Heuristic evaluation of user interfaces. In Proceedings of the Conference on Human Factors in Computing Systems, Seattle, WA, USA, 1–5 April 1990; pp. 249–256.
44. Moreno, L.; Valencia, X.; Pérez, J.E.; Arrue, M. Exploring the Web navigation strategies of people with low vision. In Proceedings of the International Conference on Human Computer Interaction, ACM, Las Vegas, NV, USA, 15–20 July 2018; p. 13.
45. World Health Organization (WHO) Blindness and Vision Impairment. Available online: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment (accessed on 22 October 2020).

46. Acosta-Vargas, P.; Salvador-Ullauri, L. (Dataset) A Heuristic Method for Serious Games. Available online: https://data.mendeley.com/datasets/y4zy6wcb7k/2 (accessed on 28 October 2020).

Parte III

CONCLUSIONES Y TRABAJOS FUTUROS

13 Conclusiones y contribuciones

13.1. Conclusiones

La accesibilidad es un área de investigación esencial que surge de la Web. En los últimos años, se han publicado muchos estudios con un creciente interés en este tema. En este estudio se pusieron de relieve las tendencias actuales, las cuestiones pendientes en materia de accesibilidad y se aplicaron las directrices mínimas necesarias para el diseño de juegos serios inclusivos.

Esta investigación permitió caracterizar el estado de los juegos serios y la accesibilidad relacionada con la discapacidad sensorial, motora y cognitiva. Este estudio muestra la necesidad de investigar los problemas relacionados con las políticas, directrices y prácticas de accesibilidad para los juegos serios y las amenazas de transgresiones cometidas contra la accesibilidad.

A lo largo de esta investigación, se evaluaron 82 juegos serios relacionados con el área educativa con un método combinado y 40 juegos serios con el método heurístico para determinar el nivel de accesibilidad. El método combinado incluyó como parte de la evaluación dos herramientas automáticas para valorar el contraste, pues para evaluar los otros parámetros no existe herramienta alguna, por lo cual se aplicó un método de revisión manual considerando los criterios incluidos en la WCAG 2.1. En el método heurístico, que consiste en la variación al método de Barrier Walkthrough se aplicó una revisión manual considerando las barreras de accesibilidad basadas en los criterios de WCAG 2.1 para usuarios con baja visión.

En esta investigación se encontró que las empresas desarrolladoras de juegos serios educativos deben realizar grandes esfuerzos para mejorar e incluir en los diseños los principios de accesibilidad perceptible, operable, comprensible y robusto. Por otro lado, es importante motivar y fortalecer las políticas públicas relacionadas con la accesibilidad de cada país. En estos tiempos de emergencia sanitaria debido a la pandemia se está intensificando la desigualdad académica por las deficiencias de accesibilidad que presentan los recursos educativos, generando nuevas amenazas. Por tanto, es esencial velar para que las personas con discapacidad cuenten con los mismos derechos para

acceder al uso de los juegos serios utilizados en las plataformas educativas. El enfoque combinado y heurístico puede ser replicado para cualquier tipo de juego serio con usuarios que presentan diferentes tipos de discapacidades.

Para mejorar la accesibilidad en los juegos serios, se propone incluir: 1) transcripciones automáticas o el uso de bots para transcribir el audio o el vídeo presentando en los juegos serios, prescindiendo de la intervención humana, de modo que el usuario pueda estar asistido por estas transcripciones mientras juega; 2) lenguaje de señas para establecer un canal de comunicación con el entorno social, esta opción es útil para los usuarios con discapacidades auditivas; 3) control de fotosensibilidad, para configurar el exceso de luz y brillo, útil en usuarios con problemas de epilepsia; 4) dispositivos externos para permitir la realidad virtual y aumentada, por ejemplo, con la búsqueda de óculos el usuario puede lograr una mayor inmersión en el proceso de aprendizaje; y 5) una opción de ayuda contextual para que los usuarios puedan operar sin perder de vista lo que están haciendo. Se encontró que ningún juego serio entre los seleccionados ha alcanzado un nivel de accesibilidad aceptable. Por lo tanto, los desarrolladores de juegos serios deberían hacer esfuerzos significativos para mejorar la accesibilidad de sus productos. El estudio reveló que existe una gran cantidad de barreras de accesibilidad en los juegos serios basados en la Web que transgreden los principios de accesibilidad.

Finalmente, es esencial que la formación de los profesionales en el área de desarrollo se software incluya en sus contenidos los criterios contenidos en las WCAG 2.1 desde el inicio de su formación para concienciar y mejorar las buenas prácticas de programación. Esta investigación puede servir como referencia para trabajos futuros relacionados con el diseño de juegos serios accesibles.

13.2. Contribuciones

Las contribuciones que se presentan en esta investigación permiten compartir el conocimiento, colaborar y difundir lo encontrado durante todo el proceso del estudio realizado. Queda mucho por hacer y mejorar en el campo de la accesibilidad en juegos serios, como se refleja en las conclusiones de los artículos compartidos en el compendio.

Se aporta con dos métodos para la evaluación de juegos serios accesibles basados en la Web de tal forma que puedan ser aplicados y replicados en cualquier tipo de juego serio considerando el tipo de discapacidad y las respectivas barreras de accesibilidad basadas en los criterios de las WCAG 2.1. Una de las ventajas de esta propuesta es la concepción de dos métodos: uno combinado y otro heurístico con el objeto de evaluar los juegos serios basados en la Web, de tal forma que se facilite la identificación de las barreras de accesibilidad para los usuarios. Estos métodos están orientados a que los evaluadores puedan contar con una aproximación más realista de la existencia de las barreras de accesibilidad presentes en las aplicaciones Web y realizar oportunamente las correcciones pertinentes para mejorar la accesibilidad de los juegos serios basados en la Web.

Se comparte, como aporte, además, una revisión de literatura del estado actual de los juegos serios basados en la Web considerando las discapacidades sensoriales, motoras y cognitivas, así como la tendencia al uso de rampas digitales y de tecnologías asistivas para lograr un mayor nivel de accesibilidad en juegos serios y aplicaciones afines.

Esta investigación aporta con varios conjuntos de datos resultado de las evaluaciones aplicadas, de la literatura revisada y de los documentos de apoyo consultados durante todo el proceso de investigación para proponer los métodos combinado y heurístico que permitan evaluar la accesibilidad de los juegos serios, pues en la actualidad no se cuenta con herramientas de revisión automática. Los conjuntos de datos compartidos documentan las barreras encontradas y la frecuencia de repetición de estas, de tal manera que premitan alertar a los diseñadores y desarrolladores de juegos serios basados en la Web sobre los problemas de accesibilidad que presentan este tipo de aplicaciones, apoyándoles en la construcción de juegos serios más inclusivos y accesibles. Es así que, se considera que la información abierta del conjunto de datos puede acelerar los procesos de investigación. Finalmente, los datos abiertos permiten a los investigadores académicos e industriales unir esfuerzos para hacer nuevos descubrimientos científicos que pueden generar un mayor impacto en el área de la educación relacionada con los juegos serios accesibles.

14 Trabajos futuros y recomendaciones

14.1. Trabajos futuros

Como trabajos futuros sugerimos continuar analizando la evolución de la accesibilidad de los juegos serios en el campo educativo, pues los juegos serios ofrecen experiencias interactivas que se pueden adaptar al contexto de los usuarios para mejorar los procesos de aprendizaje. Por esta razón es esencial que este tipo de aplicaciones sean accesibles para todas las personas.

Se sugiere replicar los métodos combinado y heurístico propuestos en esta investigación para diferentes tipos de usuarios, considerando las barreras de accesibilidad de acuerdo con el tipo de discapacidad sensorial, cognitiva y motora con el propósito de construir juegos serios más inclusivos.

14.2. Recomendaciones

Se recomienda construir una herramienta de software que aplique las pautas de la WCAG 2.1 para apoyar a los desarrolladores de juegos serios; así como realizar una revisión de la literatura sobre la accesibilidad de los juegos serios para aplicaciones móviles y de computadora considerando las discapacidades sensoriales, motoras y cognitivas.

Se sugiere reunir y difundir las buenas prácticas en el diseño de juegos serios accesibles que permitan aprender de distintas experiencias, así como promover soluciones efectivas e innovadoras que aporten a la investigación y a las políticas públicas de cada país.

APÉNDICES

A Artículos de apoyo

Durante el doctorado se realizaron varias publicaciones, no se incluyen estos artículos en el compendio con el fin de garantizar la unidad temática de los documentos presentados.

B Improving the Performance of Web Servers for Educational Multiplayer Serious Videogames

Referencia:
Salvador-Ullauri, L. and Luján-Mora, S. and Acosta-Vargas, P. (2016). Improving the Performance of Web Servers for Educational Multiplayer Serious Videogames. En: International Conference on Education and New Learning Technologies (EDULEARN16) (pp. 8000-8010). IATED. (Salvador-Ullauri, Luján-Mora, y Acosta-Vargas, 2016b)

Disponible en:

- https://library.iated.org/view/SALVADORULLAURI2016IMP
- https://doi.org/10.21125/edulearn.2016.0756

Temas a los que aporta:

1. Caracterización de los problemas de accesibilidad en juegos serios desarrollados para trabajar sobre la Web.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico en servidores Web educativos.
3. Evaluar el nivel de accesibilidad de los juegos serios educativos.

IMPROVING THE PERFORMANCE OF WEB SERVERS FOR EDUCATIONAL MULTIPLAYER SERIOUS VIDEOGAMES

Luis Salvador-Ullauri[1], Sergio Luján-Mora[2], Patricia Acosta-Vargas[3]

[1] Escuela Politécnica Nacional (ECUADOR)
[2] University of Alicante (SPAIN)
[3] Universidad de Las Américas - UDLA (ECUADOR)

Abstract

In this paper, we present a set of features for managing web servers that host *Accessible Online Serious Videogames*. Serious videogames are games that are developed to be used on instructional challenges over several academic topics. With this set of features, the web servers are customized to improve the user experience of learners with disabilities in the interaction with online serious videogames according to their needs. Besides, we also identify and discuss rules about the study of the increment of the performance of the web servers that require interchange of information to implement concurrent access to data. The impact of the performance of web servers has been studied and documented over the last few years.

This study focuses on answering selected questions over methodological guidelines and it suggests ways that can contribute to the institutional strategies related with loading of data from online videogames adding new ideas, but maintaining and respecting the guidelines of the company. We outline the best practices found in our experience over online videogames development and several trends related to the managing of information of each instance of the videogame. Besides, we explain how to write local tests for tracking statistics and locating problem areas.

The concept of serious videogames previously did not exist in Ecuador, but there were examples of Ecuadorian games that could be considered as serious games. Several software have been developed in the classroom. Software also has been developed for the learning of programing languages and basic concepts of computer sciences. This software enables the learner to gain knowledge of programming through gaming development, but it is required that the performance of the communications between instances of our videogames that run online, have to be improved. Therefore, we expect to improve the performance of this software, optimizing the configuration of the web servers, changing the main parameters related with transfer of data and timeouts.

Web server simple configuration does good jobs for simple applications. However when many connections are needed to be handled, it may soon reach the limits of the resources in the web server. We research how to enhance the performance of web server to host online multiplayer serious videogames.

Keywords: Innovation, e-learning, technology, videogames.

1 INTRODUCTION

Nowadays, videogame trend is one of most important industry branch of the software development. A variety of themes are used in videogames. Videogames can be used as an education method. The use of videogames can help to improve the teaching and learning process. They can be used to teach computer sciences to the students of different education's levels. They can also be used to improve the understanding of how current technology works. It's important to take into consideration that there are many kinds of videogames, and that it is difficult to decide which of these has to be applied in order to reach the goals suggested in the different educative models. The intervention of each student in this process is to help other students reach their goals.

The teamwork of each student is important in order to support the learning of the classroom. The development of multiplayer videogames, may integrate the abilities of heterogeneous groups of students in the construction of tools that might help other people to improve their coexistence, and resolve their individual learning problems.

Commercial Multiplayer videogames, allow the gathering of many players who share their experiences to help other gamers with the difficulties and challenges proposed by the thematic of the videogame.

C Development of Serious Games Using Automata Theory as Support in Teaching People with Cognitive Disabilities

Referencia:
Salvador-Ullauri, L. and Luján-Mora, S. and Acosta-Vargas, P. (2016). Development of serious games using automata theory as support in teaching people with cognitive disabilities. En: 9th Annual International Conference of Education, Research and Innovation (ICERI2016) (pp. 4508-4516). IATED. (Salvador-Ullauri y otros, 2016a)

Disponible en:

- https://library.iated.org/view/SALVADORULLAURI2016DEV
- https://doi.org/10.21125/iceri.2016.2067

Temas a los que aporta:

1. Caracterizar los problemas de accesibilidad en juegos serioseducativos.
2. Identificación de los requisitos de accesibilidad en juegos serios, caso específico para personas con discapacidades cognitivas.
3. Evaluación del nivel de accesibilidad de los juegos serios para personas con discapacidades cognitivas.

DEVELOPMENT OF SERIOUS GAMES USING AUTOMATA THEORY AS SUPPORT IN TEACHING PEOPLE WITH COGNITIVE DISABILITIES

Luis Salvador-Ullauri[1], Sergio Luján-Mora[2], Patricia Acosta-Vargas[3]

[1] Escuela Politécnica Nacional (ECUADOR)
[2] University of Alicante (SPAIN)
[3] Universidad de Las Américas (ECUADOR)

Abstract

In this article, it is presented our experience in the use of the automata theory in the development of serious videogames oriented to people with special necessities. Serious videogames were developed to be used in virtual platforms in order to ease the learning of basic concepts about the management and attending of tiny business for people with disability for understanding. The serious videogames were created using finite state machines in order to represent the special use cases in the operation and management of a tiny business. The logic of the finite state machines is stored in arrays considering the variables: events, states and calendars. The serious videogames permit to the students that they decide several strategies of resolve defined problems. The videogames are used to evaluate the degree of acceptance of the selected solution by of the student, and they suggest methods to improve the manner of to do the assigned tasks. Besides, the students obtain of the videogame, samples of gratitude instead of money, when they use available tools in correct manner. However, a tiny quantity of money is accredited to their virtual wallets in order to help in the buy of food (represented by quantity of live) and transportation (represented by scenes of mobility in a virtual city). Other experiences are described. These experiences include the analysis of the topics considered to generate the motivational environment of the serious videogames. Four important concepts are described. These concepts have relation with the treat to the clients, the timely use of business resources, the time used to do the assigned tasks and the necessity of solicit help of other institutions, business and other people. The objective of this work is to use new technology tools in order to teach to the people with disability of understanding about the essential elements of the world of the commerce. The serious videogames consider three stages. The first stage is specially oriented to develop the memory of the students. The purpose of the second stage is improved the understanding of the students. Finally, the last stage is used to obtain of the students an acceptable grade of collaboration in the work and tasks to be performed in tiny business. Many conclusions are exposed, and results of the use of serious videogames with several students group are presented. New threads are suggested to start investigations in the use and develop of serious videogames in order to they can be incorporated to virtual e-learning classrooms.

Keywords: e-learning, serious videogames, automata theory.

1 INTRODUCTION

The automata theory permits the use of finite state machines. The finite state machines can be used to determine if a set of words are part of a specific grammar. If each letter of each word is associated to an action and each word is associated to a sequential procedure, then, we can have a group of valid procedures stored in matrixes. In this article we show, our experience in defining a group of tasks which will have to be executed to accomplish an effective procedure. These tasks are stored in matrixes and are identified with numbers. Each performed task produces the change of state of a specific procedure. The correct culmination of an entire procedure is considered how the execution of a valid procedure. A valid procedure is a valid word in the defined grammar. Initially, tiny and simple tasks are defined to identify the ability of the users to memorize and understand the sequence of task that are part of a procedure [2]. Then, in more advanced levels, complex procedures can be specified and tested by the users of a computational program transformed in a funny serious game. The simplest method is a sequential procedure, but more complex methods can be specified. That permits to define valid procedures that might be performed with task in different sequences. The purpose of these computational applications is to illustrate how to perform certain tasks by using the computer as a teaching media through serious videogames. The users can use the keyboard or a mouse to specify what task has to be performed in a determined process, and the computer will respond with a

Referencias

Acosta-Vargas, P., y Salvador-Ullauri, L. (2020). *Dataset Evaluation in Serious Games.* doi: 10.17632/t2tr35ww4c.5 (citado en las páginas 41, 43, 50)

Acosta-Vargas, P., Salvador-Ullauri, L., y Luján-Mora, S. (2019). A Heuristic Method to Evaluate Web Accessibility for Users With Low Vision. *IEEE Access*, *7*, 125634–125648. doi: 10.1109/ACCESS.2019.2939068 (citado en las páginas 47)

Aguado-Delgado, J., Gutiérrez-Martínez, J. M., Hilera, J. R., De-Marcos, L., y Otón, S. (2020). Accessibility in Video Games: A Systematic Review. *Universal Access in the Information Society*, *19*(1), 169–193. doi: 10.1007/s10209-018-0628-2 (citado en las páginas 4, 5, 19, 22)

Araújo, M. C. C., Façanha, A. R., Darin, T. G. R., Sánchez, J., Andrade, R. M. C., y Viana, W. (2017). Mobile Audio Games Accessibility Evaluation for Users Who Are Blind. En *International Conference on Universal Access in Human-Computer Interaction* (Vol. 10278, pp. 242–259). Springer, Cham. doi: 10.1007/978-3-319-58703-5_18 (citado en las páginas 21)

Bourne, R. R., Flaxman, S. R., Braithwaite, T., Cicinelli, M. V., Das, A., Jonas, J. B., y Naidoo, K. (2017, sep). Magnitude, Temporal Trends, and Projections of the Global Prevalence of Blindness and Distance and Near Vision Impairment: A Systematic Review and Meta-analysis. *The Lancet Global Health*, *5*(9), e888–e897. doi: 10.1016/S2214-109X(17)30293-0 (citado en las páginas 36)

Braga, H., Pereira, L., Ferreira, S., y Da Silveira, D. (2014). Applying the Barrier Walkthrough Method: Going Beyond the Automatic Evaluation of Accessibility. *Procedia Computer Science*, *27*, 471–480. doi: 10.1016/j.procs.2014.02.051 (citado en las páginas 47)

Brajnik, G. (2006). Web Accessibility Testing: When the Method is the Culprit. En *International Conference on Computers for Handicapped Persons* (Vol. 4061, pp. 156–163). Springer, Berlin, Heidelberg. doi: 10.1007/11788713_24 (citado en las páginas 48)

Brajnik, G. (2008). Measuring Web Accessibility by Estimating Severity of Barriers. En *International Conference on Web Information Systems Engineering* (Vol. 4061, pp. 112–121). Springer, Berlin, Heidelberg. doi: 10.1007/978-3-540-85200-1_13

(citado en las páginas 36, 47, 48)

Brajnik, G., y Lomuscio, R. (2007). SAMBA: A Semi-Automatic Method for Measuring Barriers of Accessibility. En *International Conference on Computers and Accessibility* (p. 43–50). Association for Computing Machinery. Descargado de https://doi.org/10.1145/1296843.1296853 doi: 10.1145/1296843.1296853 (citado en las páginas VII, X, 48)

Brajnik, G., Yesilada, Y., y Harper, S. (2011). Web Accessibility Guideline Aggregation for Older Users and its Validation. *Universal Access in the Information Society*, *10*(4), 403–423. doi: 10.1007/s10209-011-0220-5 (citado en las páginas 48)

Budgen, D., Turner, M., Brereton, O. P., y Kitchenham, B. A. (2008). Using Mapping Studies in Software Engineering. En *Psychology of Programming Interest Group* (Vol. 8, pp. 195–204). doi: 10.1.1.222.9091 (citado en las páginas 28)

Cairns, P., Power, C., Barlet, M., y Haynes, G. (2019). Future Design of Accessibility in Games: A Design Vocabulary. *International Journal of Human-Computer Studies*, *131*, 64–71. doi: 10.1016/j.ijhcs.2019.06.010 (citado en las páginas 21)

Cheng, M., Chen, J., Chu, S., y Chen, S. (2015). The Use of Serious Games in Science Education: A Review of Selected Empirical Research from 2002 to 2013. *Journal of Computers in Education*, *2*, 353–375. doi: 10.1007/s40692-015-0039-9 (citado en las páginas V, VI, IX, X)

de Castro Lozano, C. (2015). El Futuro de las Tecnologías Digitales Aplicadas al Aprendizaje de Personas con Necesidades Educativas Especiales. *Revista de Educación a Distancia (RED)*(32). Descargado de https://revistas.um.es/red/article/view/233051 (citado en las páginas 3)

de Miguel, M. (2003). Glosario de Discapacidad Visual. *Organización Nacional de Ciegos Españoles. Dirección de Cultura y Deportes.*. Descargado de https://pdfslide.net/documents/glosario-de-discapacidad-visual-5665ec2634368.html (citado en las páginas 60)

Eriksen, M. B., y Frandsen, T. F. (2018). The Impact of Patient, Intervention, Comparison, Outcome (PICO) as a Search Strategy Tool on Literature Search Quality: A Systematic Review. *Journal of the Medical Library Association*, *106*(4), 420–431. doi: 10.5195/jmla.2018.345 (citado en las páginas 4, 22, 24)

Fuster-Guilló, A., Pertegal-Felices, M. L., Jimeno-Morenilla, A., Azorín-López, J., Rico-Soliveres, M. L., y Restrepo-Calle, F. (2019). Evaluating Impact on Motivation and Academic Performance of a Game-Based Learning Experience Using Kahoot. *Frontiers in Psychology*, *10*, 2843. doi: 10.3389/fpsyg.2019.02843 (citado en las páginas 23)

García-Holgado, A., y García-Peñalvo, F. J. (2018). Mapping the Systematic Literature Studies about Software Ecosystems. En *International Conference on Technological Ecosystems for Enhancing Multiculturality* (pp. 910–918). Association for Computing Machinery. doi: 10.1145/3284179.3284330 (citado en las páginas 4, 22, 25)

Gore, F. M., Bloem, P. J., Patton, G. C., Ferguson, J., Joseph, V., Coffey, C., ... Mathers, C. D. (2011). Global Burden of Disease in Young People Aged 10–24 Years: A Systematic Analysis. *The Lancet*, *377*(9783), 2093–2102. doi: 10.1016/S0140-6736(11)60512-6 (citado en las páginas 58)

Hersh, M., y Leporini, B. (2018). Serious Games, Education and Inclusion for Disabled People Editorial. *British Journal of Educational Technology*, *49*(4), 587–595. doi: 10.1111/bjet.12650 (citado en las páginas 23)

IHME, Human Development Network, The World Bank. (2013). *La Carga Mundial de Morbilidad: Generar Evidencia, Orientar Políticas. Edición regional para América Latina y el Caribe.* Institute for Health Metrics and Evaluation Seattle. Descargado de http://documents1.worldbank.org/curated/pt/266171468266065295/pdf/808510PUB0SPAN0Box0379820B00PUBLIC0.pdf (citado en las páginas 58)

Interactive Simulations. (2019). *PhET: Free Online Physics, Chemistry, Biology, Earth Science and Math Simulations.* Descargado 2019-03-28, de https://phet.colorado.edu/ (citado en las páginas 31)

Jain, Y. K., y Bha, S. K. (2011). Min Max Normalization Based Data Perturbation Method for Privacy Protection. *International Journal of Computer & Communication Technology*, *2*(8), 45–50. doi: 10.47893/ijcct.2013.1201 (citado en las páginas 31)

Jaramillo-Alcázar, A., y Luján-Mora, S. (2017). Mobile Serious Games: An Accessibility Assessment for People with Visual Impairments. En *International Conference on Technological Ecosystems for Enhancing Multiculturality* (pp. 1–6). Association for Computing Machinery. doi: 10.1145/3144826.3145416 (citado en las páginas 5, 19)

Jaramillo-Alcázar, A., Luján-Mora, S., y Salvador-Ullauri, L. (2017). Accessibility Assessment of Mobile Serious Games for People with Cognitive Impairments. En *International Conference on Information Systems and Computer Science* (pp. 323–328). IEEE. doi: 10.1109/INCISCOS.2017.12 (citado en las páginas 5, 19)

Kazimoglu, C., Kiernan, M., Bacon, L., y Mackinnon, L. (2012). A Serious Game for Developing Computational Thinking and Learning Introductory Computer Programming. *Procedia-Social and Behavioral Sciences*, *47*, 1991–1999. doi: 10.1016/j.sbspro.2012.06.938 (citado en las páginas V, IX)

Kitchenham, B. (2004). Procedures for Performing Systematic Reviews. *Keele, UK, Keele University*, *33*(TR/SE-0401), 28. doi: 10.1.1.122.3308 (citado en las páginas 4, 6, 22, 26)

Kitchenham, B., Pearl Brereton, O., Budgen, D., Turner, M., Bailey, J., y Linkman, S. (2009). Systematic Literature Reviews in Software Engineering - A Systematic Literature Review. *Information and Software Technology*, *51*(1), 7–15. doi: 10.1016/j.infsof.2008.09.009 (citado en las páginas 6)

Kompen, R. T., Edirisingha, P., Canaleta, X., Alsina, M., y Monguet, J. M. (2019). Personal Learning Environments Based on Web 2.0 Services in Higher Education. *Telematics and Informatics*, *38*, 194–206. doi: 10.1016/j.tele.2018.10.003 (citado en las páginas 3)

Lau, H. M., Smit, J. H., Fleming, T. M., y Riper, H. (2017). Serious Games for Mental Health: Are They Accessible, Feasible, and Effective? A Systematic Review and Meta-analysis. *Frontiers in Psychiatry*, *7*(209). doi: 10.3389/fpsyt.2016.00209 (citado en las páginas 3)

Lewis, E., Chamel, O., Mohsenin, M., Ots, E., y White, E. T. (2018). *Sustainaspeak:*

A Guide to Sustainable Design Terms. Routledge. doi: 10.4324/9781315270326 (citado en las páginas V)

López, J. M., Medina, N. M., y de Lope, R. P. (2016). Interaction in Video Games for People with Impaired Visual Function: Improving Accessibility. En *International Conference on Human Computer Interaction* (pp. 1–2). Association for Computing Machinery. doi: 10.1145/2998626.2998643 (citado en las páginas 5, 19)

Lukosch, H. K., Bekebrede, G., Kurapati, S., y Lukosch, S. G. (2018). A Scientific Foundation of Simulation Games for the Analysis and Design of Complex Systems. *Simulation & Gaming*, *49*(3), 279–314. doi: 10.1177/1046878118768858 (citado en las páginas 59)

Lunn, D., Yesilada, Y., y Harper, S. (2009). *Barriers Faced by Older Users On Static Web Pages Criteria Used In The Barrier Walkthrough Method* (n.º June). HCW — SCWeb2 Technical Report WP1 D1 and RIAM. Descargado 2020-11-10, de http://hcw-eprints.cs.manchester.ac.uk/108/ doi: 10.1.1.613.7905 (citado en las páginas 47)

Martin, F., y Betrus, A. K. (2019). Instructional Simulations and Games. En *Digital Media for Learning* (pp. 85–110). Springer, Cham. doi: 10.1007/978-3-030-33120-7_5 (citado en las páginas V, VI, IX, X)

McDonald, Heidi. (2018). iThirve Games Empathy Jam at DigiPen. En *International Conference on Game Jams, Hackathons, and Game Creation Events* (pp. 28–33). doi: /10.1145/3196697.3196704 (citado en las páginas 58)

Michael, D. R., y Chen, S. L. (2005). *Serious Fames: Games that Educate, Train, and Inform*. Muska & Lipman/Premier-Trade. doi: 10.5555/1051239 (citado en las páginas 3)

Moher, D., Liberati, A., Tetzlaff, J., y Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-analyses: The PRISMA Statement. *Journal of Clinical Epidemiology*, *62*(10), 1006–1012. doi: 10.1016/j.jclinepi.2009.06.005 (citado en las páginas 6)

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., y Prisma Group. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*, *6*(7), e1000097. doi: 10.1371/journal.pmed.1000097 (citado en las páginas 22)

Moreno, L., Valencia, X., Pérez, J. E., y Arrue, M. (2018). Exploring the Web Navigation Strategies of People with Low Vision. En *International Conference on Human Computer Interaction* (p. 13). Association for Computing Machinery. doi: 10.1145/3233824.3233845 (citado en las páginas 36)

Paddison, C., y Englefield, P. (2004). Applying Heuristics to Accessibility Inspections. *Interacting with Computers*, *16*(3), 507–521. doi: 10.1016/j.intcom.2004.04.007 (citado en las páginas 46)

Park, H. J., y Kim, S. B. (2013). Guidelines of Serious Game Accessibility for the Disabled. En *International Conference on Information Science and Applications* (pp. 1–3). IEEE. doi: 10.1109/ICISA.2013.6579380 (citado en las páginas 20, 21)

Petersen, K., Feldt, R., Mujtaba, S., y Mattsson, M. (2008). Systematic Mapping

Studies in Software Engineering. En *Ease* (Vol. 12, pp. 1–10). doi: 10.14236/EWIC/EASE2008.8 (citado en las páginas 4, 22, 24, 50, 54)

Prisma-Statement. (2015). *PRISMA*. Descargado 2020-10-22, de http://www.prisma-statement.org/ (citado en las páginas 4, 22, 25)

Roselló Leyva, A., Bernal Reyes, N., Rojas Rondón, I., Roselló Silva, N., y Lázaro Izquierdo, Y. (2015, 10). Caracterización de Pacientes Adultos Mayores con Diagnóstico de Miopía Degenerativa y Baja Visión, y su Rehabilitación Visual. *Revista Habanera de Ciencias Médicas*, *14*, 599 - 610. Descargado de http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1729-519X2015000500007&nrm=iso (citado en las páginas 60)

Salvador-Ullauri, L., Jaramillo-Alcázar, A., y Luján-Mora, S. (2017). A Serious Game Accessible to People with Visual Impairments. En *International Conference on Education Technology and Computers* (pp. 84–88). doi: 10.1145/3175536.3175576 (citado en las páginas 9, 10, 85)

Salvador-Ullauri, L., Acosta-Vargas, P., Gonzalez, M., y Luján-Mora, S. (2020a). Combined Method for Evaluating Accessibility in Serious Games. *Applied Sciences*, *10*(18), 6324. doi: 10.3390/app10186324 (citado en las páginas VII, X, 9, 103)

Salvador-Ullauri, L., Acosta-Vargas, P., Gonzalez, M., y Luján-Mora, S. (2020b). A Heuristic Method for Evaluating Accessibility in Web-based Serious Games for Users with Low Vision. *Applied Sciences*, *10*(24), 8803. doi: 10.3390/app10248803 (citado en las páginas VII, X, 9, 10, 149)

Salvador-Ullauri, L., Acosta-Vargas, P., y Luján-Mora, S. (2020). Accessibility Evaluation of Video Games for Users with Cognitive Disabilities. En *International Conference on Intelligent Human Systems Integration* (Vol. 1131, pp. 853–859). Springer, Cham. doi: 10.1007/978-3-030-39512-4_130 (citado en las páginas 9, 10, 19, 93)

Salvador-Ullauri, L., Acosta-Vargas, P., y Luján-Mora, S. (2020). Web-Based Serious Games and Accessibility: A Systematic Literature Review. *Applied Sciences*, *10*(21), 7859. Descargado de https://www.mdpi.com/2076-3417/10/21/7859/htm doi: 10.3390/app10217859 (citado en las páginas VI, X, 9, 121)

Salvador-Ullauri, L., Jaramillo-Alcázar, A., y Luján-Mora, S. (2017). Juego Serio Móvil de Cálculo Binario para Personas con Discapacidad Visual. En *ATICA, Tecnología. Accesibilidad. Educar en la Sociedad Red* (pp. 266–273). (citado en las páginas 9, 10, 77)

Salvador-Ullauri, L., Luján-Mora, S., y Acosta-Vargas, P. (2016a, November). Development of Serious Games Using Automata Theory as Support in Teaching People with Cognitive Disabilities. En *International Conference of Education, Research and Innovation* (p. 4508-4516). IATED. doi: 10.21125/iceri.2016.2067 (citado en las páginas 5, 187)

Salvador-Ullauri, L., Luján-Mora, S., y Acosta-Vargas, P. (2016b, 4-6 July, 2016). Improving the Performance of Web Servers for Educational Multiplayer Serious Videogames. En *8th International Conference on Education and New Learning Technologies* (p. 8000-8010). IATED. doi: 10.21125/edulearn.2016.0756 (citado en las páginas 183)

Salvador-Ullauri, L., Luján-Mora, S., y Acosta-Vargas, P. (2016c). Producción de

Videojuegos Orientados a la Enseñanza Mediante Lenguajes de Programación por Bloques Aplicables a Aulas Virtuales Mediante SCORM. En *Tecnología, Innovación e Investigación en los Procesos de Enseñanza-Aprendizaje* (pp. 2992–3001). Octaedro. Descargado de http://hdl.handle.net/10045/61851 (citado en las páginas 9, 11, 65)

Sears, A. (1997). Heuristic Walkthroughs: Finding the Problems Without the Noise. *International Journal of Human-Computer Interaction*, *9*(3), 213–234. doi: 10.1207/s15327590ijhc0903 (citado en las páginas 48)

Song, S., Wang, C., Li, L., Yu, Z., Lin, X., y Bu, J. (2017). WAEM: A Web Accessibility Evaluation Metric Based on Partial User Experience Order. En *Web for All Conference on The Future of Accessible Work*. Association for Computing Machinery. doi: 10.1145/3058555.3058576 (citado en las páginas 4)

Spyridonis, F., y Daylamani-Zad, D. (2020). A Serious Game to Improve Engagement with Web Accessibility Guidelines. *Behaviour & Information Technology*, 1–19. doi: 10.1080/0144929X.2019.1711453 (citado en las páginas 21)

Statista. (2020). *Game-based Learning Market Revenue Worldwide in 2018 and 2024*. Descargado 2020-10-22, de https://www.statista.com/statistics/733616/game-based-learning-industry-revenue-world/ (citado en las páginas 3, 50)

The Paciello Group. (2020). *Colour Contrast Analyser*. Descargado 2020-11-20, de https://developer.paciellogroup.com/resources/contrastanalyser/ (citado en las páginas 41)

University of Maryland. (2016). *Photosensitive Epilepsy Analysis Tool*. Descargado 2020-11-20, de https://trace.umd.edu/peat (citado en las páginas 41)

Urrútia, G., y Bonfill, X. (2010). Declaración PRISMA: Una Propuesta para Mejorar la Publicación de Revisiones Sistemáticas y Metaanálisis. *Medicina Clínica*, *135*(11), 507–511. doi: 10.1016/j.medcli.2010.01.015 (citado en las páginas 6)

Waki, A. L., Fujiyoshi, G. S., y Almeida, L. D. (2015). Games Accessibility for Deaf People: Evaluating Integrated Guidelines. En *International Conference on Universal Access in Human-Computer Interaction* (pp. 493–504). Springer, Cham. doi: 10.1007/978-3-319-20684-4_48 (citado en las páginas 21)

Western Washington University. (2019). *Western Digital Accessibility*. Descargado 2019-11-03, de https://access.wwu.edu/ (citado en las páginas 19)

Westin, T., Ku, J., Dupire, J., y Hamilton, I. (2018). Game Accessibility Guidelines and Wcag 2.0–a Gap Analysis. En *International Conference on Computers Helping People with Special Needs* (pp. 270–279). Springer, Cham. doi: 10.1007/978-3-319-94277-3_43 (citado en las páginas 21)

Wilson, A., y Crabb, M. (2018). W3C Accessibility Guidelines for Mobile Games. *The Computer Games Journal*, *7*(2), 49–61. doi: 10.1007/s40869-018-0058-7 (citado en las páginas 21)

World Health Organization. (2001). *Clasificación Internacional del Funcionamiento, de la Discapacidad y de la Salud*. World Health Organization. Descargado de https://aspace.org/assets/uploads/publicaciones/e74e4-cif_2001.pdf (citado en las páginas 56)

World Health Organization. (2016). *Discapacidades*. World Health Organization. Des-

cargado 2019-10-28, de https://www.who.int/topics/disabilities/es/ (citado en las páginas 56)

World Health Organization. (2017). *10 Facts on Disability.* World Health Organization. Descargado 2020-10-22, de https://www.who.int/features/factfiles/disability/en/ (citado en las páginas V, IX)

World Health Organization. (2019). *Blindness and Vision Impairment.* Descargado 2020-10-22, de https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment (citado en las páginas 36, 59)

World Wide Web Consortium. (1997). *World Wide Web Consortium Launches International Program Office for Web Accessibility Initiative.* (Disponible en https://www.w3.org/Press/IPO-announce) (citado en las páginas VI, X)

World Wide Web Consortium. (2008). *Web Content Accessibility Guidelines 2.0.* Descargado de https://www.w3.org/TR/WCAG20/ (citado en las páginas 4, 5, 19, 20)

World Wide Web Consortium. (2014). *Website Accessibility Conformance Evaluation Methodology (WCAG-EM) 1.0.* Descargado 2019-09-15, de https://www.w3.org/TR/WCAG-EM/ (citado en las páginas 6)

World Wide Web Consortium. (2015). *Media Accessibility User Requirements.* Descargado de http://w3c.github.io/apa/media-accessibility-reqs/ (citado en las páginas 4)

World Wide Web Consortium. (2016). *User Agent Accessibility Guidelines (UAAG) Overview.* Descargado 2019-06-06, de https://www.w3.org/WAI/intro/uaag (citado en las páginas 4)

World Wide Web Consortium. (2018). *Web Content Accessibility Guidelines (WCAG) 2.1.* Descargado 2019-10-01, de https://www.w3.org/TR/WCAG21/ (citado en las páginas VI, VII, X, 20, 51)