UNIVERSIDAD COMPLUTENSE DE MADRID

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MEJORANDO LA ACCESIBILIDAD DE LOS *SERIOUS GAMES* MEDIANTE HERRAMIENTAS DE AUTORÍA

MEMORIA PARA OPTAR AL GRADO DE DOCTOR PRESENTADA POR

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Bajo la dirección de los doctores

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"Tenemos el deber moral de eliminar los obstáculos a la participación y de invertir fondos y conocimientos suficientes para liberar el inmenso potencial de las personas con discapacidad. Los gobiernos del mundo no pueden seguir pasando por alto a los cientos de millones de personas con discapacidad a quienes se les niega el acceso a la salud, la rehabilitación, el apoyo, la educación y el empleo, y a los que nunca se les ofrece la oportunidad de brillar"

Prof. Stephen W Hawking.

Resumen

Los juegos digitales (término paraguas que abarca tanto videojuegos como juegos de ordenador y para dispositivos móviles) se han convertido en un fenómeno sociocultural y económico. En los últimos años este fenómeno ha traspasado la frontera del ámbito lúdico, permeando en otros entornos como la educación, dando origen a lo que informalmente se conoce como *serious games* (juegos digitales aplicados con propósito no lúdico). La desventaja de los *serious games* es que su nivel de accesibilidad es muy bajo, lo que pone a las personas con discapacidad en riesgo de exclusión. El problema es especialmente relevante cuando los juegos digitales se introducen en el aula, puesto que la educación constituye un derecho fundamental para el desarrollo de todos los seres humanos.

La baja accesibilidad de los *serious games* se debe en gran medida al esfuerzo que supone para los desarrolladores, que deben realizar múltiples adaptaciones en el diseño e interfaz del juego, así como desarrollar nueva tecnología (p.ej. motores de síntesis de voz) para adecuar el juego a las necesidades de las personas con discapacidad. Es por esto que esta tesis considera al *desarrollador* como una pieza esencial sobre la que trabajar para aumentar el nivel de accesibilidad de los *serious games*.

En este sentido, la principal aportación de esta tesis es la propuesta de una serie de características de accesibilidad configurables que pueden integrarse en herramientas de creación de juegos digitales, a fin de facilitar la creación de juegos digitales accesibles en general, y *serious games* en particular. También se ha desarrollado una implementación de estas características sobre la herramienta eAdventure a modo de prueba de concepto, junto con tres casos de estudio que han sido evaluados por usuarios y expertos.

El enfoque seguido tiene principalmente dos ventajas. En primer lugar, se reduce el esfuerzo que los desarrolladores necesitan invertir para hacer que un juego sea accesible para personas con discapacidad. En segundo lugar, se aumenta la visibilidad del problema de la accesibilidad entre la comunidad de desarrolladores, gracias a la integración en sus herramientas de trabajo diario, lo que también ayuda a mejorar su concienciación en referencia a este problema.

Abstract

Digital games, defined as an umbrella term encompassing computer games, videogames and mobile games, have become a socio-cultural and economic phenomenon. In recent years, digital games have also transcended the boundaries of the entertainment field reaching areas like education, giving rise to what is informally known as *serious games* (digital games applied with a purpose). One of the current limitations of *serious games* is that their level of accessibility is still low, which poses a significant risk of digital divide for people with disabilities. The problem is especially relevant when digital games are introduced in the classroom, since education is a universal right indispensable for the full development of all human beings.

We believe the lack of accessible *serious games* is a consequence of the effort dealing with accessibility entails for the game developer, who has to make numerous adaptations in design and interface and produce new technology (e.g. text-to-speech engines) to cater for the needs of people with disabilities. Therefore, in this dissertation the developer is considered an essential stakeholder to work with in order to increase the level of accessibility of *serious games*.

In this regard, the main contribution of this PhD dissertation is the proposal of a set of configurable accessibility features (conceptual model) that can be integrated in popular digital game creation tools, in order to facilitate the development of accessible digital games in general, and *serious games* in particular. A prototype of this conceptual model has been developed and integrated into the eAdventure tool, which has been used to produce three case studies that have been evaluated by users and experts alike.

Overall, this approach has two main advantages. First, it reduces the effort that developers need to invest to make a game accessible for people with disabilities. Second, it helps raise awareness among the developer community about the special needs of people with disabilities, since accessibility is given visibility in the own tools they use daily.

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Acerca de este documento

Este trabajo es presentado como una recopilación de publicaciones editadas, de acuerdo a la sección 4.4[1] de la Normativa de desarrollo en la Universidad Complutense de Madrid del Real Decreto 1393/2007, de 29 de Octubre (BOE 30 de octubre de 2007[2]), por el que se establece la ordenación de las enseñanzas universitarias oficiales, aprobada por el Consejo de Gobierno de la UCM a 14 de Octubre de 2008, publicada en el BOUC el 20 de Noviembre de 2008 y modificado por la Comisión Permanente del Consejo de Gobierno con fecha de 29 de Octubre de 2010. Los artículos presentados son los siguientes:

- Torrente J, Freire M, Moreno-Ger P, Fernández-Manjón B. **Evaluation of Semi-automatically Generated Accessible Interfaces for Educational Games**. Computers & Education [JCR-SCI 2,775 2012; 15/100 Categoría *Computer Science, Interdisciplinary Applications*] (En proceso de revisión, enviado julio 2014).

- Torrente J, Del Blanco Á, Moreno-Ger P, Fernández-Manjón B. **Designing Serious Games for Adult Students with Cognitive Disabilities.** En: Huang T, Zeng Z, Li C, Leung C (editors). Neural Information Processing, Lecture Notes in Computer Science Volume 7666 [Internet]. Springer Berlin Heidelberg; 2012. p. 603–10. http://dx.doi.org/10.1007/978-3-642-34478-7_73.

- Torrente J, Del Blanco Á, Moreno-Ger P, Martínez-Ortiz I, Fernández-Manjón B. **Accessible Games and Education: Accessibility Experiences with eAdventure**. En: Carmen Mangiron, Pilar Orero MO, (editores). *Fun for All: Translation and Accessibility Practices in Video Games*. Bern, Switzerland: Peter Lang AG, International Academic Publishers; 2014. p. 67–90. ISBN 978-3-0343-1450-3.

- Torrente J, Del Blanco Á, Moreno-Ger P, Martínez-Ortiz I, Fernández-Manjón B. **Implementing Accessibility in Educational Videogames with <e-Adventure>**. Primer ACM international workshop on Multimedia technologies for distance learning - MTDL '09 [Internet]. Pekín, China: ACM Press; 2009. p. 57–66. Disponible en línea en: http://portal.acm.org/citation.cfm?doid=1631111.1631122.

- Torrente J, del Blanco Á, Serrano-Laguna Á, Vallejo-Pinto JA, Moreno-Ger P, Fernández-Manjón B. **Towards Universal Game Development in Education: Automatic and Semiautomatic Methodologies**. Advances in Web-Based Learning - ICWL 2012. Springer; 2012; Lecture Notes in Computer Science 7558:160–9.

[1] http://pendientedemigracion.ucm.es/bouc/completos/2008/14.pdf
[2] http://www.boe.es/boe/dias/2007/10/30/pdfs/A44037-44048.pdf

- Torrente J, del Blanco Á, Serrano-Laguna Á, Vallejo-Pinto J, Moreno-Ger P, Fernández-Manjón B. **Towards a low cost adaptation of educational games for people with disabilities.** Comput Sci Inf Syst [JCR-SCI 0,549 2012; 97/132 Categoría *Computer Science, Information Systems*]. 2014; 11(1):369–91. Disponible online desde: http://www.doiserbia.nb.rs/Article.aspx?ID=1820-02141400013T

- Torrente J, Marchiori E, Vallejo-Pinto JA, Ortega-Moral M, Moreno-Ger P, Fernández-Manjón B. **Eyes-free Interfaces for Educational Games**. 8º Simposio Internacional en Informática Educativa (SIIE). *IEEE*. Andorra la Vella (Andorra); 2012. p. 1–6.

- Torrente J, Marchiori E, Vallejo-Pinto JA, Ortega-Moral M, Moreno-Ger P, Fernández-Manjón B. (2013): **Evaluation of Three Accessible Interfaces for Educational Point-and-Click Computer Games**. Aceptado para su publicación en Journal of Research and Practice in Information Technology (JRPIT), En prensa, vol 46. [JCR-SCI 0,222 2012; Computer Science, Software Engineering 99/105].

- Torrente J, Serrano-Laguna Á, del Blanco Á, Moreno-Ger P, Fernández-Manjón B (2013): **Development of a Game Engine for Accessible Web-Based Games**. Games And Learning Alliance Conference (GALA) 2013, 23-25 October 2013, Paris, France.

- Moreno-Ger P, Torrente J, Hsieh YC, Lester WT (2012): **Usability Testing for Serious Games: Making Informed Design Decisions with User Data**. Advances in Human-Computer Interaction, vol. 2012, Article ID 369637, 13 pages. doi:10.1155/2012/369637.

- Torrente J (2012): **Reusable Game Interfaces for People with Disabilities**. 14th ACM SIGACCESS International Conference on Computers and Accessibility (ASSETS), 22-24 octubre 2012, Boulder, Colorado.

- Torrente J (2013): **Supporting Player Diversity: Game Interfaces for People with Disabilities.** Enviado a la fase final mundial (*Grand Finals*) del *ACM Student Research Competition 2013*. Disponible en: http://src.acm.org/2013/JavierTorrente.pdf.

De acuerdo a la normativa, este documento incluye una introducción, un estudio del estado del arte en el dominio, una descripción de los objetivos propuestos para esta tesis y una discusión integrando los contenidos de los doce artículos incluidos, relacionándolos con los objetivos mencionados. Adicionalmente, se presenta un capítulo en el que se aportan unas breves conclusiones y se sugieren unas líneas de trabajo futuro. Finalmente se incluye un resumen amplio de la tesis en inglés, los artículos en su formato original, y una bibliografía que integra y complementa las referencias de los artículos incluidos en esta tesis doctoral.

Estructura del trabajo

El núcleo de este trabajo es una recopilación de publicaciones editadas que se reproducen en su totalidad en el último capítulo. Los capítulos previos integran y comentan las contribuciones de cada uno de los artículos.

El trabajo está estructurado de la siguiente manera:

- Capítulo 1. Introducción y motivación.
- Capítulo 2. Estudio del dominio.
- Capítulo 3. Objetivos y planteamiento del trabajo.
- Capítulo 4. Discusión y contribuciones.
- Capítulo 5. Conclusiones y trabajo futuro.
- Capítulo 6. Resumen amplio en inglés.
- Capítulo 7. Artículos presentados.

Las referencias bibliográficas completas se encuentran a continuación del último capítulo.

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Capítulo 1: Introducción y Motivación

En este capítulo se introduce la motivación de esta investigación (sección 1.1) que da origen a la propuesta inicial de objetivos de esta tesis doctoral (sección 1.2). Finalmente se incluye una breve nota aclaratoria sobre la terminología relacionada con la discapacidad utilizada en esta tesis doctoral (sección 1.3).

1.1. Motivación de la investigación

El acceso a la educación es un derecho universal reconocido por la Declaración Universal de Derechos Humanos en su artículo 26 (Naciones Unidas, 1948). Esto abarca también, como no podía ser de otra manera, a las personas con discapacidad, cuyo derecho a la educación también ha sido reconocido de forma explícita por Naciones Unidas a través del artículo 24 de la Convención sobre los Derechos de las Personas con Discapacidad (Naciones Unidas, 2006). Sin embargo, es un hecho contrastado que a nivel mundial las personas con discapacidad tienen numerosos obstáculos para acceder a servicios como la salud y la educación, tal y como expresa el Informe mundial sobre Discapacidad realizado por la Organización Mundial de la Salud (OMS) y el Banco Mundial (2011). Aunque pueda parecer un problema que alude a una minoría, lo cierto es que más de mil millones de personas viven con algún tipo de discapacidad (de nuevo, según datos de la Organización Mundial de la Salud), definido como un término amplio que incluye cualquier lesión temporal o persistente que afecte a una estructura o función corporal y que suponga una limitación o dificultad para ejecutar acciones o tareas, y/o restrinja la participación del individuo en situaciones vitales. Esta cifra, en constante crecimiento por el envejecimiento de la población mundial así como por el aumento de las enfermedades crónicas, acrecienta la importancia de buscar soluciones a un problema ya de por sí relevante.

Es interesante analizar las implicaciones que esto tiene en una sociedad altamente dependiente de la tecnología, lo que también tiene su reflejo en el ámbito educativo. La creciente penetración de la tecnología en la educación a todos los niveles puede agravar el riesgo de exclusión ya existente para las personas con discapacidad. Esto implica que es necesario considerar la accesibilidad de las nuevas tecnologías que se introducen en el aula como un requisito indispensable, a fin de no poner en riesgo los derechos de las personas con discapacidad.

Este debería ser el caso de los denominados *serious games*, anglicismo referido a aquellos juegos digitales que tienen un propósito más allá de lo lúdico (Sara de Freitas & Oliver, 2006). Nótese que el término se define de una manera muy amplia, abarcando bajo su paraguas aplicaciones de juegos digitales en campos tan diversos como la salud (Akl et al., 2013; Arnab, Dunwell, & Debattista, 2012; Brox, Fernandez-Luque, & Tøllefsen, 2011; Rosser et al., 2007), el marketing (Pempek & Calvert, 2009) o la investigación (Cooper et al., 2010). No obstante, uno de los principales campos de aplicación de los *serious games* hasta la fecha es el ámbito educativo, dónde se plantean como un medio efectivo para aumentar la implicación de los alumnos en su propio aprendizaje (M D Dickey, 2005; Kirriemur & McFarlane, 2004; Michael & Chen, 2006) gracias a su alta capacidad de generar inmersión (S De Freitas, 2006; Dede, 2009; James Paul Gee, 2003), lo que en última instancia produce un aprendizaje más significativo y duradero (a veces también denominado aprendizaje permanente), y/o un mayor rendimiento académico (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Hwang & Wu, 2012; Perrotta, Featherstone, Aston, & Houghton, 2013), entre otros beneficios. Su eficacia cuando se diseñan e implementan de forma adecuada ha sido contrastada ampliamente mediante evidencia experimental (Annetta, Minogue, Holmes, & Cheng, 2009; Barzilai & Blau, 2013; Cheng, Su, Huang, & Chen, 2013; Hainey et al., 2013; Papastergiou, 2009; Tuzun, Yilmazsoylu, Karakus, Inal, & Kizilkaya, 2009). Esta última acepción, la que asocia el término *serious games* al campo educativo, es la que se usará en el marco de este trabajo de tesis.

Llama la atención por tanto la escasa atención que se ha prestado hasta la fecha a garantizar la plena accesibilidad de los *serious games*, al igual que a otros materiales multimedia (Abrahams, 2010), teniendo en cuenta que las últimas previsiones de los expertos apuntan a que el uso de los *serious games* se extenderá progresivamente en los próximos años hasta convertirse en una herramienta más a disposición de los profesores de todos los niveles del sector educativo (Johnson et al., 2013; Johnson, Adams, & Cummins, 2012). De hecho, la accesibilidad de los juegos digitales en general, independientemente de que su propósito sea lúdico o educativo, sigue siendo claramente insuficiente, según indican expertos en la materia (Bierre et al., 2004, 2005; Westin, Bierre, Gramenos, & Hinn, 2011; Yuan, Folmer, & Harris, 2011).

En gran medida la baja accesibilidad de los juegos digitales (y por ende, de los *serious games*) está relacionada con el impacto que la accesibilidad tiene en los desarrolladores de juegos digitales. En primer lugar, la accesibilidad plantea una carga extra, tanto en diseño como en implementación, lo que aumenta su coste de producción. Los juegos son aplicaciones cuyo éxito radica entre otras cuestiones en una interactividad mucho mayor que en otros contenidos (J P Gee, 2007). Este plus de interactividad hace que considerar aspectos de accesibilidad sea mucho más costoso que con aplicaciones de otro tipo (Grammenos, Savidis, & Stephanidis, 2009). Por otro lado, la accesibilidad complica de manera casi exponencial el diseño del juego, una tarea que ya de por sí es un arte que requiere de experiencia y creatividad a partes iguales, pues debe combinar de manera equilibrada diferentes estrategias a fin de llegar a un público diverso y con distintas motivaciones (Egenfeldt-Nielsen, 2007). Por ejemplo, hay jugadores cuya motivación para jugar a un determinado juego digital radica en superar todos los retos tanto principales como secundarios que el juego les plantea (*achievers*, en inglés), mientras que otros buscan más la socialización con otros jugadores o se sienten atraídos por la narrativa conductora del juego (Yee, 2006). En este contexto la accesibilidad supone un añadido de diversidad, pues cada persona con discapacidad puede tener necesidades diferentes y/o requerir sus propias adaptaciones, incluyendo pero sin limitarse a la dificultad general de los puzles, el lenguaje utilizado o la narrativa que da sentido al juego, por dar algunos ejemplos. Por este motivo pocos de los escasos juegos digitales disponibles con características de accesibilidad incluyen soporte para más de los dos o tres tipos de discapacidad más comunes. Por otro lado, también es necesario resolver retos técnicos como la integración y/o desarrollo de tecnologías complejas y costosas como pueden ser módulos de conversión de texto a voz o la producción de hardware especial (controladores de juegos adaptados) (Bierre et al., 2004).

El sobrecoste que implican estas tareas adicionales es asumible únicamente en proyectos de gran envergadura, normalmente ligados al ámbito del entretenimiento. Rara vez en proyectos ligados a la educación, donde el presupuesto es limitado. De hecho, hay voces que abogan por que el impulso a los *serious games* debe realizarse desde la austeridad y la optimización de costes a fin de lograr una penetración mayor (F A S, 2006).

Otro factor que suele indicarse como causa de la baja accesibilidad de los juegos digitales es la falta de formación y de concienciación de los desarrolladores en materia de accesibilidad (Heron, 2012). Sólo así puede entenderse que se lancen al mercado con frecuencia juegos con accesibilidad intermitente o con barreras de accesibilidad de fácil resolución (Archambault, Gaudy, Miesenberger, Natkin, & Ossmann, 2008; Ossmann, Archambault, & Miesenberger, 2008). Un caso muy conocido, por ejemplo, es el del videojuego *Half Life*™, publicado en 1998 por *Valve*™ y que recibió numerosas críticas desde la comunidad de personas con problemas de audición porque se proporcionaba información imprescindible para completar el juego únicamente a través de audio. A raíz de estas críticas, el estudio decidió incluir subtitulado oculto[3] (*Closed Captioning*) de manera consistente en la secuela publicada en 2004, *Half Life 2* (ver Figura 1), así como en las que vendrían en los años siguientes.

1.2. Objetivos de la línea de investigación

La línea de investigación en la que se enmarca este trabajo de tesis trata de mejorar la accesibilidad de los *serious games* siguiendo un enfoque eminentemente práctico y centrado en el *desarrollador* como figura esencial del proceso. Por *enfoque centrado en el desarrollador* nos referimos a que tratamos de proporcionar soluciones a los problemas que experimentan los desarrolladores referentes a la introducción de accesibilidad en los juegos anteriormente descritos: (1) aumento del esfuerzo y coste de desarrollo, de manera inasumible en muchos casos y (2) falta de formación y concienciación, poniendo especial énfasis en el primero. Para ello el trabajo se ha centrado, por diversas razones, en las herramientas que utilizan los desarrolladores para crear los juegos. Primero, porque consideramos que todo enfoque centrado en el desarrollador debe tener un carácter eminentemente práctico. Los modelos puramente teóricos

[3] El subtitulado oculto es una técnica avanzada de subtitulado dirigida a personas con discapacidad auditiva, y que trata de integrar información en los subtítulos que permita comprender cualquier estímulo sonoro, lo que incluye efectos de sonido (disparos, por ejemplo) además de los diálogos locutados.

que no tengan buenas herramientas de soporte están, bajo esta óptica, abocadas al fracaso, pues no suponen una ventaja real para el desarrollador en el desempeño de su actividad diaria. En segundo lugar, las herramientas que los desarrolladores utilizan para crear juegos digitales son para ellos entornos amigables y de lenguaje e interfaz conocidos, por lo que parecen una vía de ataque al problema adecuada.

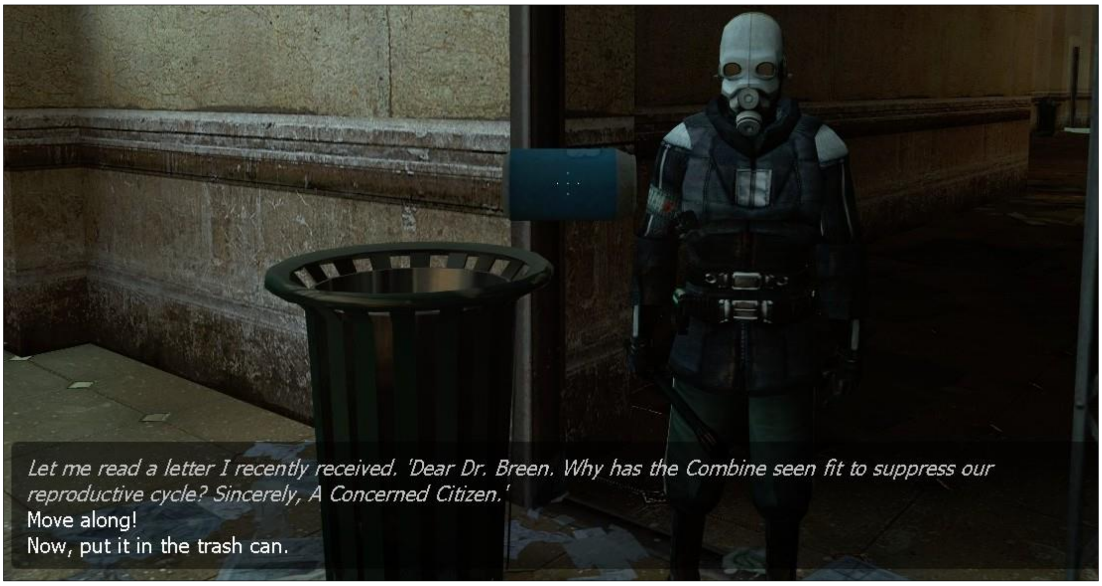

Figura 1. Captura de pantalla del juego *Half Life 2*™, © *Valve*, 2004, mostrando la funcionalidad de subtitulado oculto (*Closed Captions*). (Imagen obtenida de https://developer.valvesoftware.com/wiki/Closed_Captions)

Una de las estrategias que nos parece más prometedora de las propuestas para reducir el coste asociado a la accesibilidad (aunque no es la única) consiste en la adaptación automática (o semiautomática) del juego, fundamentalmente de su interfaz. Ésta es, además, la que hemos explorado en mayor profundidad en este trabajo de tesis. La generación y adaptación automática de interfaces de usuario es un campo con recorrido desde hace décadas y que ha proporcionado buenos resultados en distintos ámbitos, incluyendo el educativo (Boutekkouk, Tolba, & Okab, 2011; Chen & Magoulas, G. D., 2005; Falb et al., 2009). Este tipo de técnicas también se ha aplicado en juegos digitales, aunque el desafío es mucho mayor por la complejidad de sus interfaces de usuario (Robin, 2005). En este caso se han combinado fundamentalmente aspectos de procesamiento del lenguaje natural con adaptaciones del *pipeline* gráfico.

Dada la complejidad y heterogeneidad del área en la que se enmarca este trabajo de tesis, se ha seguido una metodología de trabajo iterativa y basada en casos de estudio, con el objetivo de lograr un refinamiento progresivo de las características de accesibilidad propuestas así como de las pruebas de concepto implementadas.

El enfoque y resultados de esta línea de investigación pueden aplicarse en principio a cualquier tipo de juego digital, independientemente de cuál sea su propósito. No obstante, el trabajo se ha enfocado al campo educativo por ser un derecho fundamental de cada individuo, tal y como se ha discutido anteriormente, y por ser un campo en el que tanto el autor como los directores tienen una dilatada experiencia desde 2008 (del Blanco, Marchiori, Torrente, Martínez-Ortiz, & Fernández-Manjón, 2013; Moreno-Ger, Burgos, Martínez-Ortiz, Sierra, & Fernández-Manjón, 2008; Moreno-Ger, Burgos, & Torrente, 2009; Torrente, Del Blanco, Cañizal, Moreno-Ger, & Fernández-Manjón, 2008; Torrente, Lavín-Mera, Moreno-Ger, & Fernández-Manjón, 2008; Torrente, Moreno-Ger, & Fernández-Manjón, 2008; Torrente, Borro-Escribano, et al., 2014; Torrente, Moreno-Ger, Martínez-Ortiz, & Fernández-Manjón, 2009).

Dada la diversidad de tipos de juegos digitales existente, y a fin de mantener el alcance del trabajo dentro de los límites razonables, el enfoque se ha centrado en juegos tipo aventura gráfica *point-and-click*[4], cuya efectividad en términos educativos está contrastada (Amory, Naicker, Vincent, & Adams, 1999; M D Dickey, 2005; Garris, Ahlers, & Driskell, 2002), y que plantea menos problemas de accesibilidad que otros tipos de juego por utilizar mecánicas de juego con presión por tiempo menos frecuentemente.

De esta manera, una vez contextualizado el enfoque adoptado, se concluye planteando los objetivos fundamentales identificados para esta tesis, que se desarrollarán en profundidad en la sección 3.1:

1. Proponer un conjunto de características de accesibilidad que puedan integrarse en herramientas de creación de juegos para facilitar la introducción de características de accesibilidad en *serious games* tipo aventuras *point-and-click* (Modelo conceptual).

Este modelo se desarrolla primero en *anchura*, tratando de abarcar en la propuesta soluciones para las principales necesidades de los tipos de discapacidad más común (ver sección 1.3), y luego en *profundidad*, proponiendo distintas soluciones alternativas para un tipo de discapacidad concreto (ceguera en este caso).

Una vez cumplido el primer objetivo, se plantea el siguiente, a fin de evaluar el modelo conceptual propuesto:

2. Implementar una prueba de concepto sobre una herramienta de creación de juegos concreta (Implementación).

En este caso la prueba de concepto se ha desarrollado sobre la herramienta eAdventure de creación de juegos educativos tipo *point-and-click*, que tiene una complejidad razonable, un modelo explícito de juego e interfaz, así como una comunidad de usuarios estable.

A partir de esta implementación que sirva de prueba de concepto se plantea el penúltimo objetivo de la tesis:

[4] Tipo de juegos muy popular en la década de los 90 (ejemplos: *Monkey Island*™, © *LucasArts*™) en los que el jugador, ya sea en primera persona o a través de un personaje avatar que éste controla, va descubriendo la historia en la que se ven inmersos los personajes mediante la resolución de problemas y acertijos de distinta índole. La denominación *point-and-click* proviene de la mecánica de interacción más frecuentemente utilizada en estos juegos, basada en el uso del ratón.

3. Evaluar la adecuación del modelo propuesto (ver objetivo 1) mediante el desarrollo de casos de estudio y su posterior análisis de usabilidad incluyendo usuarios con discapacidad (Usabilidad).

Finalmente se identifica la necesidad de estimar cuál es el coste (expresado en términos de esfuerzo) asociado a la introducción de características de accesibilidad en un juego concreto, a fin de poder determinar su efectividad real desde un punto de vista práctico. Esto se formaliza a través del último objetivo:

4. Analizar el coste asociado a la introducción de las características de accesibilidad identificadas en un juego completo, a fin de valorar si el enfoque produce una reducción significativa de esfuerzo asociado a la accesibilidad en juegos digitales para el desarrollador del juego (Evaluación final).

Por último, cabe destacar que este trabajo de tesis nace del proyecto INREDIS y de la colaboración establecida a partir del mismo con *Technosite*, empresa del grupo Fundosa (ONCE) líder en tecnologías accesibles y discapacidad, canalizada fundamentalmente a través de Lourdes González Perea, Directora de Tecnologías Accesibles e I+D+i.

1.3. Nota sobre tipos de discapacidad

El mundo de la discapacidad es muy amplio y complejo, y puede abordarse desde distintos ángulos. Rara vez se abordan múltiples discapacidades de una vez por las necesidades tan diferentes que presentan los usuarios según su discapacidad.

No existe además una única clasificación sobre tipos de discapacidad. Es por esto que en accesibilidad resulta necesario comenzar definiendo cada uno de los términos que se utilizarán para referirse a distintos perfiles de discapacidad. Para este trabajo, trataremos de utilizar siempre la siguiente terminología y clasificación, basándonos en el tipo de adaptación que cada usuario suele necesitar para interactuar con dispositivos de computación (PC, smartphones, etc.) en general y con juegos digitales en particular:

- Ceguera: Por usuarios ciegos nos referimos a personas que necesitan la ayuda de un software lector de pantalla (por ejemplo *JAWS*™[5]) para utilizar cualquier dispositivo de computación (PC, smartphone, etc.).
- Visión limitada: los usuarios con visión limitada son aquellos que por lo general necesitan herramientas de ampliación de pantalla, tamaños de fuente mayores y una combinación de colores de alto contraste.

[5] Popular producto de apoyo para personas con ceguera: http://www.freedomscientific.com/Products/Blindness/Jaws

- Movilidad reducida: nos referiremos con este término a aquellos usuarios con discapacidad motriz que afecte a las extremidades superiores (manos), imposibilitando el uso del ratón o de una pantalla táctil como dispositivos de entrada. Estos usuarios necesitan utilizar software de reconocimiento de voz para interactuar con un dispositivo de computación.

- Discapacidad auditiva: Aquellos usuarios que requieren reemplazar o complementar el retorno de información en forma de audio mediante estímulos visuales.

- Discapacidad cognitiva: Entenderemos el término discapacidad cognitiva de una manera amplia, abarcando en general a usuarios con discapacidad intelectual, del desarrollo o relacionadas con el aprendizaje. Dichos usuarios suelen requerir de un ritmo de juego más lento, así como de un ajuste en la dificultad planteada por los puzles, retos e historia del juego.

Somos conscientes de que esta clasificación puede considerarse una simplificación incluso excesiva, ya que las discapacidades se pueden presentar de forma combinada o con características muy específicas en cada persona. El propósito es únicamente proporcionar una terminología común y consistente para el trabajo en base a las adaptaciones más comunes que necesita cada grupo de usuarios.

Capítulo 2: Estudio del dominio

En este capítulo se analizan distintos aspectos que son relevantes para la temática y enfoque del presente trabajo de tesis. En primer lugar se aborda el campo de la creación de juegos digitales, haciendo especial hincapié en las herramientas y metodologías existentes (sección 2.1). A continuación se analiza el estado del arte en materia de accesibilidad en entornos Web en general y de e-learning (aplicación de tecnologías de la información y comunicación a la educación) en particular (sección 2.2). Esta discusión es relevante pues sirve como referencia para evaluar el nivel de accesibilidad de los juegos digitales y *serious games*.

El grueso de este capítulo lo conforman las secciones 2.3 y 2.4. En la sección 2.3 se realiza un análisis general de los distintos enfoques a la accesibilidad en juegos digitales de los que se tiene constancia hasta la fecha, destacando por un lado los enfoques *ad-hoc* que se centran en juegos y discapacidades concretas (sección 2.3.1), y por otro lado los enfoques más universales o generalistas (sección 2.3.2). En la sección 2.4 se aporta un análisis del campo desde una óptica diferente y complementaria, pues se estudian las principales barreras a las que se enfrentan las personas a la hora de interactuar con juegos digitales según su discapacidad y las principales estrategias propuestas para su resolución, así como un breve resumen sobre la cantidad y tipo de juegos disponibles.

En la sección 2.5 se analiza cómo se ha evaluado hasta la fecha la accesibilidad de los juegos digitales, un aspecto que es relevante según los objetivos definidos en el primer capítulo. El capítulo se cierra con una sección (2.6) de conclusiones que resume el estado del dominio.

Cabe destacar que no se pretende hacer un estudio exhaustivo sino considerar aquellas propuestas que se consideran más prometedoras.

2.1. La diversificación de los juegos digitales y sus herramientas de creación

De cara a contextualizar el presente trabajo de tesis es necesario realizar un breve repaso a la multitud de enfoques existentes sobre creación de juegos digitales (sección 2.1.2). Esta gran variedad de herramientas surgen como respuesta a la diversificación experimentada por un sector en constante crecimiento. Por ello, antes de abordar el aspecto de su creación, en esta sección se revisa el actual impacto de los juegos digitales y su diversificación (sección 2.1.1).

2.1.1. Diversificación de los juegos digitales y su impacto socioeconómico

No es ningún secreto que los juegos digitales, en todas sus variantes, han sufrido una rápida expansión tanto a nivel social como económico, hasta conformar una de las principales industrias del entretenimiento. Teniendo en cuenta únicamente datos del mercado de Estados Unidos, el sector ha pasado de facturar 2.600 millones de dólares en 1996 (73,8 millones de unidades vendidas) a 11.700 millones en 2008 (casi 300 millones de unidades vendidas) según datos de la *Entertainment Software Association*[6] (ESA, 2009), si bien es cierto que en los últimos años ha sufrido un retroceso moderado (ESA, 2014) como fruto de la crisis económica y del incremento de precios (Sharkey, 2010). Esta expansión ha llevado a algunos autores a proponer los videojuegos como una nueva forma de arte y cultura contemporánea (J P Gee, 2007; Goldberg, 2011).

El crecimiento de los juegos digitales como fenómeno sociocultural y económico ha provocado una lógica diversificación del sector, siendo la oferta actual de juegos digitales diversa y adaptada a todos los gustos, plataformas y bolsillos. Aunque las grandes producciones AAA[7], cuyo coste de producción puede llegar a superar los 100 millones de dólares actualmente (según estimaciones)[8] siguen teniendo una gran cuota de mercado, otras fórmulas consiguen abrirse paso, como el desarrollo independiente (*Indie*) que ha encontrado en los *smartphones* y tabletas una plataforma idónea para llegar al consumidor. El caso más significativo es probablemente el de *Flappy Bird* (ver Figura 2), un popular juego desarrollado por una única persona para las plataformas Android y iOS que llegó a recaudar, según estimaciones, hasta 50.000 dólares al día en ingresos por publicidad[9] antes de su retirada de los mercados de aplicaciones.

Como se analizaba en el primer capítulo de este trabajo, también se han diversificado los dominios en los que se utilizan los juegos digitales, que progresivamente han conseguido traspasar la frontera del entretenimiento y permear en dominios como la salud, la publicidad o la investigación, dando origen al término *serious games* (juegos digitales aplicados con un propósito más allá de lo recreacional). Por ejemplo, el juego *Re-mission*™, disponible para su descarga de manera gratuita[10], ha sido utilizado con gran éxito para mejorar la actitud que adolescentes con cáncer se enfrentan a su enfermedad (Kato, Cole, Bradlyn, & Pollock, 2008). En (Pempek & Calvert, 2009) se describe cómo el uso de un *advergame*[11] fue efectivo a la hora de mejorar los hábitos alimenticios de sectores desfavorecidos de la población. El juego *FoldIt!*™ (ver Figura 3) ha sido uno de los más impactantes de los últimos años (sus resultados fueron publicados en la revista *Nature*). Este juego multijugador online ha sido capaz de involucrar a

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[6] Asociación que agrupa a los principales desarrolladores de juegos digitales a nivel mundial.
[7] En la industria de los juegos digitales se utiliza el término AAA para referirse a las producciones con mayor presupuesto de desarrollo y marketing, que suelen copar las listas de juegos más vendidos.
[8] http://kotaku.com/how-much-does-it-cost-to-make-a-big-video-game-1501413649
[9] http://www.cnet.com/news/no-flappy-bird-developer-didnt-give-up-on-50000-a-day/
[10] http://www.re-mission.net/get-the-game/
[11] Término que hace referencia a juegos que se crean con el propósito de publicitar un determinado producto o servicio.

más de medio millón de jugadores[12] en el descubrimiento de nuevas proteínas, demostrando que se puede utilizar el atractivo de los juegos digitales para resolver problemas científicos complejos (Cooper et al., 2010). Otro ejemplo en la misma línea es *EyeWire*[13], que tiene como objetivo realizar un mapeado 3D de las estructuras neuronales del cerebro de forma colaborativa y masiva.

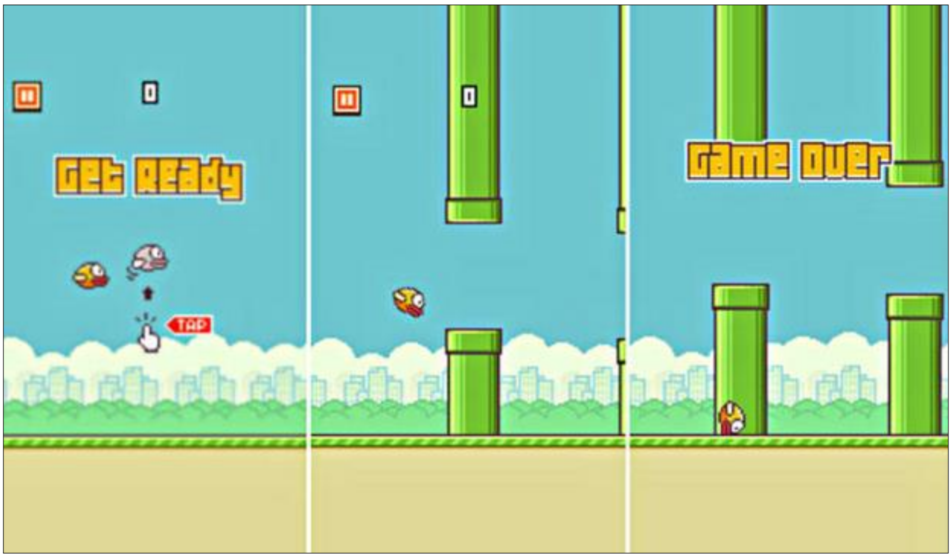

Figura 2. Imagen del popular juego digital para plataformas móviles *Flappy Bird*. Este sencillo juego consiguió una gran popularidad, lo que reportó grandes beneficios para su creador. Imagen obtenida de cnet.com.

No obstante, uno de los campos en el que más impacto han tenido los juegos digitales es el educativo, ámbito donde el término *serious games* ha alcanzado una mayor relevancia. La investigación en teorías o metodologías educativas basadas en juegos digitales, de una u otra forma, ha crecido exponencialmente en los últimos años (Hwang & Wu, 2012), proporcionando una evidencia mayor y más sólida sobre su efectividad a la hora de desarrollar habilidades de resolución de problemas (Hwang, Wu, & Chen, 2012; Sánchez & Olivares, 2011; Spires, Rowe, Mott, & Lester, 2011) conocimiento complejo tanto procedimental (Cheng et al., 2013) como conceptual (Sadler, Romine, Stuart, & Merle-Johnson, 2013), aumentar la motivación intrínseca e implicación de los alumnos (Tuzun et al., 2009) y reducir las tasas de abandono (Sancho, Torrente, & Fernández-Manjón, 2012), entre otros beneficios.

Su penetración en todos los niveles del sistema educativo también ha aumentado, aunque a un ritmo quizás más moderado (Johnson et al., 2013; Mcclarty, Frey, & Dolan, 2012; Perrotta et al., 2013), destacando aplicaciones en áreas tan variopintas como la química (Rastegarpour & Marashi, 2012), biología (Annetta et al., 2009), programación (Chen & Cheng, 2007; Papastergiou, 2009; Resnick et al., 2009; Sancho, Fuentes-Fernández, & Fernández-Manjón, 2009), ciencias, matemáticas y tecnología (Mayo, 2009), técnicas de escritura (Michele D.

[12] Estimación a fecha de julio de 2014. Incluye usuarios inactivos.
[13] https://eyewire.org/signup

Dickey, 2011), idiomas (Smith et al 2011), comunicación intercultural (Guillén-Nieto & Aleson-Carbonell, 2012), *soft skills*[14] (Schrier, 2005), resucitación cardiopulmonar (Marchiori et al., 2012) o ciencias de la salud (Akl et al., 2013; Rosser et al., 2007).

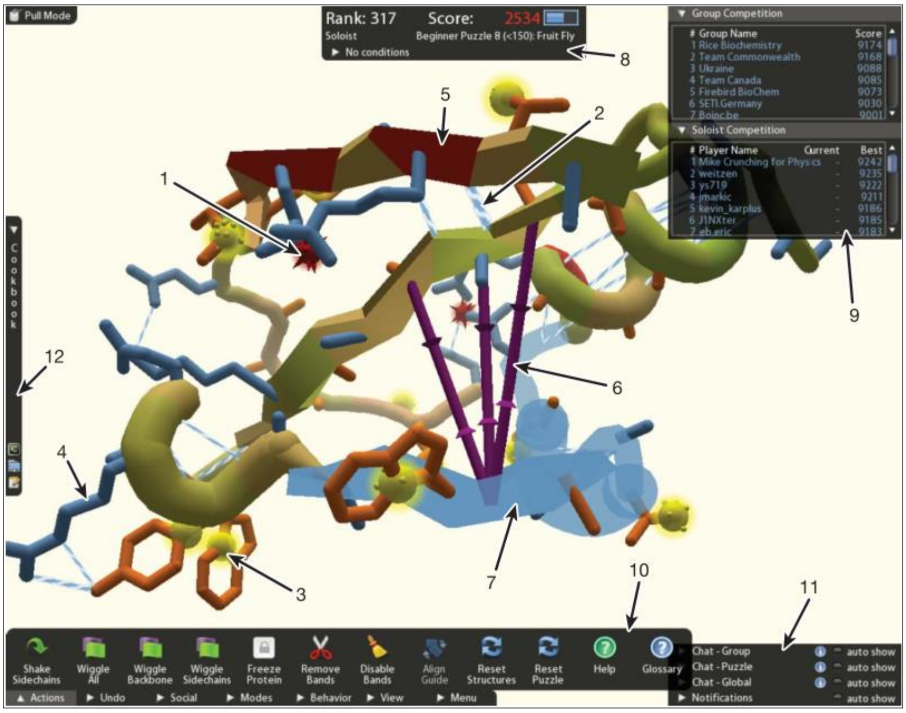

Figura 3. Captura del juego para descubrimiento de nuevas proteínas *FoldIt!* Imagen obtenida de *(*Cooper et al., 2010*)*. © Macmillan Publishers Limited

Esto no quiere decir que el campo de los *serious games* esté libre de detractores y que no tenga todavía problemas pendientes de resolución (Dondlinger, 2007; Hays, 2005). Uno de los más relevantes de los identificados hasta la fecha es su elevado coste de producción (Adkins, 2013), inasumible en muchos entornos educativos. Para lograr una penetración aún mayor en el sector educativo parece imprescindible proponer nuevas fórmulas y modelos de *serious games* así como metodologías de desarrollo que permitan reducir su coste (Torrente et al., 2014).

Tampoco resultan igual de adecuados todos los tipos de juegos digitales para su aplicación en educación. Aunque muchos géneros diferentes presentan potencial pedagógico, los juegos con alto contenido narrativo, tales como los juegos de aventuras, son más fáciles de alinear con objetivos educativos (Amory et al., 1999; Garris et al., 2002). Esto se debe a que en estos juegos suele predominar la reflexión sobre la acción, lo que favorece el desarrollo de habilidades de resolución de problemas y el pensamiento creativo. Al disponer de un ritmo menos vivo estos juegos también presentan menos barreras desde el punto de vista de la accesibilidad, pues la

[14] Término que suele asociarse con habilidades dependientes de la inteligencia emocional del individuo, que son muy difíciles de adquirir y que resultan determinantes en el ámbito profesional moderno, como la capacidad de liderazgo, la habilidad para causar empatía en otras personas o de entablar comunicaciones efectivas.

presión por tiempo es menor, lo que favorece que personas con distintas capacidades puedan responder de forma adecuada a los distintos eventos del juego.

2.1.2. Desarrollo de juegos digitales: enfoques y herramientas

Como respuesta a la expansión y diversificación de los juegos digitales, también ha aumentado el número de enfoques y herramientas disponibles para su creación. Cabe destacar que, independientemente del enfoque que se adopte, el desarrollo de un juego digital se ha convertido en una actividad compleja y que requiere de una delicada combinación de habilidades multidisciplinares (Blow, 2004). El desafío es aún mayor si se pretende que el juego tenga un propósito educativo, pues es necesario equilibrar la parte lúdica y la parte educativa del juego (Moreno-Ger, Burgos, Sierra, & Fernández-Manjón, 2008).

Queda fuera del alcance de este trabajo realizar un análisis en profundidad de todas las herramientas de creación de juegos digitales existentes. Existen repositorios de herramientas donde el lector puede obtener listados y descripciones mucho más detallados[15]. El propósito de esta sección es por tanto identificar los tipos de herramientas existentes a fin de poder contextualizar mejor el trabajo realizado. Este breve análisis se estructura en orden de mayor a menor alcance y complejidad.

2.1.2.1. Herramientas AAA

Las herramientas más complejas son las que tienen como objetivo el desarrollo de los juegos de mayor calidad. En estos casos es más correcto hablar de conjuntos o ecosistemas de herramientas, pues los proyectos más ambiciosos requieren de software optimizado para cada uno de los componentes claramente diferenciados del juego (inteligencia artificial, física, niveles, animación, etc.) y para cada uno de los roles intervinientes en el proceso (programadores, diseñadores, artistas y probadores). Entre otras herramientas, estos entornos suelen integrar:

- Un motor de juegos[16] muy completo y que proporciona la funcionalidad necesaria que necesitará el juego durante su ejecución. Sobre el motor se proporcionan distintas herramientas de autoría que permiten crear contenido procesable por el motor o configurar diferentes aspectos del mismo. Este motor suele ir dirigido a programadores con experiencia en desarrollo de juegos, y habitualmente incluyen funcionalidades tales como[17]:
    - Gestión de entrada / salida (partidas guardadas, p.ej.)

[15] http://creatools.gameclassification.com/EN/creatools/index.html
[16] El motor es el componente de software fundamental que se encarga de ejecutar los juegos, y que proporciona funcionalidad básica a tal efecto.
[17] La arquitectura de un motor de juegos de última generación puede consultarse a través del siguiente enlace: http://www.gameenginebook.com/figures.html

- Comunicación de red (modos multijugador, conexión con servidores remotos, etc.)
- Carga y procesamiento de recursos artísticos (modelos 3D, imágenes, texturas, sonidos, animaciones, etc.)
- Renderizado en pantalla y efectos visuales
- Detección y gestión de colisiones
- Iluminación y gestión de cámaras
- Gestión de física
- Desarrollo multiplataforma (Web / PC / Mac / Android / iOS).

- Herramientas de autoría para configurar niveles. Van dirigidas a diseñadores que no tienen por qué tener conocimientos avanzados de programación y permiten la creación de los distintos niveles del juego en un formato que el motor luego será capaz de interpretar.

- Herramientas de autoría para crear recursos artísticos y animaciones (ver Figura 4). Van dirigidas a artistas y animadores, perfiles normalmente alejados de los entresijos de la programación.

- Herramientas de autoría para crear scripts (ver Figura 5). Van dirigidas a diseñadores responsables de la narrativa del juego, y permiten generar secuencias complejas de eventos sin necesidad de tener conocimientos avanzados de programación de videojuegos.

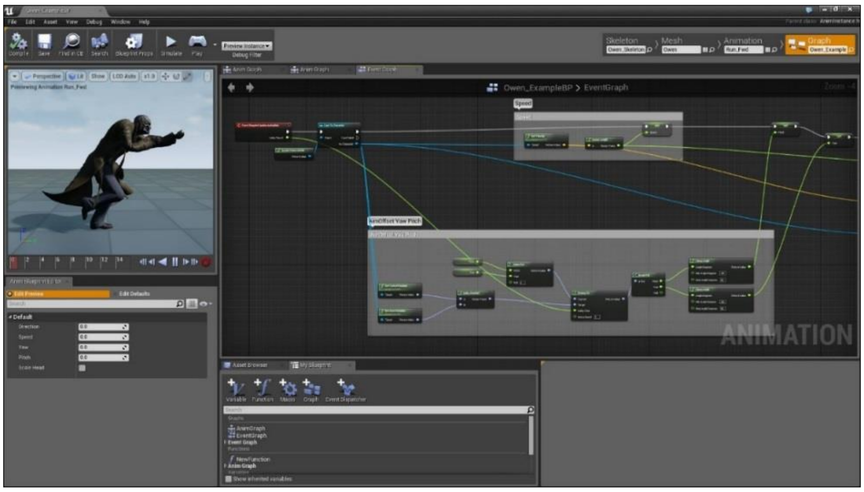

Figura 4. Captura del editor de animaciones *Persona*™, proporcionado junto con el entorno *Unreal Engine 4* ™. © Epic games.

Dos de los ejemplos más relevantes son *Unreal Engine*™[18] y *CryEngine*™[19]. Ambos entornos surgen de la expansión y comercialización de las herramientas creadas durante el desarrollo de dos videojuegos de éxito (*Unreal*™ y *FarCry*™ respectivamente), sucesivamente mejoradas, y proporcionan funcionalidades y características similares (soporte multiplataforma, por ejemplo). Los dos entornos proporcionan distintas variantes con distintos términos de licencia, aunque el coste de las licencias más avanzadas (necesarias para los desarrollos más ambiciosos) son elevados (por ejemplo, *Unreal4*™ obtiene el 5% de la facturación total del producto).

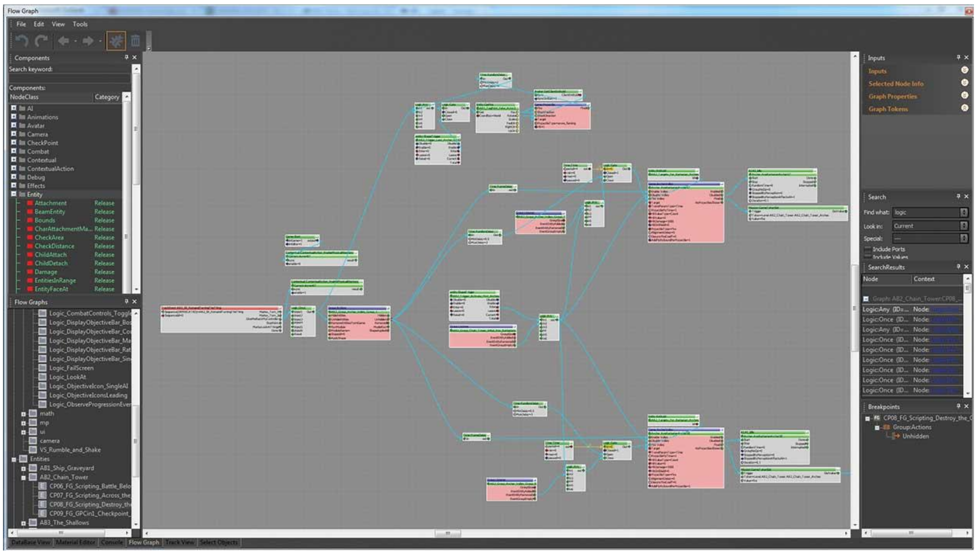

Figura 5. Captura del editor de scripts *Flow Graph*™ que proporciona el entorno *CryEngine*™. © Crytek GmbH.

2.1.2.2. Herramientas para el desarrollo semi-profesional y amateur

Las herramientas presentadas en 2.1.2.1 son muy potentes pero al mismo tiempo inaccesibles en la mayor parte de los desarrollos, tanto por coste como por complejidad. Existe otro abanico de herramientas más asequibles que permiten la creación de juegos de gran calidad, que son las que suelen utilizarse en proyectos semi-profesionales o amateur con equipos de trabajo más reducidos y donde el grado de especialización es mucho menor. También ha proliferado su uso en entornos profesionales, por ejemplo en empresas dedicadas al desarrollo de juegos para plataformas móviles.

Estas herramientas pueden ser tanto comerciales como libres y gratuitas, y la variedad es muy amplia. Una de las más populares, *Unity*™[20] (ver Figura 6), proporciona una única herramienta de autoría integrada que permite la configuración de todos los aspectos del juego. Comparte algunas características con los entornos AAA, como la exportación multiplataforma de los

[18] https://www.unrealengine.com/
[19] http://cryengine.com/
[20] http://unity3d.com/

juegos (videoconsolas, PC, Mac, Web y dispositivos móviles). Estas herramientas suelen orientarse más hacia programadores, dejando en un segundo plano aspectos como la creación de recursos artísticos, que suele realizarse con otras herramientas (*Maya*™, *3DStudio*™, etc.).

Figura 6. Imágenes del entorno integrado de creación de juegos *Unity*™. © Unity Technologies.

En este segmento también existen productos que no proporcionan herramientas de autoría como tal, centrándose en la tecnología de más bajo nivel y cercana al programador. Estos productos incluyen motores, frameworks y librerías relacionadas con los juegos digitales, que pueden ser tanto comerciales como libres, y suelen estar pensados para que el programador trabaje con ellos a través del entorno integrado de desarrollo de su elección (*Eclipse*™, *NetBeans*™, *IntelliJ*™, *Visual Studio*™, etc.). Algunos ejemplos son *LibGdx*™[21], *Ogre3D*™[22] o *Allegro*™[23]. En general, la complejidad de todas estas herramientas sigue siendo alta, acorde a su amplia funcionalidad, requiriendo de conocimientos avanzados de programación de juegos digitales.

2.1.2.3. Herramientas para el ámbito educativo: eAdventure.

Existen herramientas que, a costa de sacrificar algo de potencial y funcionalidad, tratan de simplificar los procesos de creación de juegos para acercarlos a un público menos experto. Éste es el caso de algunas de las herramientas que se han desarrollado a fin de abastecer el mercado educativo. Estas herramientas se dirigen a profesores y alumnos, y tiene por objetivo permitirles crear juegos sencillos pero con alto valor educativo. En muchos de estos casos se plantea la creación de juegos digitales como una actividad colaborativa y enriquecedora para los alumnos. Uno de los primeros ejemplos fue la herramienta *GameMaker™*, desarrollada por Mark Overmars y que se utilizó durante años con gran éxito en la enseñanza de conceptos relacionados con la programación (Overmars, 2004), aunque probablemente el más conocido

[21] http://libgdx.badlogicgames.com/
[22] http://www.ogre3d.org/
[23] http://alleg.sourceforge.net/

es el de la herramienta *Scratch*™[24], que trata de facilitar que niños y jóvenes aprendan a programar mediante la creación de videojuegos (Resnick et al., 2009).

Estas herramientas tienen en común utilizar un lenguaje asequible y libre de tecnicismos, así como abstraer los aspectos de más bajo nivel (por ejemplo, la sintaxis concreta de los lenguajes de programación), que son reemplazados por metáforas fácilmente reconocibles por los usuarios. Por ejemplo, *Scratch*™ utiliza una representación basada en bloques como metáfora para el concepto de instrucción de programación.

A fin de simplificar la edición, es común que estas herramientas se centren en tipos o géneros de juegos específicos con alto valor educativo, pues esto reduce la curva de aprendizaje de las herramientas y las vuelve más asequibles para el público objetivo. Este es el caso de la herramienta *eAdventure*[25], desarrollada por el grupo e-UCM (Moreno-Ger, Burgos, Sierra, et al., 2008; Torrente, Del Blanco, Marchiori, Moreno-Ger, & Fernández-Manjón, 2010) y que ha sido utilizado como entorno de pruebas para este trabajo de tesis por su licencia libre LGPL. eAdventure trata de acercar la creación de *serious games* a la comunidad educativa. Se centra en juegos 2D, especialmente en aventuras *point-and-click*, por su alto valor educativo y relativa facilidad de creación. eAdventure ha sido utilizado en la creación de distintos juegos educativos, cuya efectividad ha sido comprobada mediante su despliegue y evaluación en distintos escenarios (Torrente, Borro-Escribano, et al., 2014). Además, los juegos desarrollados con eAdventure se representan con un modelo explícito, siguiendo un enfoque documental a la creación de aplicaciones (Moreno-Ger, Sierra, Martínez-Ortiz, & Fernández-Manjón, 2007), lo que favorece su inspección y análisis en busca de problemas de accesibilidad, por ejemplo.

Es importante destacar, por ser de relevancia para este trabajo de tesis, que actualmente existen dos versiones muy claramente diferenciadas de eAdventure. La primera, eAdventure 1.5 (ver Figura 7), es una versión estable de un producto lanzado hace ya siete años. La segunda, eAdventure 2.0 (ver Figura 8), es una versión completamente renovada y actualizada tecnológicamente que está actualmente en fase de desarrollo. La mayor parte del trabajo ha sido realizado sobre eAdventure 1.5 como plataforma objetivo, aunque parte también se ha llevado a cabo sobre eAdventure 2.0.

2.2. Accesibilidad en la Web, en entornos de e-Learning, y legislación vigente

Teniendo en cuenta que los entornos de e-learning son principalmente sistemas basados en la web (véanse por ejemplo entornos virtuales de enseñanza como *Moodle*™, *Blackboard*™ o

[24] http://scratch.mit.edu/
[25] http://e-adventure.e-ucm.es/

Sakai™), realizar un análisis sobre el estado de la accesibilidad en e-learning pasa por analizar la accesibilidad de la Web en general en primera instancia.

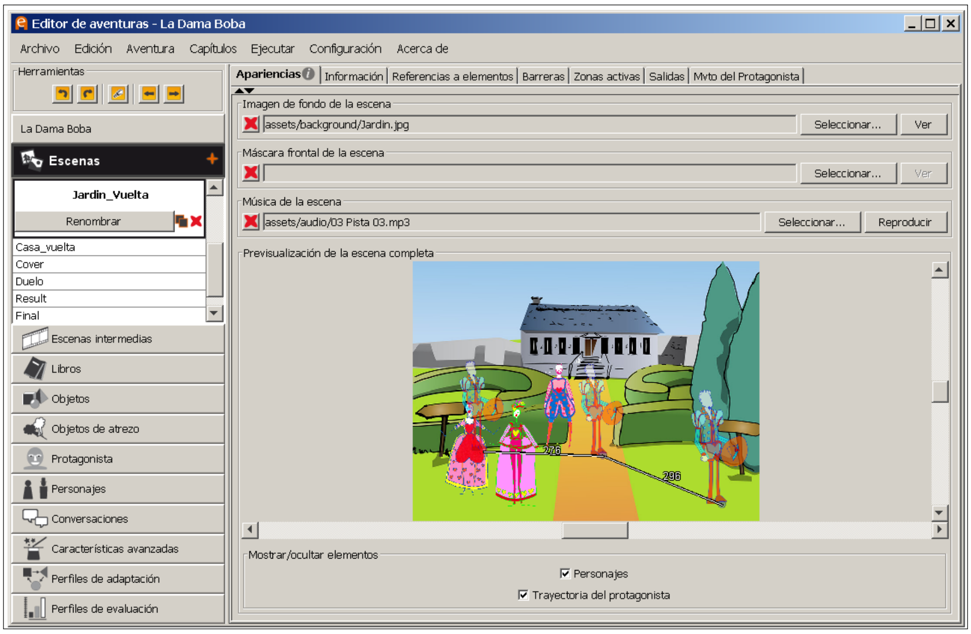

Figura 7. Captura de la herramienta de creación de *serious games* eAdventure 1.5 (versión estable).

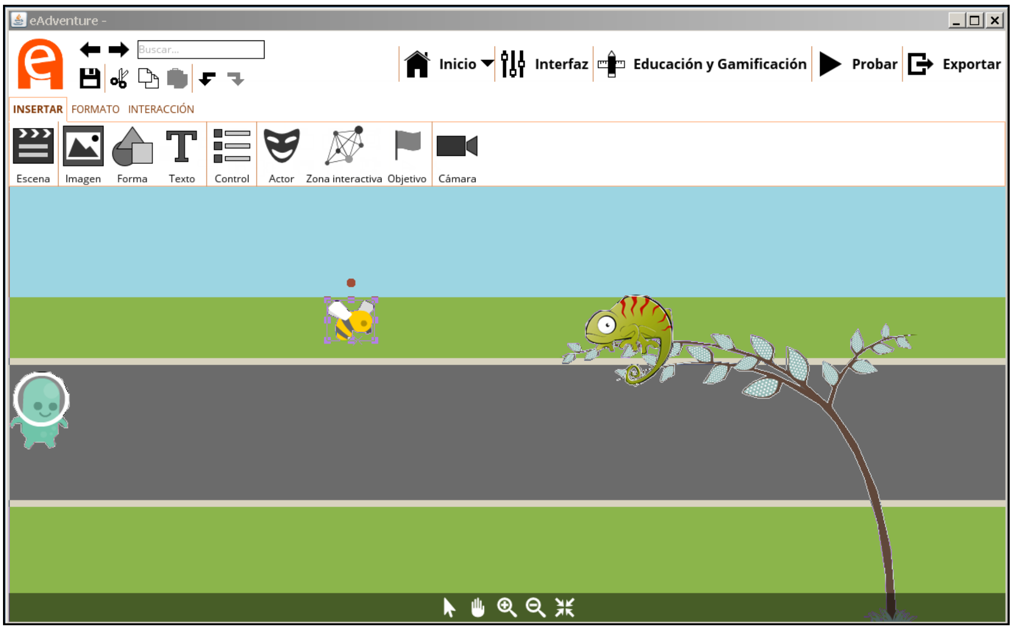

Figura 8. Captura de la herramienta eAdventure 2.0 (versión actualmente en desarrollo).

Los entornos de e-learning se han beneficiado de los esfuerzos impulsados por diversas organizaciones públicas y privadas para mejorar la accesibilidad de la web. Organizaciones muy influyentes como el W3C[26] se han dedicado intensivamente a identificar los requisitos necesarios para crear contenido web accesible a través de su Iniciativa de Accesibilidad Web (*Web Accessibility Initiative - WAI*). WAI incluye pautas y técnicas para el desarrollo y evaluación de aplicaciones Web accesibles de diversa índole. Esta iniciativa se desarrolla a través de distintas líneas de acción orientadas a proporcionar especificaciones y recomendaciones sobre accesibilidad específicas para ámbitos concretos. Éstas son algunas de las más relevantes, cuyo título se expone en inglés por simplicidad:

- **Web Content Accessibility Guidelines (WCAG)** (W3C, 2008). Este conjunto de recomendaciones, cuya versión más reciente data de 2008 (2.0) tiene el carácter de *W3C recommendation* y su propósito es ayudar a los desarrolladores de contenido Web a crear contenido más accesible para personas de un amplio rango de discapacidades. Este estándar es probablemente el más maduro y aceptado por la comunidad dentro de los que lidera W3C. WCAG proporciona doce directrices prácticas, organizadas en torno a cuatro principios de accesibilidad básicos:

    - **Perceptible** (*perceivable*): todos los usuarios deben poder percibir toda la información proporcionada, así como los componentes de la interfaz de usuario, a través de alguno de sus sentidos.

    - **Manejable** (*operable*): todos los usuarios deben ser capaces de manejar los controles de la interfaz usuario (que no debe requerir ninguna interacción que el usuario no sea capaz de realizar).

    - **Comprensible** (*understandable*): tanto la información como los controles deben ser comprensibles para todos los usuarios.

    - **Robusto** (*robust*): el contenido proporcionado debe ser robusto a evoluciones de los productos y tecnologías de apoyo (p.ej. sistemas de control por voz), de tal manera que siempre sea procesable por distintos agentes de usuario (*user agents*). El objetivo de este principio es garantizar la compatibilidad del contenido con los productos de apoyo.

  Además WCAG proporciona elementos para facilitar la verificación del cumplimiento de cada una de las directrices en una escala de tres niveles (A, AA y AAA), así como estrategias para asegurarse del correcto cumplimiento de la misma (ver Figura 9).

[26] Acrónimo de World Wide Web Consortium (W3C), consorcio internacional en el que participan expertos y organismos públicos y privados dedicado a proponer estándares abiertos que aseguren el crecimiento sostenible de la Web.

Media Alternative (Prerecorded)

1.2.8 An alternative for time-based media is provided for all prerecorded synchronized media and for all prerecorded video-only media. *(Level AAA)* Understanding Success Criterion 1.2.8

Sufficient Techniques for 1.2.8 - Media Alternative (Prerecorded)

Note: Other techniques may also be sufficient if they meet the success criterion .

Situation A: If the content is prerecorded synchronized media:

1. G69: Providing an alternative for time based media using one of the following techniques
   - G58: Placing a link to the alternative for time-based media immediately next to the non-text content
   - SL17: Providing Static Alternative Content for Silverlight Media Playing in a MediaElement (Silverlight)
2. Linking to the alternative for time-based media using one of the following techniques
   - H53: Using the body of the object element (HTML)

Situation B: If the content is prerecorded video-only:

1. G159: Providing an alternative for time-based media for video-only content

Advisory Techniques for 1.2.8 - Media Alternative (Prerecorded)

- H46: Using noembed with embed (HTML)
- Providing a corrected script (future link)
- Adding detail to audio description (future link)

Failures for SC 1.2.8 - Media Alternative (Prerecorded)

- F74: Failure of Success Criterion 1.2.2 and 1.2.8 due to not labeling a synchronized media alternative to text as an alternative

Figura 9. Ejemplo de uno de los aspectos que abarca la segunda directriz de WCAG 2.0 (1.2, *Time-based media*). Para cada aspecto se proporciona una descripción, la escala a la que pertenece (AAA), así como una selección de estrategias para cumplir la directriz (*sufficient and advisory techniques*) y de indicadores de incumplimiento (*failures*). Obtenido de: http://www.w3.org/TR/2008/REC-WCAG20-20081211/.

- **Accessible Rich Internet Applications (WAI-ARIA)** (W3C, 2014). Esta iniciativa acaba de adquirir el estatus de *W3C recommendation* (versión 1.0), y se centra en proporcionar recomendaciones para conseguir una mayor interoperabilidad dentre aplicaciones y contenidos dinámicos desarrollados con tecnologías como AJAX y Javascript y los productos de apoyo que utilizan las personas con discapacidad, especialmente lectores de pantalla.

- **User Agent Accessibility Guidelines (UAAG)** (W3C, 2002), que tiene también el carácter de *W3C recommendation*, aborda los aspectos de accesibilidad de los agentes de usuario, es decir, los navegadores que utilizan los usuarios para navegar, independientemente de la modalidad elegida.

- **Authoring Tool Accessibility Guidelines (ATAG) 2.0** (W3C, 2013). Esta iniciativa, que no tiene todavía el carácter de *W3C recommendation*, pero que está en proceso de revisión final, tiene como objetivo proporcionar recomendaciones que permitan crear herramientas de autoría que sean más accesibles para los creadores de contenido con discapacidad y que al mismo tiempo generen contenido accesible para los usuarios. Esta iniciativa se estructura en dos partes de acuerdo a su doble propósito:

- **Parte A:** Accesibilidad en herramientas de autoría Web.
- **Parte B:** Accesibilidad del contenido producido con herramientas de autoría Web.

Las iniciativas lideradas por el W3C han dado origen, de manera directa o indirecta, a diferentes herramientas cuyo objetivo es facilitar el desarrollo de contenido y aplicaciones que cumplan con los estándares de accesibilidad. Esto incluye sobre todo herramientas que detectan problemas potenciales de accesibilidad y evalúan el nivel de cumplimiento del estándar WCAG 2.0. Sólo en la página oficial de W3C se listan más de 100[27]. Estas herramientas permiten no sólo identificar problemas asociados a la accesibilidad de manera rápida e intuitiva (ver Figura 10), sino que además proporcionan recomendaciones sobre cómo resolverlas en algunos casos.

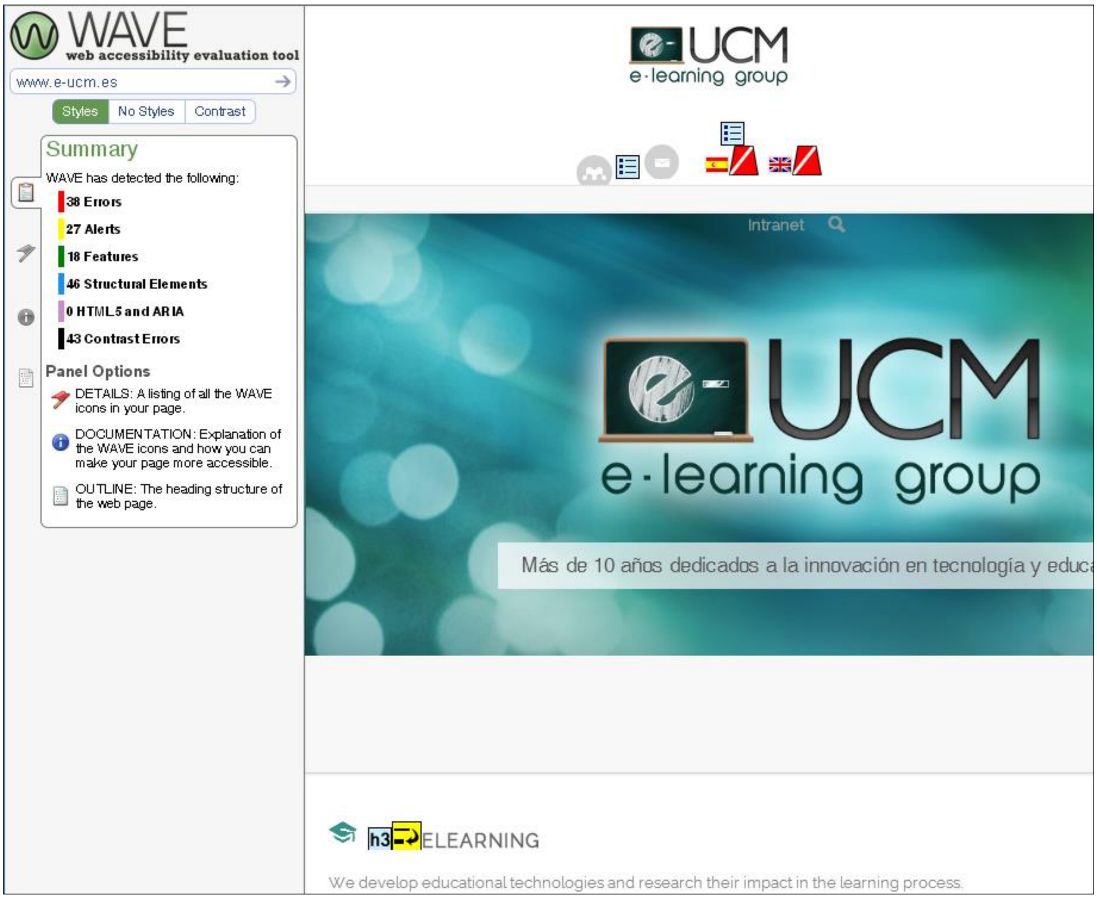

Figura 10. Informe de accesibilidad de la página web www.e-ucm.es proporcionado por la herramienta online WAVE (*Web Accessibility Evaluation Tool*), disponible en http://wave.webaim.org/. La herramienta muestra un informe con potenciales problemas

[27] http://www.w3.org/WAI/ER/tools/complete

identificados, ordenados por severidad, y marcados sobre la propia página con iconos descriptivos de varios colores.

La madurez del dominio de la accesibilidad Web se refleja en su impacto en la legislación existente. Muchos países desarrollados, como Estados Unidos (iniciativa *section 508*[28]), Alemania (iniciativas BITV1.0 y 2.0[29]) o Italia (Stanca Act[30]), por poner algunos ejemplos, han creado normativas de obligado cumplimiento que regulan las características de accesibilidad que deben cumplir los productos y servicios que proporciona el estado a través de la Web. España también ha legislado al respecto a través de varias las leyes 34/2002, de 11 de julio, ley 51/2003, de 2 de diciembre, la norma UNE 139803:2004 y la ley 11/2007, entre otras. Léase por ejemplo el siguiente fragmento de la ley 34/2002 de 11 de julio, disposición adicional quinta, artículo 1:

> *"Las Administraciones Públicas adoptarán las medidas necesarias para que la información disponible en sus respectivas páginas de Internet pueda ser accesible a personas con discapacidad y de edad avanzada de acuerdo con los criterios de accesibilidad al contenido generalmente reconocidos antes del 31 de diciembre de 2005. Asimismo, podrán exigir que las páginas de Internet cuyo diseño o mantenimiento financien apliquen los criterios de accesibilidad antes mencionados."*

También hay iniciativas que tienen que ver específicamente con contenidos y tecnologías digitales educativas. Uno de las iniciativas más completas es *IMS Access for All*[31], liderada por la organización *IMS Global Consortium*, que abarca un conjunto de estándares para identificar las necesidades especiales de los alumnos con discapacidad en los entornos de e-learning y para etiquetar las características de accesibilidad de los materiales empaquetados como objetos de aprendizaje (IMS Global Consortium, 2004, 2005), y que ya va por la tercera versión. Esto facilita que los sistemas de e-learning presenten a cada alumno actividades y contenidos que se adapten a sus necesidades. Un enfoque similar es el estándar ISO/IEC 24751-1:2008, desarrollado por la Organización Internacional de Normalización (ISO). Otras iniciativas más particulares y de menor calado se han centrado en analizar el nivel de accesibilidad de los sistemas de e-learning más populares (Freire, Power, Petrie, Tanaka, & Fortes, 2009; Minović, Štavljanin, Milovanović, & Starčević, 2008) y en su mejora (Sclater, 2008).

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[28] http://www.section508.gov/

[29] http://www.bitvtest.eu/bitv_test/intro/overview.html

[30] http://www.pubbliaccesso.it/normative/law_20040109_n4.htm

[31] http://www.imsglobal.org/accessibility/#afav3

2.3. Enfoques a la accesibilidad de juegos digitales

Aunque la accesibilidad de los juegos sea todavía insuficiente, el interés en este campo ha experimentado un crecimiento considerable en los últimos años a través de iniciativas de diversa índole provenientes fundamentalmente desde sectores de usuarios con discapacidad y del ámbito académico. No es el propósito de este documento realizar un análisis en detalle de las mismas, pues para ello existen análisis del estado del arte mucho más completos y cuya consulta se recomienda al lector que quiera ampliar su conocimiento sobre la materia. En concreto se recomiendan los análisis llevados a cabo por Yuan et al (2011) y Westin et al (2011). Por el contrario, lo que en esta sección se proporciona es una visión de alto nivel de los distintos enfoques observados hasta la fecha, agrupados en dos grandes bloques cuyo análisis es fundamental para contextualizar el enfoque seguido en este trabajo de tesis:

- *Enfoques ad-hoc* (sección 2.3.1). Son trabajos que han abordado la accesibilidad en juegos concretos (lúdicos o serios), teniendo en cuenta un conjunto limitado de discapacidades.

- *Enfoques generalistas* (sección 2.3.2). Este conjunto de trabajos aborda el problema desde una perspectiva más amplia, tratando de proporcionar recomendaciones, directrices y/o herramientas aplicables a un conjunto de juegos más amplio.

Esta subsección se cierra con un análisis de iniciativas relacionadas con el hardware y los productos de apoyo (sección 2.3.3), que aunque tienen menos relación con el presente trabajo de tesis, son relevantes por su peso específico en el campo.

2.3.1. Enfoques *ad-hoc*

El enfoque *ad-hoc*, en el que se estudia cómo mejorar la accesibilidad de un juego digital concreto (normalmente teniendo en cuenta una discapacidad o un conjunto limitado de discapacidades), es el más común. Esto es esperable dado lo incipiente del campo de la accesibilidad en juegos digitales que, aunque con marcha firme, apenas ha dado sus primeros pasos. Hacer juegos universalmente accesibles es un tema muy complejo, que implica llevar a cabo actuaciones de distinta índole en varios aspectos del juego, como la producción de versiones adaptadas de los recursos artísticos (p.ej. imágenes en alto contraste, varias versiones de los sonidos utilizando un lenguaje adecuado para personas con distintas capacidades), la integración de los principios de diseño universal (CAST, 2011; Hitchcock & Stahl, 2003) en el diseño del juego (historia, puzles, mecánica, etc.), o la ampliación de la funcionalidad de la tecnología de soporte subyacente (motores de juego, *frameworks* y librerías) con características como reconocimiento de voz, renderizado adaptado a personas con problemas de visión, o soporte para interacción simplificada utilizando uno o varios pulsadores, por citar unos pocos ejemplos (Ossmann et al., 2008). Todo este proceso de adaptación depende en gran medida del género del juego (p.ej. *First Person Shooters*, aventura, deportes, etc.) y los tipos específicos de discapacidad que se consideren (Grammenos, Savidis, & Stephanidis, 2007). En muchos casos las adaptaciones realizadas para un juego concreto no son escalables a otros juegos, incluso del mismo género o de naturaleza similar, ni desde el punto de vista de las soluciones técnicas desarrolladas ni de los enfoques conceptuales propuestos. La desventaja es que no se pueden reutilizar, parcial o totalmente, las soluciones propuestas cuando se acometen nuevos proyectos.

Dentro de los enfoques *ad-hoc*, la mayoría opta por considerar la accesibilidad *a priori* (desde el comienzo del diseño y desarrollo), siguiendo normalmente metodologías de desarrollo centradas en usuario (Pagulayan, Keeker, Wixon, Romero, & Fuller, 2003) e involucrando a los usuarios finales (personas con discapacidad) de manera directa (Grammenos et al., 2007). Algunos de los trabajos más relevantes en esta línea son los liderados por Gutschmidt, Schiewe, Zinke, & Jürgensen (2010), que desarrollaron un Sudoku háptico (táctil) para personas ciegas (ver Figura 11), o por el grupo *FORTH* en Grecia, que ha desarrollado desde *Pongs* accesibles para ciegos hasta juegos de acción (Grammenos, Savidis, Georgalis, & Stephanidis, 2006; Grammenos, Savidis, & Stephanidis, 2005; Savidis, Stamou, & Stephanidis, 2007). Otro ejemplo muy relevante, por ser además pionero, es el juego *Terraformers*[32], un *First Person Shooter* desarrollado por Thomas Westin y que tiene entre sus principales innovaciones un modo en alto contraste para personas con visión limitada y un modo acústico para personas ciegas. (Nota: Este caso se analizará con más detalle en secciones posteriores por ser de gran influencia para este trabajo de tesis).

Considerar la accesibilidad *a priori* tiene ventajas claras. En las primeras etapas de desarrollo es más fácil modificar tanto el diseño del juego (por ejemplo, los diálogos, puzles, mecánicas, interfaz de usuario, etc.) como la tecnología subyacente (por ejemplo, el motor de juego, los productos de apoyo integrados como el motor de síntesis de texto a voz, etc.), lo que permite obtener una experiencia de usuario más personalizada y compatible con las necesidades de los jugadores con discapacidad. Sin embargo, este enfoque también tiene sus inconvenientes. Considerar la accesibilidad *a priori* puede complicar a veces el desarrollo y aumentar el coste de producción, ya que requiere mantener diversas ramas de desarrollo desde el comienzo. La complejidad de este problema se incrementa cuantos más tipos de discapacidad se tienen en cuenta.

En otros muchos casos la accesibilidad se considera *a posteri*. Esto es, una vez que existe un juego completo y funcional disponible, pero sin características de accesibilidad. Cuando se aplica este enfoque suele ser por dos razones. En primer lugar, porque se pretenda añadir accesibilidad a un juego ya disponible, circunstancia ciertamente común pues los juegos que gozan de una mayor popularidad no suelen incluir características de accesibilidad. Precisamente por su alta popularidad existe una gran demanda por parte de la comunidad de jugadores con discapacidad para conseguir versiones adaptadas de los mismos. Algunos ejemplos de juegos adaptados para personas con discapacidad siguiendo este enfoque son *Blind Hero™* (adaptación del popular juego *Guitar Hero™* de *Activision™*, ver Figura 12) (Yuan & Folmer, 2008), *Audio*

[32] http://terraformers.nu/

Quake™, (adaptación del mítico *First Person Shooter* de *idSoftware*™) (Atkinson, Gucukoglu, Machin, & Lawrence, 2006) o *RockVibe*™ (modificación del juego *RockBand*™ de *Harmonix*™ combinando realimentación acústica y táctil) (Allman, Dhillon, Landau, & Kurniawan, 2009), todos ellos creados para personas ciegas y/o con visión limitada.

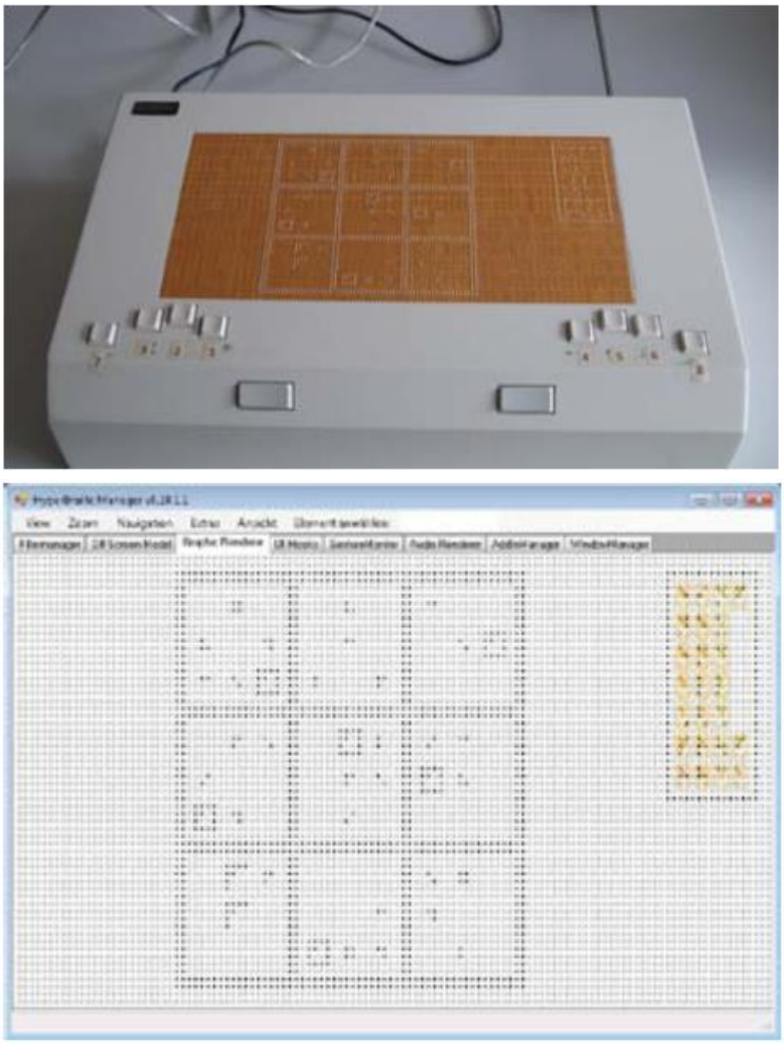

Figura 11. Sudoku háptico para personas ciegas desarrollado por *(Gutschmidt et al., 2010)*. © ACM.

Cuando la accesibilidad se considera *a posteriori* rara vez se abordan múltiples tipos de discapacidad al mismo tiempo, ya que hacer modificaciones en el núcleo del juego es mucho más complicado (o impracticable si no se tiene acceso al código fuente) una vez que el desarrollo se ha completado.

En general, las soluciones *ad-hoc* son necesarias pues sirven para mejorar el conocimiento que la comunidad ligada a los juegos digitales tiene sobre las acciones y estrategias que permiten adaptar distintos tipos y mecánicas de juego para personas con discapacidad, permitiendo una aproximación gradual al problema y desde diferentes perspectivas. Sin embargo, es necesario la construcción de modelos más generales que puedan aplicarse ampliamente para el desarrollo de juegos accesibles y que, al menos en parte, permitan mejorar la accesibilidad del juego sin tener que empezar desde cero.

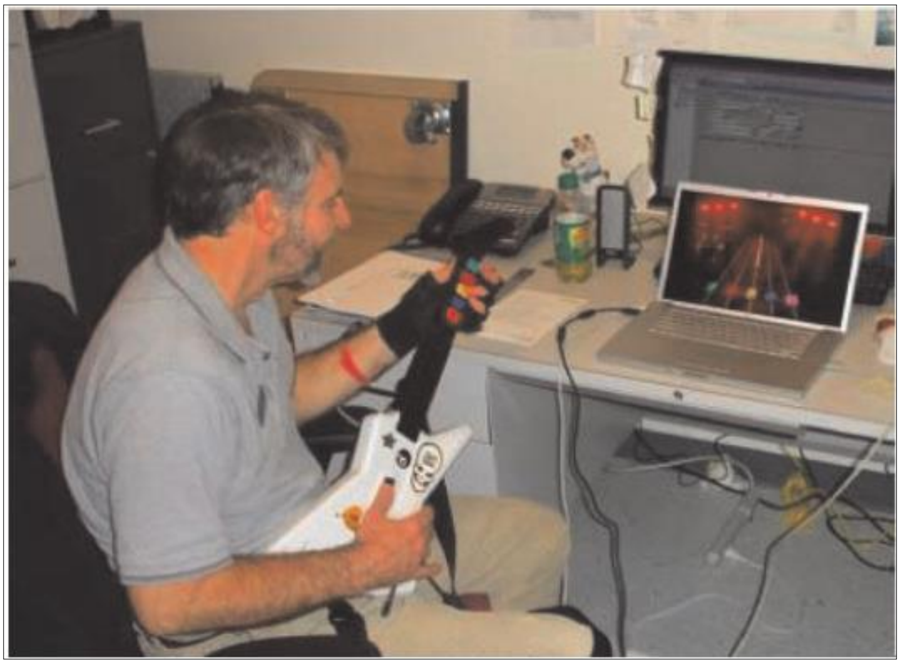

Figura 12. Imagen de una persona ciega jugando a *Blind Hero*™, versión adaptada del popular *Guitar Hero*™, gracias a un guante especial que proporciona realimentación táctil al usuario. Imagen obtenida de *(Yuan & Folmer, 2008)*. © ACM, 2008.

2.3.2. Enfoques generales: metodologías, recomendaciones y herramientas de soporte

Otros enfoques han abordado la accesibilidad en juegos digitales adoptando una perspectiva más general y global, en forma de propuesta de directrices, recomendaciones, marcos teóricos y metodologías. Estos trabajos, menos frecuentes que los enfoques *ad-hoc*, tienen como característica fundamental que normalmente tienen en cuenta las necesidades de personas con diferentes tipos de discapacidad (con la dificultad añadida que esto supone), y también abordan más de un juego o tipos de juego. En esta línea existen tanto iniciativas provenientes de la comunidad de jugadores con discapacidad y la industria como del ámbito académico.

Una de las primeras iniciativas reseñables en esta línea son las pautas de accesibilidad para videojuegos desarrolladas por el Grupo de Especial Interés (*Special Interest Group – SIG*) en accesibilidad de la Asociación Internacional de Desarrolladores de Videojuegos *(International Game Development Association – IGDA*[33]) (Bierre et al., 2004), cuya publicación celebra actualmente su décimo aniversario. En este documento, de carácter fundamentalmente técnico y práctico publicado en 2004, se propusieron una serie de recomendaciones para evitar las barreras de accesibilidad más comunes identificadas en los videojuegos de la época. El desarrollo de este documento se hizo mediante (1) análisis de las principales limitaciones en materia de

[33] http://igda-gasig.org/

accesibilidad de los juegos comerciales y (2) análisis de casos de éxito (juegos desarrollados con características de accesibilidad con gran aceptación por parte de la comunidad). Tomando este documento como punto de partida, el grupo noruego MediaLT publicó un conjunto de recomendaciones y directrices más detallado agrupadas por perfiles de discapacidad (MediaLT, 2004, 2006). Recientemente se ha publicado un nuevo conjunto de buenas prácticas dirigidas a desarrolladores de videojuegos (Game Accessibility Guidelines, 2012). Este conjunto de buenas prácticas se estructura en diferentes niveles de detalle (básico, intermedio y avanzado), de manera similar a los niveles de adecuación propuestos por W3C en sus *Web Content Accessibility Guidelines (WCAG 2.0)*, lo que facilita a los desarrolladores abordar el problema de manera gradual. Otra característica interesante de estas directrices es que proporciona abundantes ejemplos de cómo se han resuelto ciertos problemas en juegos digitales de última o penúltima generación.

Pese a lo interesante de todas estas propuestas, ninguna de ellas puede compararse en oficialidad, madurez, adopción y soporte legal a las descritas en la sección 2.2 sobre accesibilidad en la web en general y en e-learning en particular, sobre todo si se tiene en cuenta el impacto de las recomendaciones del consorcio W3C. En primer lugar, ninguno de los conjuntos de directrices presentados anteriormente goza de apoyo directo de cuerpos legisladores o reguladores. En segundo lugar, no existen apenas herramientas de apoyo que faciliten el cumplimiento de estas recomendaciones ni la evaluación de su nivel de cumplimiento, como sí ocurre con las recomendaciones referentes a la Web.

También hay propuestas con un tono más académico. Este es el caso de las directrices tituladas *Design Guidelines for Audio Games* (Garcia & De Almeida Neris, 2013), que proporcionan un conjunto de recomendaciones para hacer juegos accesibles para personas con discapacidad visual teniendo en cuenta desde la instalación de los juegos hasta su compleción. No obstante, dentro de estas iniciativas una de las más consolidadas es la del grupo griego *FORTH* de tecnologías accesibles, que ha propuesto una metodología denominada *Unified Design of Universally Accessible Games* (UDUAG) (Grammenos et al., 2007), que hasta la fecha ha sido aplicada en el desarrollo de cuatro juegos diferentes (Grammenos et al., 2009) y que tiene una especial relevancia para este trabajo de tesis. UDUAG propone un flujo de trabajo (Figura 13) que comienza por diseñar las tareas y actividades del juego de manera abstracta y sin vinculación directa con ningún dispositivo del mundo físico. A partir de ahí se comienza a diseñar diferentes alternativas de interacción teniendo en cuenta las necesidades específicas del público objetivo. Posteriormente se realiza un análisis de compatibilidad de las distintas alternativas, se realizan prototipos y se evalúa su nivel de accesibilidad de manera formal. Este flujo debe repetirse de manera iterativa tantas veces como sea necesario hasta obtener la calidad de producto deseada. Otra característica interesante de UDUAG es que aboga por tener en cuenta tanto a los usuarios finales como a expertos en accesibilidad desde el primer momento. En conjunto, una de las principales ventajas de UDUAG es que plantea un diseño y desarrollo del juego extensibles, lo que facilita la posterior inclusión de características de accesibilidad para atender a las necesidades de nuevos usuarios.

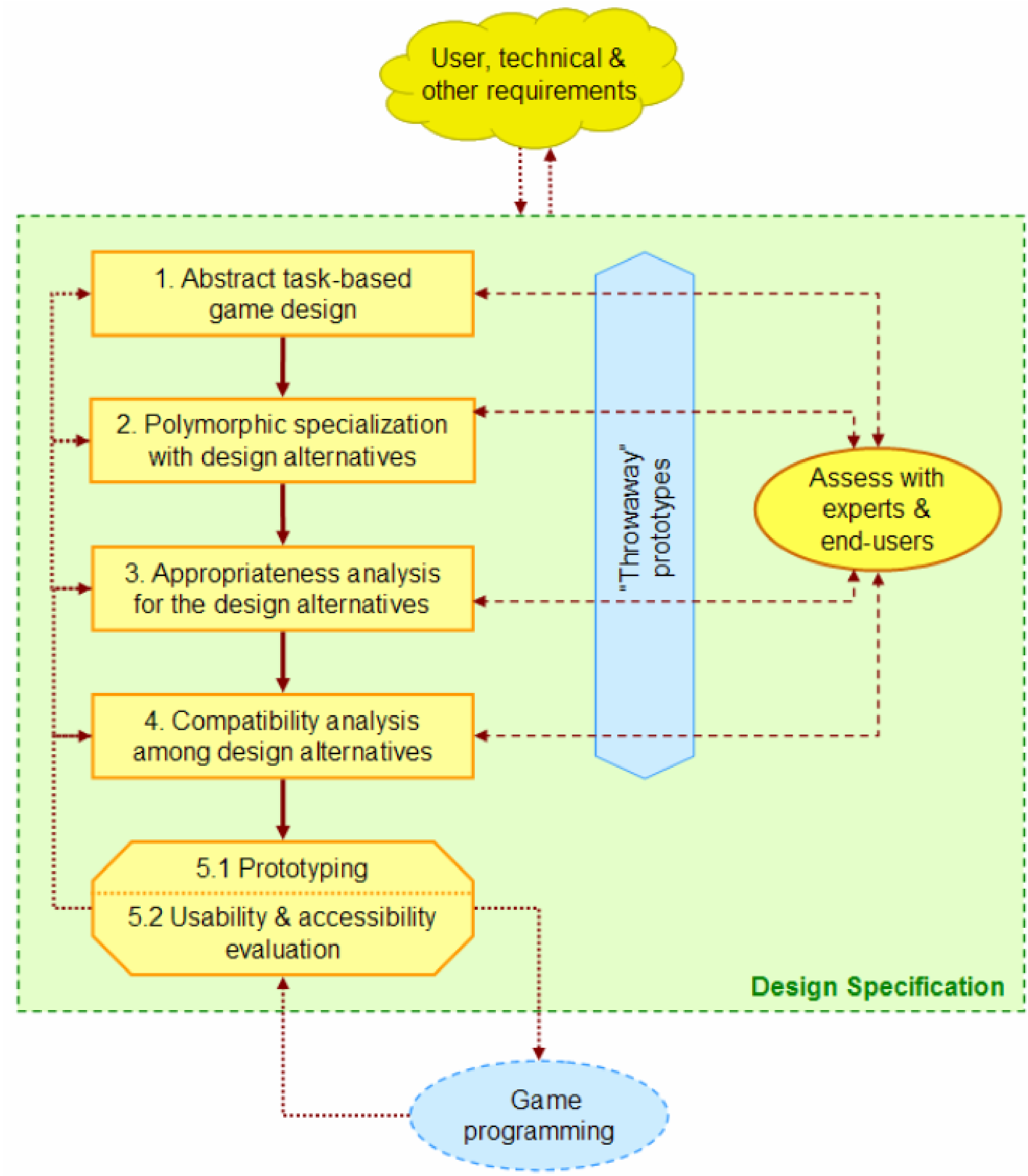

Figura 13. Flujo de trabajo especificado por la metodología UDUAG. Imagen obtenida de (Grammenos et al., 2007). © Springer-Verlag.

El inconveniente de estas líneas de trabajo es la ausencia de implementaciones de referencia y herramientas que faciliten el trabajo de los desarrolladores. Por herramientas e implementaciones de referencia nos referimos a software que sea reutilizable y que presente componentes orientados a la accesibilidad que el desarrollador pueda utilizar, ya sea en forma de motores de juego, librerías de apoyo, o herramientas de alto nivel. Una excepción es el sistema llamado *Blindstation* (Archambault & Olivier, 2005), un motor sencillo que separa los componentes de interfaz de la lógica del juego para facilitar la interoperabilidad con diferentes dispositivos de entrada y salida. Otra tecnología similar se describe en (Roden & Parberry, 2005), y consiste en un motor de audio 3D para desarrollar juegos basados en audio (*audio games*) que proporciona una arquitectura de software para hacer juegos inmersivos para personas con discapacidad visual. Otra iniciativa más reciente que proporciona un pequeño prototipo a modo de implementación de referencia es el motor para la creación de juegos universalmente accesibles descrito en (Garcia & de Almeida Neris, 2014), que toma como punto de partida la metodología UDUAG y tiene como punto de interés la implementación de una arquitectura basada en entidades y componentes, tendencia de actualidad en el desarrollo de tecnologías de juegos puesto que facilita el desarrollo de juegos versátiles y de alta calidad (Llansó, Gómez-Martín, Gómez-Martín, & González-Calero, 2011). Otro ejemplo interesante es el *framework ACCESS* (Heron, Hanson, & Ricketts, 2013), originalmente diseñado para desarrollar juegos para personas mayores y que recientemente ha sido extendido para dar soporte de manera dinámica a personas con distintos tipos de discapacidad física y cognitiva (Vickers, Istance, & Heron, 2013).

La mayor desventaja de estas implementaciones software es que su alcance se limita a pequeños prototipos y que han tenido un impacto muy limitado en las principales herramientas de desarrollo del mercado, tales como pueden ser *Unity*™[34], *Libgdx*™[35], *FPS Creator*™[36] o *Adventure Game Studio*™[37], por citar algunos ejemplos de herramientas populares entre desarrolladores de juegos digitales de distinta índole. Hasta la fecha el soporte que tienen estas herramientas de cara a la accesibilidad es muy limitado, cubriendo aspectos sencillos como puede ser el subtitulado oculto de los juegos (*closed captions*), como es el caso del sistema XNA™[38] de Microsoft ™ o del motor *Torque™*[39], de *GarageGames*™. Otro ejemplo es el popular motor de juegos *Unreal*™[40], cuya versión más reciente (4) fue lanzada al mercado en marzo de 2014, y que incluye entre sus novedades algunas opciones de configuración para mejorar la accesibilidad de su interfaz de edición para personas con siete tipos diferentes de daltonismo (ver Figura 14). Nótese que esta funcionalidad va dirigida sólo a desarrolladores daltónicos y que por tanto no supone ningún beneficio directo para los jugadores con este tipo de discapacidad.

2.3.3. Dispositivos especiales o adaptados y productos de apoyo software

Un enfoque relativamente común para aumentar la accesibilidad de los videojuegos consiste en buscar su compatibilidad con productos de apoyo externos y dispositivos de entrada y/o salida de la manera más flexible posible (Kearney, 2005).

La principal ventaja de este enfoque es que no implica desarrollo ni mantenimiento de tecnologías de accesibilidad propias como parte del núcleo tecnológico del juego, pues cuenta con que el usuario pueda utilizar los suyos propios. Esto incluye tanto hardware específico, normalmente en forma de dispositivos de entrada especiales, como productos software de apoyo. Dentro de los productos de apoyo software hay multitud de opciones, tales como

[34] http://unity3d.com/es
[35] http://libgdx.badlogicgames.com/
[36] http://fpscreator.thegamecreators.com/
[37] http://www.adventuregamestudio.co.uk/
[38] http://msdn.microsoft.com/es-es/library/bb200104(v=xnagamestudio.40).aspx
[39] http://www.garagegames.com/community/resources/view/13437
[40] https://www.unrealengine.com/blog/welcome-to-unreal-engine-4

programas que permiten la interacción mediante ligeros movimientos oculares (Argue, Boardman, Doyle, & Hickey, 2004), como sintetizadores de voz, módulos de control por voz, magnificadores de pantalla, joysticks virtuales controlados por movimientos de la cabeza, etc.

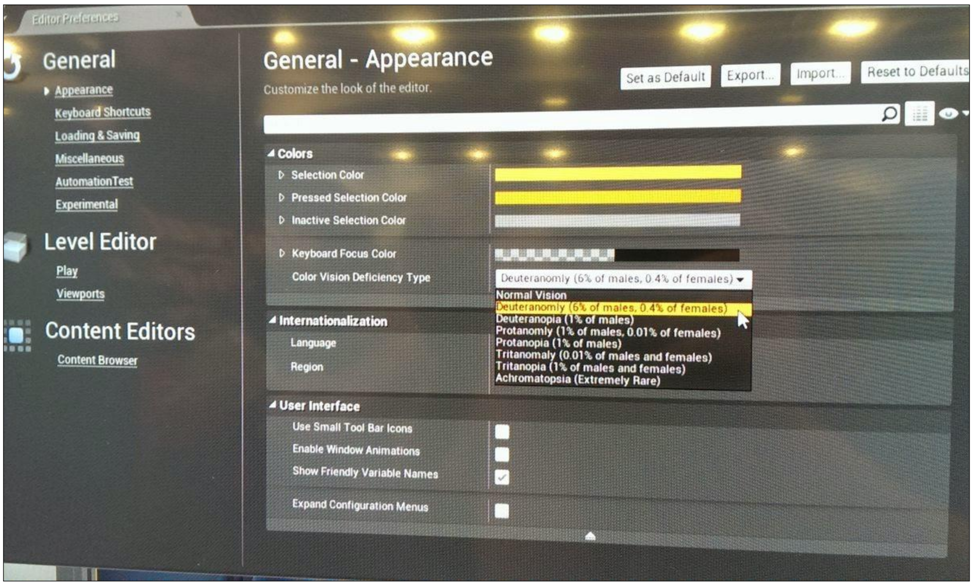

Figura 14. Foto mostrando opciones de configuración de accesibilidad de la herramienta de autoría de *Unreal 4*™. Fuente de la imagen: Ian Hamilton (https://twitter.com/ianhamilton_).

El mercado de hardware específico para personas con discapacidad incluye dispositivos especialmente diseñados o modificados para adaptarse a las condiciones del usuario a partir de modelos estándar. Hay también dispositivos especiales dirigidos a un conjunto amplio de personas con discapacidad, así como dispositivos que se personalizan para ajustarse a la ergonomía y situación de los usuarios de manera individualizada. El abanico final es muy variado.

Entre las opciones que utilizan hardware convencional cobra fuerza el uso de dispositivos de control de juego de vanguardia, como pueden ser *Microsoft Kinect*™ o *Play Station Move*™, por ser soluciones muy asequibles y que pueden integrarse en distintos juegos gracias a los kit de desarrollo que proporcionan sus fabricantes (D. Q. Freitas et al., 2012; Wattanasoontorn, Magdics, Boada, & Sbert, 2013). Por ejemplo, en (Standen, Camm, Battersby, Brown, & Harrison, 2011) se propone el uso del popular controlador *Wii Nunchuk*™, de Nintendo, como alternativa a los dispositivos que tradicionalmente utilizan las personas con discapacidad física y/o cognitiva.

Entre las soluciones específicas más vanguardistas destacan los controladores cerebrales (*brain controllers*), que permiten al usuario interactuar con el juego a través de unos dispositivos (ver Figura 15) que registran su actividad cerebral y reconocen patrones asociados a ciertas acciones del juego (Lécuyer et al., 2008). Aunque estos dispositivos son poco más que pruebas de concepto todavía, suponen una gran esperanza para personas con todo tipo de discapacidades de cara al futuro.

Figura 15. Imagen de una persona con discapacidad controlando una nave espacial en un juego ambientado en el mundo de *Star Wars*© gracias a un dispositivo que interpreta parte de su actividad cerebral. Imagen obtenida de (Lécuyer et al., 2008). © IEEE, 2008.

Otros dispositivos de entrada disponibles en el mercado están diseñados para su control con la boca, y van dirigidos a personas con grados de discapacidad motriz elevada. Por ejemplo, en (Huo & Ghovanloo, 2010) se describe un dispositivo que permite controlar distintos sistemas (entre ellos juegos) mediante un pequeño controlador que se vincula a la lengua del usuario, aunque la opción más común es que el dispositivo incluya una pequeña palanquita al acceso de la boca del individuo que es la que éste utiliza para controlar el sistema. Otra solución muy común es utilizar pulsadores (*switches*). Estos dispositivos permiten interactuar con los juegos de una manera rápida y efectiva con simples toques de la mano, la cabeza u otras partes del cuerpo[41]. Son soluciones sencillas y baratas y que pueden adaptarse a las necesidades de cada usuario.

En esta línea, uno de los trabajos más destacados es el presentado por Sjöström y Rassmus-Gröhn (1999), que muestran el uso de *PHANToM*™(ver Figura 16). Consiste en un dispositivo háptico que sirve tanto como dispositivo de entrada como de salida, pues permite la interacción mediante movimientos con el dedo (registrados por un sensor 3D) y proporciona realimentación táctil al mismo tiempo (fundamentalmente en forma de vibraciones), y que puede utilizarse para controlar un entorno 3D virtual muy parecido al que se utiliza en los juegos digitales.

[41] http://www.videojuegosaccesibles.es/2010/09/guante-pulsador.html

Figura 16. Imagen del dispositivo especial *PHANToM*™, desarrollado por *SensAble* Technologies, Inc. Imagen obtenida de (Sjöström & Rassmus-Gröhn, 1999).

2.4. Estrategias para la adaptación de juegos para personas con personas con discapacidad.

En esta sección se proporciona un análisis más detallado del estado del arte en juegos digitales accesibles desglosado por tipo de discapacidad, en base a la clasificación descrita en el primer capítulo: ceguera (sección 2.4.1), visión limitada y daltonismo (sección 2.4.2), movilidad reducida (sección 2.4.3), discapacidad auditiva (sección 2.4.4) y discapacidad cognitiva (sección 2.4.5). Cada una de estas subsecciones incluye un análisis de algunos de los juegos disponibles para el tipo de discapacidad, así como una descripción de alto nivel de las principales estrategias de diseño acometidas a la hora de adaptar juegos digitales para ese tipo de discapacidad.

Cabe destacar que no todos los perfiles de discapacidad han sido abordados ni desde el plano académico ni desde de la industria con igual profundidad, siendo las discapacidades visuales las que más atención han recibido.

2.4.1. Ceguera

La ceguera es probablemente el tipo de discapacidad que más se ha analizado hasta la fecha. Por ejemplo, la comunidad online *AudioGames*[42] proporciona una gran cantidad de juegos cuyo retorno de la información se realiza en su totalidad a través de audio (sin menoscabo del uso combinado de otros canales sensoriales), lo que permite su uso por parte de personas ciegas (Friberg & Gärdenfors, 2004). Algunos juegos de este tipo, como *Papa Sangre*™ (Somethin'Else, 2013), disponible tanto para entornos de escritorio como *smartphones*, incluso evitan la incorporación de soporte gráfico alguno.

Por lo general, el catálogo de juegos accesibles para personas con ceguera es también más amplio, comparado con otros tipos de discapacidad. Esto incluye juegos de carreras, arcades de disparos, juegos de rol (RPG), de aventuras o juegos de música y baile. La mayoría de los juegos disponibles para personas ciegas están orientadas al entretenimiento, aunque también se ha explorado su uso como herramientas educativas. Este es el caso, por ejemplo, del juego de realidad virtual descrito en (Sánchez & Espinoza, 2011; Sánchez, 2012), que utiliza realimentación háptica para mejorar la orientación espacial y capacidad de navegar por espacios cerrados de las personas ciegas. Una aplicación similar es el sistema *Virtual Eye-Cane*™, descrito en (Maidenbaum, Levy-Tzedek, Chebat, & Amedi, 2013).

Los principales obstáculos encontrados por los jugadores ciegos suelen estar relacionados con la percepción de la realimentación proporcionada por el juego. Por esa razón, las adaptaciones suelen estar relacionados con la sustitución de los estímulos visuales con audio (Friberg & Gärdenfors, 2004; Miller, Parecki, & Douglas, 2007), la realimentación háptica en diversas variantes (De Pascale, Mulatto, & Prattichizzo, 2008), o más a menudo una combinación de ambos (Allman et al., 2009; Y. E. Kim, Doll, & Migneco, n.d.; Morelli, Foley, Columna, Lieberman, & Folmer, 2010; Savidis et al., 2007).

Las técnicas basadas en audio son de lo más variadas. Una estrategia consiste en utilizar iconos auditivos (*auditory icons*) o *earcons*[43], que fundamentalmente lo que hacen es asociar información específica a un sonido concreto. La principal diferencia entre ambos es que, mientras que los iconos auditivos suelen diseñarse para parecerse a sonidos reales que sean fácilmente reconocibles para el usuario (p.ej. el sonido de papeles arrugados cuando se vacía la papelera de reciclaje), los *earcons* son mensajes que se transmiten a través de estructuras musicales (Brewster, 1998). Ambas técnicas se han aplicado en varios juegos como El viaje de Tim (*Tim's Journey*) (Friberg & Gärdenfors, 2004), Os*™* y *Xs*™ (Targett & Fernström, 2003). Otros juegos aplican soluciones de audio más sofisticadas como sonido espacial o 3D (Sánchez, Sáenz, & Ripoll, 2009). En estos casos suele asignarse sonidos característicos a distintas entidades del juego, que se posicionan a su vez en un sistema 3D (ver Figura 17) de tal manera que el oyente percibe su posición relativa (izquierda o derecha) y su distancia a través de

[42] http://www.audiogames.net/

[43] No se ha encontrado una traducción al castellano del término *earcon*, que es un juego de palabras en inglés intraducible al castellano (*icon* vs. *eye-con*)

variaciones progresivas en el volumen (Vallejo-Pinto, Torrente, Ortega-Moral, & Fernández-Manjón, 2011).

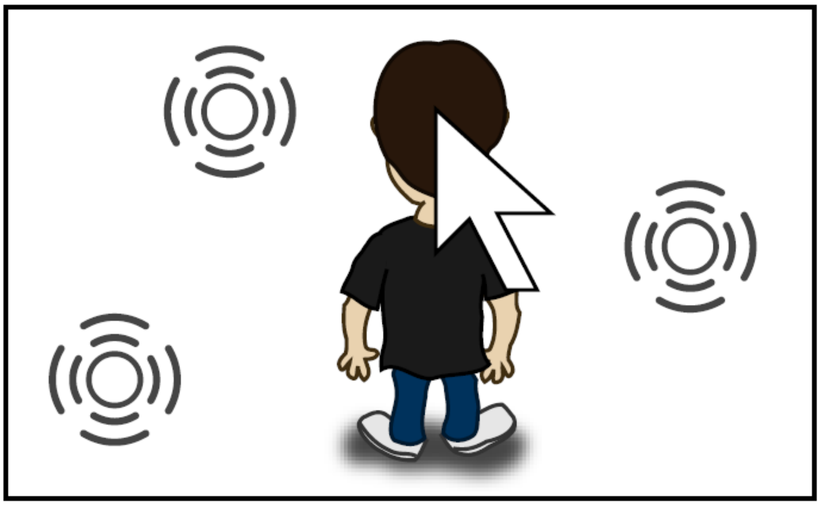

Figura 17. Ejemplo de sistema de audio 3D con tres fuentes de sonido. El oyente (jugador) percibe cada uno de los sonidos con intensidad y posición relativas al cursor. Imagen obtenida de (Vallejo-Pinto et al., 2011).

En muchos casos, los usuarios ciegos también pueden encontrar obstáculos referentes a la entrada, por ejemplo, si el juego se controla con el ratón. En estos casos, también es necesario proporcionar una modalidad alternativa, como la de permitir controlar el juego utilizando un teclado (que es el enfoque más común por ser el dispositivo de entrada más familiar para las personas ciegas) (Sánchez & Espinoza, 2011), o hardware especial tal y como se ha descrito en la sección 2.3.3 (Gutschmidt et al., 2010). En estos casos las interacciones más frecuentes suelen asociarse a unas pocas teclas para permitir su rápido acceso (por ejemplo, moverse en un mundo virtual mediante las flechas izquierda, derecha, arriba y abajo). En los casos en los que el número de interacciones sea muy elevado suelen combinarse con menús anidados que permiten navegar al usuario entre las opciones de una manera rápida y efectiva (y normalmente cíclica). Además suele incluirse un control específico para proporcionar al usuario información sobre su localización dentro del mundo virtual, o que recoloque dicho mundo de manera automática en torno a un origen conocido, a fin de resolver el conocido problema de desorientación que sufren las personas ciegas cuando interactúan con la tecnología (*Where am I?*) (J. Kim & Ricaurte, 2011). Todas estas interacciones suelen complementarse igualmente con realimentación auditiva para que el usuario sea consciente de cuándo ha introducido un comando correcto y cuando no, así como para verificar que el comando introducido es el que el usuario esperaba.

2.4.2. Visión limitada y daltonismo

Los problemas de acceso que sufren las personas con visión limitada en su interacción con juegos digitales son muy similares a los que experimentan con cualquier tipo de aplicación o contenido digital. Éstos suelen estar relacionadas con objetos o fuentes de texto demasiado pequeños o cuyo tamaño no es configurable por el usuario (Bierre et al., 2004). El uso de códigos de color para transmitir información es otro problema común, especialmente para usuarios con daltonismo o que tengan dificultades para distinguir ciertos colores de baja luminosidad. Otra situación que dificulta el acceso es el uso de esquemas de bajo contraste, lo que causa que elementos interactivos u otras entidades del juego se difuminen con en el fondo, problema que es difícil de resolver en juegos digitales por componerse la interfaz de usuario a partir de imágenes sobrepuestas a otras imágenes. También suele identificarse como un problema que el seguimiento visual de un elemento en constante movimiento sea esencial para avanzar en el juego (S. M. Trewin, Laff, Cavender, & Hanson, 2008).

Para abordar estas cuestiones, tres tipos de adaptaciones son las más frecuentes. En primer lugar, proporcionar funcionalidad para configurar el tamaño de la fuente y los elementos (al menos elementos clave), y/o integrar una utilidad para aumentar partes de la pantalla haciendo zoom (algo parecido a una lupa). En segundo lugar, ofrecer modos alternativos para transmitir información que no dependan del color (por ejemplo, el uso de símbolos e iconos) o, al menos, ofrecer varias combinaciones de colores configurables por el usuario. Por último, algunos juegos ofrecen un modo de alto contraste automático que afecta el *pipeline* gráfico (Wood, 2009). El funcionamiento más típico consiste en aplicar un filtro blanco y negro para hacer más fácil distinguir los elementos importantes de los irrelevantes y mejorar el contraste del texto sobre el fondo, como en el juego *PowerUp*™ (S. Trewin, Hanson, Laff, & Cavender, 2008) o en *Attractor HD*™ (ver Figura 18), juego desarrollado por *The Game Kitchen*™ en colaboración con *AccessAble games*™[44] y que está disponible tanto para escritorio como para iPad y Android.

Otra alternativa consiste en alterar la luminosidad de las entidades del juego, por ejemplo, haciendo que los personajes y objetos interactivos más relevantes sean más brillantes y el resto más oscuro, y viceversa. Esto puede lograrse mediante la producción de versiones alternativas de los recursos artísticos cuando se crea el juego o mediante la aplicación de filtros en tiempo de ejecución. Esta técnica se utiliza, por ejemplo, en el juego *Terraformers*™, pionero en este tipo de adaptaciones (Westin, 2004).

2.4.3. Movilidad reducida

Las personas con movilidad reducida en las manos por lo general tienen problemas para jugar con los dispositivos de juego estándar (por ejemplo, *joysticks* o *gamepads*). Este problema puede abordarse de diversas maneras según el grado de discapacidad y preferencias del usuario, tanto con soluciones software como hardware. Las soluciones basadas en hardware usan dispositivos especialmente diseñados o modificados para adaptarse a las condiciones del usuario. Hay tanto dispositivos estándar como dispositivos que se personalizan para ajustarse a la ergonomía y situación de los usuarios de manera individualizada, tal y como se describe en la sección 2.3.3. Entre los enfoques basados en software lo más frecuente es utilizar sistemas de reconocimiento de voz, sobre todo si el grado de discapacidad del usuario es elevado. Estos sistemas convierten los comandos que dicta el usuario en acciones del juego que luego pueden ser ejecutadas.

[44] http://www.thegamekitchen.com/attractor/attractor.html

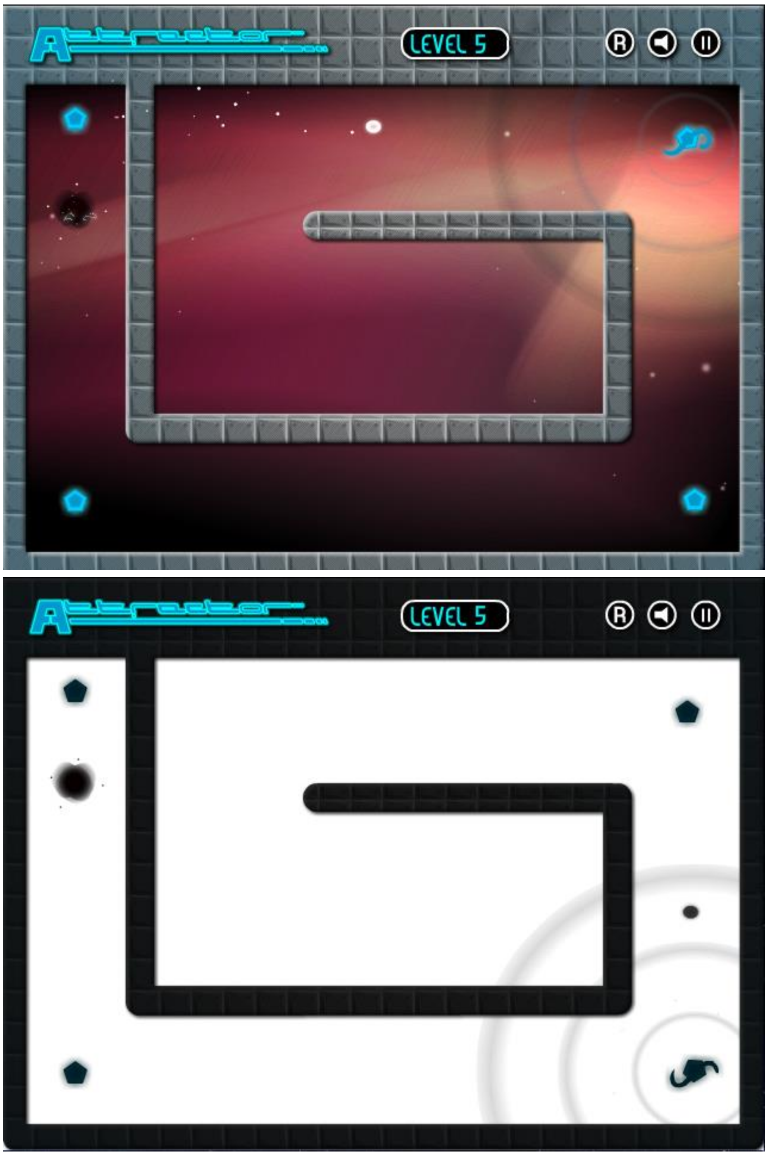

Figura 18. Dos capturas del juego *AttractorHD*™, en su modo normal (arriba) y modo alto contraste (abajo).

Otra estrategia no alternativa sino complementaria es permitir una configuración lo más flexible posible de la interacción por parte del usuario. Esto incluye no sólo el dispositivo de entrada a utilizar, sino también aspectos como la velocidad de los dispositivos o la cantidad de eventos de entrada que son necesarios para lanzar una determinada acción del juego. Incluso si el usuario dispone de un controlador que se adapte a sus necesidades, lo más habitual es que necesite que el ritmo del juego sea menor para tener tiempo suficiente para tomar decisiones y responder a los eventos del juego. Por ejemplo, en (Sporka, Kurniawan, Mahmud, & Slavík, 2006) se presenta una adaptación del clásico juego *Tetris* que utiliza dos interfaces diferentes para mejorar su accesibilidad para personas con movilidad reducida en las manos: una basada en el reconocimiento del habla y otra en zumbidos (*hummings*) que el usuario emite con la boca, adecuada para personas que además de discapacidad motora tienen problemas con el habla. En (Norte & Lobo, 2010) se presenta una adaptación del popular juego *Sudoku* que incluye dos modos de control aptos para personas con discapacidad motora de diversa índole: el primero incluye el uso de un único pulsador, mientras que el segundo utiliza un sistema de barrido que cambia el objeto que tiene el foco de forma automática con una frecuencia temporal configurable y siguiendo un orden predecible por el usuario.

2.4.4. Discapacidad auditiva

Las barreras que experimentan los usuarios con discapacidad auditiva aparecen en juegos en los que se proporcionan efectos, diálogos o cualquier otro tipo de estímulo únicamente mediante audio. El problema se acrecienta cuando dentro del contenido del juego que se proporciona únicamente mediante sonido se incluye información esencial para entender la trama del juego o para completarlo (véase el conocido caso de *Half Life*™ descrito en el primer capítulo). Este tipo de barreras se resuelve complementando el estímulo auditivo con uno visual. El enfoque más común es utilizar técnicas como el subtitulado o subtitulado oculto (*closed captioning*) (Archambault et al., 2008).

Existen también alternativas al subtitulado, aunque son menos frecuentes. Dos ejemplos son *CopyCat*™ y *SMILE*™, dos juegos educativos desarrollados para niños sordos. *CopyCat*™ reconoce los gestos del lenguaje de signos (Brashear, Henderson, Park, Hamilton, & Lee, 2006), y fue desarrollado para ayudar a niños sordos a practicar el lenguaje de señas americano (ASL). *SMILE*™ fue desarrollado para enseñar ciencias y matemáticas a alumnos con problemas de audición (Adamo-villani & Wright, 2007). En este caso también se utiliza ASL para interactuar con el juego.

2.4.5. Discapacidad cognitiva

Las discapacidades cognitivas son complejas y heterogéneas, y el número de barreras a las que se enfrentan estos jugadores son variadas y dependen en gran medida del tipo de discapacidad e incluso de las habilidades y capacidades de cada jugador. De hecho no existe un consenso sobre cómo realizar una adecuada clasificación de las discapacidades cognitivas. Dada su complejidad, queda fuera del alcance de este trabajo hacer un análisis pormenorizado de este tipo de discapacidad y, por tanto, la discusión se orientará a proporcionar al lector una visión de alto nivel de las principales barreras a las que se enfrentan estos usuarios, así como las principales estrategias propuestas para resolverlas y algunos ejemplos de juegos que tienen en cuenta este tipo de discapacidad.

Los problemas más comunes para estos jugadores están relacionados con el diseño, el contenido y la mecánica del juego. Esto incluye aspectos tales como la complejidad de los enigmas y puzles que se deben resolver para avanzar en la historia del juego, el registro del lenguaje utilizado, o el tiempo del que se dispone para decidir el próximo movimiento cuando se recibe un nuevo estímulo (por ejemplo, se recibe un disparo). Las estrategias más comunes incluyen reducir o eliminar la presión por tiempo, así como disminuir la cantidad de interacciones necesarias para interaccionar con el juego (Yuan et al., 2011), o proporcionar niveles de dificultad alternativos (Lanyi & Brown, 2010). Esto contrasta con los problemas y adaptaciones identificados para las personas con discapacidades físicas en las secciones 2.4.1-2.4.4, que fundamentalmente se centran en la interfaz más que en el diseño.

El número de juegos orientados a personas con discapacidad cognitiva que puede encontrarse en la literatura es considerablemente más alto que para otros tipos de discapacidades. El propósito de estos juegos suele encontrarse más cerca de los *serious games* que de los juegos dedicados al entretenimiento, aunque también hay ejemplos de aplicación en este segundo ámbito (Yalon-Chamovitz & Weiss, 2008).

En este sentido destacan desde hace años las aplicaciones orientadas a la rehabilitación (Holden, 2005; Levac, Rivard, & Missiuna, 2012). Esto se debe a que ciertos tipos de discapacidad cognitiva son consecuencia de lesiones o pérdidas de funcionalidad corporal (relacionadas con el cerebro en la mayor parte de los casos) que afectan también a la condición física del individuo (por ejemplo, parálisis cerebral[45] o trastornos del espectro alcohólico fetal[46]). La presencia de interfaces naturales de usuario[47] en las videoconsolas de última y penúltima generación, tales como la consola *Nintendo Wii*™ o el sistema *Microsoft Kinect*™, ha sido extremadamente útil en este campo por su alta disponibilidad y bajo coste. Además la consistente presencia de objetivos claros en los juegos digitales, que son fácilmente identificables por los usuarios y se integran estructurados a distintos niveles es una característica que se alinea adecuadamente con las últimas tendencias en rehabilitación, donde se ha demostrado que es más efectivo plantear ejercicios con objetivos concretos que pedirle al paciente que realice movimientos sin ninguna motivación evidente (Legg et al., 2007). Por ejemplo, en (Loreto, Lange, Seilles, Andary, & Dyce, 2013) los autores presentan *Hammer and Plancks*, un juego orientado a mejorar problemas relacionados con el equilibrio en personas con hemiplejia[48]. El juego es multiplataforma y puede jugarse tanto con el dispositivo *Wii Balanceboard*™ como con *Microsoft Kinect*™. En (Lotan, Yalon-Chamovitz, & Weiss, 2009) se investiga el uso terapéutico de algunos *exergames*[49] disponibles en el mercado (en concreto, para el sistema *EyeToy*™ de la *Sony PlayStation II*™) en personas con discapacidad intelectual moderada, obteniendo mejoras significativas en su condición física. En (Wuang, Chiang, Su, & Wang, 2011) se demuestra

[45] Para más información sobre qué es una parálisis cerebral y los diferentes tipos existentes, se recomienda visitar el siguiente enlace: http://www.aspace.org/paralisis-cerebral/tipos-de-paralisis-cerebral

[46] Los trastornos del espectro alcohólico fetal (*Fetal alcohol spectrum disorders – FASD* en inglés) son problemas tanto físicos como intelectuales que se desarrollan durante el embarazo como consecuencia del consumo de bebidas alcohólicas por parte de la madre. Para una definición concisa pero precisa, véase el enlace http://www.cdc.gov/ncbddd/fasd/documents/fasd_english_spanish.pdf

[47] El término "interfaces naturales de usuario" (del inglés, *Natural User Interfaces*) es un concepto pujante en el campo de la interacción hombre-máquina que hace referencia a interfaces que son efectivamente invisibles para el usuario, o que se vuelven invisibles rápidamente tras sucesivas interacciones, y cuya curva de aprendizaje es muy baja o inexistente.

[48] El término hemiplejia hace referencia a la parálisis completa de la mitad del cuerpo como consecuencia de sufrir daños en los centros motores del cerebro. Para más información puede visitarse el enlace http://hemiplejia.org/.

[49] El término *exergame* hace referencia a juegos digitales, normalmente de consola, que incluyen realizar algún ejercicio físico moderado como parte de la mecánica de juego. Algunos ejemplos son Wii Fit©, de Nintendo, o *Dance Dance Revolution*© para *Play Station III*©.

mediante diseño cuasi-experimental la efectividad del juego *Nintendo Wii Sports*™ a la hora de mejorar las capacidades motoras y la coordinación óculo-motriz en niños de entre 7 y 12 años con síndrome de Down[50] frente a terapias tradicionales. Gagglioli también destaca junto a otros autores el potencial de los juegos y mundos virtuales para la rehabilitación de personas en tratamiento psiquiátrico (2007).

También existen juegos dirigidos a personas mayores, en número creciente tras haberse contrastado su potencial para mejorar los problemas degenerativos propios de la vejez en poblaciones envejecidas (Kueider, Parisi, Gross, & Rebok, 2012). Aunque este perfil de usuario no encaje necesariamente dentro del grupo de usuarios con discapacidad, existen similitudes palpables entre los juegos dirigidos a personas con discapacidad cognitiva y personas mayores, lo que justifica su inclusión dentro de esta sección, además de por haber sido uno de los grupos con los que se ha trabajado dentro de este trabajo de tesis. Estas semejanzas tienen que ver tanto con las estrategias de diseño orientadas a mejorar su accesibilidad, pues algunos de los problemas que experimentan ambos grupos son comunes (dificultad para recordar tareas y objetivos a realizar en el juego, dificultad para entender el lenguaje utilizado, etc.), como con el propósito, muy ligado a la rehabilitación tanto física como mental. Por ejemplo, en (Schoene et al., 2013) se describe el uso de una versión adaptada del juego libre *Stepmania*[51] (ver Figura 19) en personas mayores con avanzada degeneración cognitiva y física, mostrando mejoras significativas en parámetros tanto psíquicos como intelectuales comparado con el grupo de control. También se ha discutido el potencial que los juegos digitales de diversa índole para mejorar condiciones asociadas a la demencia (Mccallum & Boletsis, 2013).

También se ha explorado el uso de juegos digitales para mejorar la educación de personas con discapacidad cognitiva. De hecho, los juegos digitales llevan usándose años en el campo de la educación especial (Durkin, Boyle, Hunter, & Conti-Ramsden, 2013). Por ejemplo, en (Ohring, 2008) se describe el uso de un juego multijugador Web para fomentar el desarrollo de habilidades sociales en los niños autistas, continuando con la línea de trabajo ya propuesta en (Sehaba, Estraillier, & Lambert, 2005). En (Coles, Strickland, Padgett, & Bellmoff, 2007) se demuestra la efectividad de un juego 3D desarrollado con el objetivo de enseñar cuestiones relacionadas con la seguridad y la actuación en caso de incendio en niños con trastorno del espectro alcohólico. En (Piper, O'Brien, Morris, & Winograd, 2006) se describe el uso de *SIDES*™, un juego colaborativo que se juega en torno a una mesa táctil, para desarrollar las habilidades sociales de adolescentes con síndrome de Asperger[52].

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[50] El síndrome de Down es una alteración genética natural y fortuita producida por la presencia de un cromosoma extra, ya sea parcialmente o en su totalidad, que se considera una de las principales causas de discapacidad intelectual. Fuente: http://www.sindromedown.net/index.php?idMenu=6.

[51] http://www.stepmania.com

[52] El síndrome de Asperger es un trastorno severo del desarrollo que implica una alteración en el procesamiento de la información. Las personas afectadas tienen un aspecto e inteligencia normal o incluso superior a la media. Aunque el síndrome se manifiesta de manera diferente en cada persona afectada, algunos de los problemas comunes incluyen la dificultad para establecer relaciones sociales, la alteración de los patrones de comunicación no verbal, o dificultades en las funciones ejecutivas y de planificación, así como la interpretación de los sentimientos y emociones (Fuente: http://www.asperger.es/).

Figura 19. Captura del juego libre *Stepmania* (www.stepmania.com), versión 5, modo batalla. Imagen con licencia CreativeCommons.

El gran interés que se observa en el uso de juegos digitales como medio para mejorar la vida de las personas con discapacidad cognitiva, ya sea a través de su condición física, mental o social, contrasta con la escasa atención que se ha prestado a la accesibilidad de los juegos lúdicos comerciales, que prácticamente no incluyen características de soporte para este grupo de personas. Si bien es cierto que, tal y como se ha expuesto anteriormente, algunos juegos comerciales disponibles en el mercado como *Wii Sports*™ o *WiiFit*™ son aptos para su uso por personas con discapacidad, esta circunstancia es más bien anecdótica por deberse al azar más que a una intencionalidad clara. Esto se debe en gran medida a la extrema complejidad asociada a las adaptaciones que las personas con discapacidad cognitiva necesitan, ya que suelen afectar al núcleo del diseño y contenido del juego. En este sentido la adaptación de juegos para personas con discapacidad física puede resultar más sencilla, puesto que las adaptaciones son más superficiales (aunque su resolución también es compleja) al centrarse sobre todo en la interacción y la interfaz.

2.5. Evaluación de juegos y su accesibilidad

Un aspecto relevante para este trabajo, y que por lo tanto debe analizarse, concierne a la evaluación de juegos accesibles. La evaluación de juegos digitales desde un punto de vista de interacción hombre-máquina es una cuestión compleja y que no ha sido resuelta de manera efectiva hasta la fecha, ni en juegos orientados al entretenimiento ni en *serious games* (Bellotti, Kapralos, Lee, Moreno-Ger, & Berta, 2013). Existen algunas propuestas concretas sobre evaluación de usabilidad centrada en juegos digitales (Ak, 2012; Federoff, 2002; Garcia Marin, Lawrence, Felix Navarro, & Sax, 2011; Ijsselsteijn, De Kort, Poels, Jurgelionis, & Bellotti, 2007;

Pinelle & Wong, 2008), normalmente basadas en heurísticas (Nielsen & Molich, 1990), pero carecen de amplio consenso. Normalmente los juegos se evalúan siguiendo enfoques centrados en usuario (Eladhari & Ollila, 2012), que tienden a ser informales. Aunque este tipo de evaluación es muy útil a la hora de mejorar el diseño del juego y de su interfaz, haciéndolos más usables, su efectividad disminuye drásticamente según va avanzando el proceso de desarrollo. En ocasiones también se realizan evaluaciones finales a fin de validar la usabilidad de los productos generados, pero suelen realizarse aplicando enfoques generalistas que no siempre son adecuados para juegos.

En este sentido, la evaluación de accesibilidad de los juegos puede considerarse un caso específico de evaluación de usabilidad con ciertas particularidades. En primer lugar, el acceso a los usuarios finales es mucho más complejo, lo que dificulta la aplicación de técnicas de validación de usabilidad más formales que requieren normalmente de al menos siete o diez usuarios (Boring & Gertman, 2005). Además los usuarios con discapacidad requieren de una atención mucho más individualizada, lo que también supone una dificultad añadida a la hora de generalizar los resultados obtenidos.

La última dificultad añadida es consecuencia de la ausencia de metodologías específicas para la evaluación de la usabilidad y accesibilidad en juegos, así como de heurísticas ampliamente aceptadas (al estilo del W3C) y herramientas que faciliten la tarea. Como consecuencia, no siempre los juegos que incorporan accesibilidad (véanse los ejemplos descritos a lo largo de las secciones 2.3 y 2.4) disponen de validaciones formales de su nivel de accesibilidad, o en el caso de que estas existan, los métodos utilizados no son siempre suficientemente rigurosos por no disponer de grupos de control (Sánchez & Espinoza, 2011), utilizar instrumentos sin validación previa (Lanyi, Brown, Standen, Lewis, & Butkute, 2010) o no incluir un número suficiente de usuarios (Brashear et al., 2006).

2.6. A modo de conclusión

Este capítulo se cierra resumiendo de manera esquemática las principales conclusiones extraídas del análisis del dominio.

1. **La accesibilidad en juegos digitales se encuentra en un estado incipiente e inmaduro comparado con la accesibilidad en la Web.**

   Como se ha analizado en la sección 2.2, la accesibilidad Web viene impulsada desde comienzos de milenio por un organismo altamente influyente como es el W3C, y dispone actualmente de numerosos estándares y herramientas de amplia aceptación. En el campo de la accesibilidad en juegos digitales también hay iniciativas relevantes, pero mucho menos maduras y consolidadas (ver sección 2.3.2).

2. **Los desarrolladores de juegos digitales disponen de poco apoyo e información para la creación de juegos accesibles.**

   El análisis de las herramientas de creación de juegos disponibles (sección 2.1.2) y de las iniciativas de accesibilidad en juegos generalistas (sección 2.3.2) muestra claramente el escaso soporte técnico del que disponen los creadores de juegos digitales para lidiar con aspectos de accesibilidad. Esto, además de aumentar el esfuerzo necesario para conseguir que un juego sea accesible, dificulta que el desarrollador sea consciente de las necesidades que tienen las personas con discapacidad y de cómo se pueden satisfacer.

3. **No todas las discapacidades han recibido la misma atención a la hora de abordar sus necesidades respecto a los juegos digitales. La oferta de juegos accesibles disponible para cada discapacidad también es variable.**

   Tal y como se analiza en la sección 2.4, el perfil de discapacidad que más atención ha recibido es el de la ceguera. Es sin duda el perfil que aglutina más casos de estudio dedicados a analizar estrategias para mejorar la su acceso a los juegos digitales de diversa índole. También son el perfil que dispone de un catálogo de juegos con características de accesibilidad más amplio (aunque todavía insuficiente), tanto para propósitos serios como lúdicos, junto con el perfil de discapacidad cognitiva, aunque esta comparación es algo irreal por agrupar este último a un conjunto de discapacidades muy amplio y por su orientación al ámbito de la rehabilitación y la educación, dejando un poco más de lado el aspecto lúdico. Esto puede atribuirse fundamentalmente al peso de la comunidad de jugadores ciegos, así como a representar un perfil de usuario más homogéneo y con necesidades específicas definidas.

4. **Existe la necesidad de proponer metodologías de evaluación adecuadas para validar la accesibilidad de los juegos digitales.**

   Tal y como se describe en la sección 2.5, la validación final de la accesibilidad de los juegos digitales es insuficiente, y esto se debe en gran medida a la ausencia de metodologías apropiadas. Es importante mejorar este aspecto, pues sin una validación formal de los niveles de accesibilidad de los juegos será difícil aumentar su uso en ámbitos estrechamente ligados al sector público, como es la educación, por la imposibilidad de cumplir con la legislación vigente tal y como se describe en la sección 2.2.

Capítulo 3: Objetivos y planteamiento del trabajo

En el primer capítulo se introdujeron los objetivos principales de esta tesis así como la motivación subyacente. Este capítulo desarrolla dichos objetivos, enmarcando su alcance a partir del estudio del dominio analizado en el capítulo 2. Se plantea de una manera más formal la principal estrategia para mejorar la accesibilidad de los juegos digitales, objetivo principal de esta tesis ya introducido en el capítulo 1: proponer e introducir características de accesibilidad en herramientas de creación de juegos digitales a fin de reducir su coste y esfuerzo asociado, y mejorar la visibilidad que las necesidades de las personas con discapacidad entre la comunidad de desarrolladores.

También se plantean las estrategias complementarias que se han seguido para lograr los objetivos parciales, como son el desarrollo de una metodología específica para la evaluación de accesibilidad en *serious games*, el desarrollo de tres casos de estudio y su aplicación para evaluar la accesibilidad de los mismos, así como una evaluación sobre el coste asociado a la introducción de características de accesibilidad utilizando la prueba de concepto desarrollada sobre eAdventure 1.5.

3.1. Objetivos de la tesis

El objetivo marcado por el título de esta tesis, *mejorar la accesibilidad de los serious games mediante herramientas de autoría*, da lugar al principal objetivo de la tesis:

1. Proponer un conjunto de características de accesibilidad que puedan integrarse en herramientas de creación de juegos para facilitar la introducción de características de accesibilidad en *serious games* tipo aventuras *point-and-click* (Modelo conceptual).

Esta propuesta constituye el núcleo de la tesis, así como su marco teórico, tal y como se describe en la sección 4.1.

A fin de que el modelo propuesto sea lo más completo posible, se plantea seguir un enfoque primero en *anchura* y luego en *profundidad*:

- En *anchura*: el modelo debe abarcar al menos las necesidades más importantes asociadas a las principales discapacidades identificadas en la sección 2.4. Esto es: ceguera, visión limitada, movilidad reducida (en manos), discapacidad auditiva y discapacidad cognitiva.

- En *profundidad*: profundizar en las necesidades de interacción de un perfil de usuario concreto, proponiendo distintas alternativas de adaptación de tal manera que el usuario pueda elegir la que más se adecúe a sus preferencias y características.

En análisis en profundidad se ha centrado en usuarios con ceguera. Esto se debe a varias razones que hacen que este perfil sea más asequible que otros como primera aproximación:

- Por ser un perfil menos heterogéneo que otros tipos de discapacidad (por ejemplo, cognitiva).

- Porque las necesidades específicas de este perfil son conocidas y se han estudiado en profundidad.

- Por ser uno de los perfiles para los que se encuentran más ejemplos de juegos digitales accesibles.

Dada la diversidad de tipos de juegos digitales existente, y a fin de mantener el alcance del trabajo dentro de los límites razonables, el modelo propuesto se centra en juegos tipo aventura gráfica *point-and-click,* cuya efectividad en términos educativos está contrastada y que plantea menos problemas de accesibilidad que otros tipos de juego.

Dado el alcance ambicioso de este primer objetivo, es necesario analizar la factibilidad de su implementación y aplicación en contextos reales. De esta manera, surge como segundo objetivo de manera prácticamente natural lo siguiente:

1. Implementar una prueba de concepto sobre una herramienta de creación de juegos concreta (Implementación).

En este caso se ha elegido la herramienta eAdventure por las siguientes razones:

- Constar de un modelo de juego subyacente explícito, representado en formato XML, lo que facilita su análisis y procesamiento automático en busca de problemas de accesibilidad, así como su adaptación automática.

- Proporcionar un modelo de interacción específico y predecible en su mayor parte *a priori* para los juegos (interacción *point-and-click*), lo que también facilita acotar el problema a un conjunto de problemas de accesibilidad más concreto.

- Estar orientada a la creación juegos del tipo en el que se centra el modelo propuesto (ver objetivo 1).

- Tener un nivel de complejidad acotado, lo que facilita que la aproximación al problema sea gradual.

- Tener licencia libre LGPL, lo que permite obtener su código y modificarlo según se necesite.

A partir de esta implementación que sirva de prueba de concepto se plantea el penúltimo objetivo de la tesis:

2. Evaluar la adecuación del modelo propuesto mediante el desarrollo de casos de estudio y su posterior análisis de usabilidad incluyendo usuarios con discapacidad (Usabilidad).

Finalmente se identifica la necesidad de estimar cuál es el coste (expresado en términos de esfuerzo) asociado a la introducción de características de accesibilidad en un juego concreto. Este análisis es necesario para poder determinar la efectividad real, desde un punto de vista práctico, del modelo propuesto (objetivo 1) así como de la prueba de concepto desarrollada sobre la herramienta eAdventure (objetivo 2), a la hora de facilitar las tareas de introducción de accesibilidad en juegos. Creemos que sólo a través de una reducción significativa del esfuerzo asociado a la accesibilidad en juegos se puede tener un cierto impacto en la comunidad de desarrolladores. Esto se formaliza a través del último objetivo:

3. Analizar el coste asociado a la introducción de las características de accesibilidad identificadas en un juego completo, a fin de valorar si el enfoque produce una reducción significativa de esfuerzo asociado a mejorar la accesibilidad en juegos digitales para el desarrollador del juego (Evaluación final).

Este objetivo tiene un impacto directo en el planteamiento del trabajo. Tal y como se discute en la sección 2.3.1, los enfoques en los que se tiene en cuenta la accesibilidad desde el comienzo del desarrollo (enfoques *a priori*) son los más recomendables por las ventajas que conllevan (detección temprana de barreras de accesibilidad, resolución de problemas más flexible y con menor sobrecoste, etc.). Sin embargo, en los casos de estudio que hemos llevado a cabo se ha tendido a considerar la accesibilidad *a posteriori* (una vez completada una versión final del juego), a fin de poder cuantificar el esfuerzo asociado a la introducción de características de accesibilidad una vez aislados el resto de tareas de diseño e implementación del juego.

3.2. Planteamiento del trabajo

El trabajo que se plantea es ambicioso, por la complejidad del problema de partida así como el amplio conjunto de discapacidades contempladas (planteamiento en anchura). Por esto se plantea abordar el desarrollo del trabajo siguiendo un enfoque iterativo (ver Figura 20) y basado en casos de estudio. Esto permite un refinamiento progresivo tanto del modelo de características de accesibilidad propuestas como de la implementación de referencia.

De esta manera, tal y como indica la Figura 20, el trabajo ha constado de tres fases principales, orientadas según los objetivos 1-3:

1. Planteamiento del modelo de características de accesibilidad para herramientas de autoría.

2. Implementación de las características propuestas en la herramienta eAdventure.

3. Desarrollo de un caso de estudio, consistente en crear uno o varios juegos accesibles, o adaptar uno existente, utilizando las características de accesibilidad planteadas y desarrolladas. Evaluar la usabilidad (y accesibilidad) del caso de estudio teniendo en cuenta a usuarios finales y expertos.

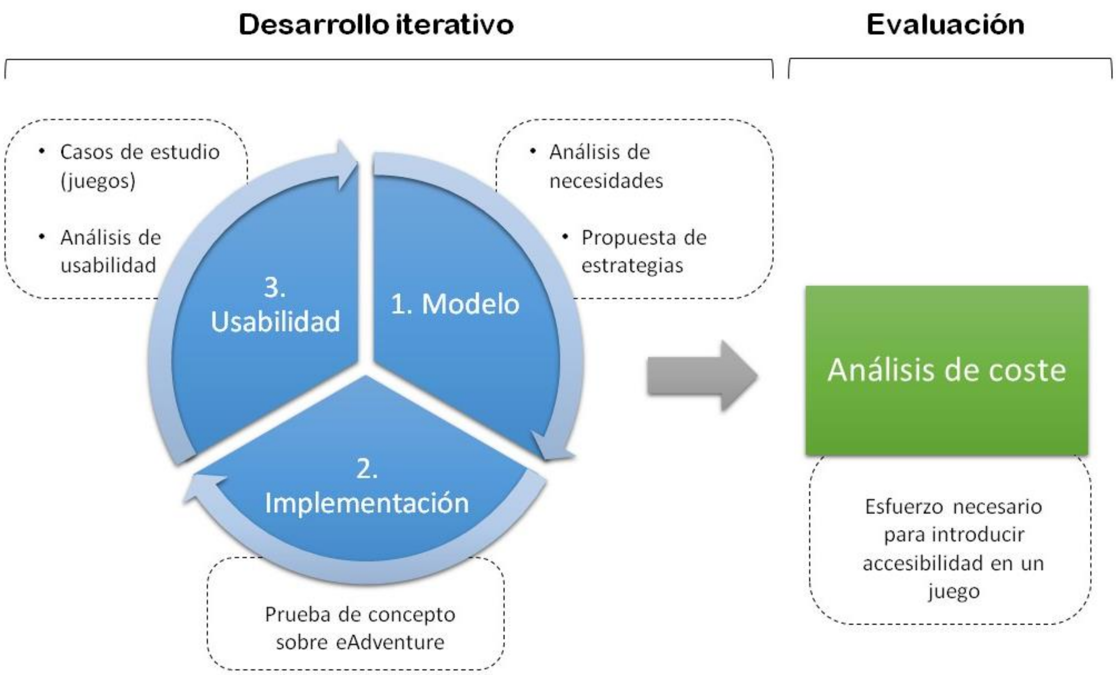

Figura 20. Metodología de trabajo propuesta

Este proceso se ha repetido durante tres iteraciones completas, dando lugar a tres casos de estudio:

1. Primera iteración: propuesta básica de características en anchura y análisis mediante adaptación de un juego existente (*1492*).

2. Segunda iteración: refinamiento de la propuesta en anchura y desarrollo de un juego completo (*Mi primer día de trabajo*).

3. Tercera iteración: ampliación en profundidad de la propuesta, centrándose en proponer soluciones alternativas para un tipo concreto de discapacidad (ceguera), y desarrollo de tres mini juegos para evaluar cada una de las interfaces.

Una vez completadas las tres iteraciones se procede a evaluar el impacto de la introducción de características de accesibilidad siguiendo el modelo propuesto en el coste del juego, a fin de cumplir con el objetivo 4.

Capítulo 4: Discusión y contribuciones

En este capítulo se proporciona una descripción de los artículos publicados que forman este trabajo de tesis doctoral y se discute cómo el contenido de cada uno de ellos contribuye a cubrir los objetivos planteados en el capítulo anterior.

El capítulo está dividido en cuatro secciones que reflejan las contribuciones referentes a cada uno de los objetivos definidos en el capítulo 3. Cada sección se divide a su vez por artículos. De esta manera, cada discusión y análisis de las contribuciones de las publicaciones se realiza en su propia sección independiente.

Esta estructura no tiene por tanto un carácter cronológico. En caso de que el lector prefiera seguir la discusión en base a la cronología de iteraciones descrita en la sección 3.2, puede utilizar la siguiente guía que relaciona dichas iteraciones con cada una de las secciones del presente capítulo:

1. Primera iteración: secciones 4.1.1, 4.2.1, 4.3.1 (primera parte).
2. Segunda iteración: secciones 4.1.2, 4.2.1, 4.3.1 (segunda parte), 4.3.2 y 4.3.3.
3. Tercera iteración: secciones 4.1.3, 4.3.4

La sección 4.4 corresponde a la fase final de evaluación propuesta en la sección 3.2.

4.1. Modelo de características de accesibilidad para herramientas de creación de juegos

4.1.1. Primera propuesta de modelo en anchura. Separación entre discapacidades físicas y cognitivas

En el artículo *Implementing Accessibility in Educational Videogames with <e-Adventure>* (ver sección 6.1) se describe la primera propuesta de características de accesibilidad para herramientas de creación de juegos. En este artículo se identifican dos estrategias diferentes para mejorar la accesibilidad de los juegos con un coste reducido:

- Para las discapacidades físicas, es decir, ceguera, visión limitada, movilidad reducida y discapacidad auditiva, se propone la adaptación automática de la interfaz hombre-máquina proporcionada por el juego.

- Para las discapacidades cognitivas, se plantea un motor de adaptación basado en reglas que permita adaptar el contenido y diseño de juego según las necesidades del usuario.

Esta separación en dos grandes bloques surge del análisis de necesidades de los distintos perfiles de usuarios presentado en la sección 2.4, y de la que se concluye que las personas con discapacidad física (ceguera, visión limitada, movilidad reducida, discapacidad auditiva) y las personas con discapacidad cognitiva se enfrentan a barreras muy diferentes. Por un lado, las personas con discapacidad física se enfrentan a problemas relacionados fundamentalmente con la interacción con el juego, ya sea a la hora de percibir los estímulos que este produce (audio, video, etc.) como a la hora de introducir eventos de entrada para lanzar acciones en el juego. Por otro lado, las personas con discapacidad cognitiva encuentran la mayor parte de las barreras en aspectos relacionados con el diseño del juego (lenguaje utilizado, complejidad de los puzles, etc.).

Esto imposibilita seguir una estrategia unificada, puesto que los aspectos de interfaz, al estar ligados a la entrada y salida del sistema, son más propicios para su adaptación automática, siempre y cuando el modelo de interacción del juego esté claramente definido, mientras que las adaptaciones de los aspectos ligados al diseño del juego son absolutamente impredecibles, requiriendo una mayor intervención por parte del creador del juego.

En esta publicación también se esboza una propuesta de implementación sobre la plataforma eAdventure (ver Figura 21). Se diferencian tres sistemas separados de la siguiente manera:

- Un sistema que procesa el modelo de juego teniendo en cuenta el perfil del usuario (tipo de discapacidad, si la tuviese) y genera una versión de la interfaz que se adapta a sus necesidades. Esto puede realizarse en una única vez, cuando se lanza el juego. Por ejemplo, si el usuario no tiene discapacidad se lanza el juego con la interfaz clásica *point-and-click* de este tipo de juegos, donde la entrada se realiza a través del ratón, mientras que la realimentación que proporciona el juego se realiza fundamentalmente de manera visual. Por el contrario, si el usuario tiene discapacidad visual se puede lanzar el juego con una interfaz en la que la entrada se realiza a través de comandos formulados en lenguaje natural y que se introducen a través del teclado y la realimentación se proporciona mediante audio, que puede generarse mediante técnicas automáticas de síntesis de voz o grabaciones. La generación mediante síntesis de voz ayuda a ahorrar costes de sonorización, que pueden ser considerables. Para más información sobre cómo se generan las interfaces adaptadas al usuario y su funcionamiento, se puede consultar la sección 4.2.1.

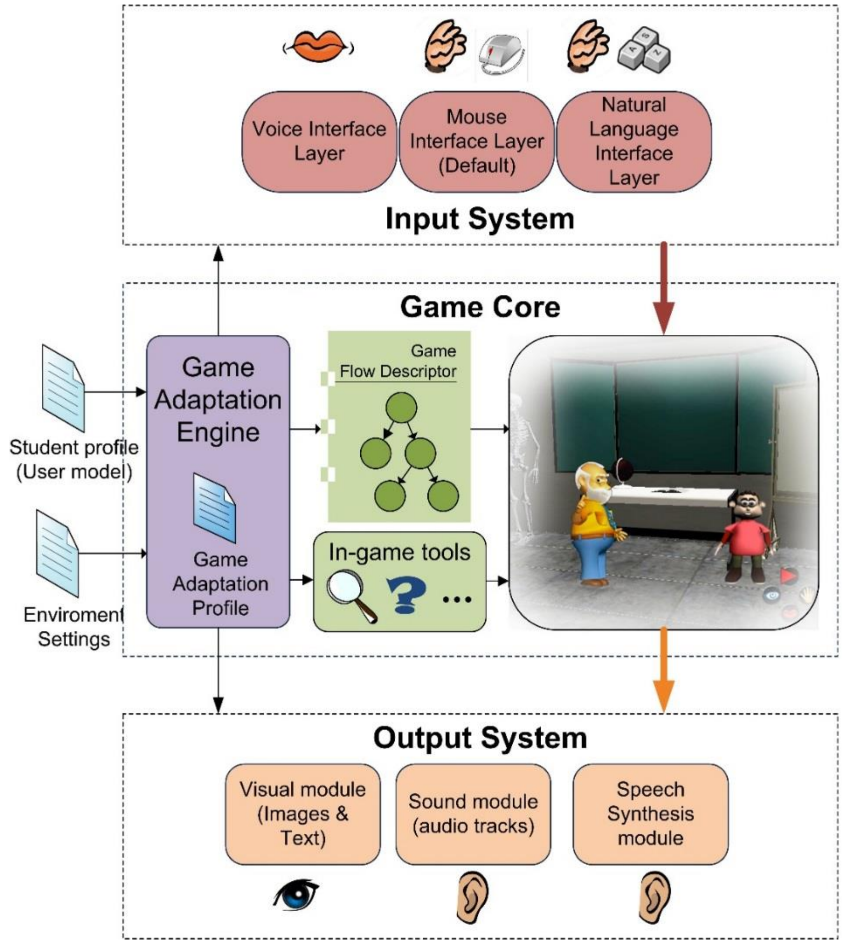

Figura 21. Propuesta inicial de implementación sobre la herramienta eAdventure.

- Un sistema de adaptación basado en reglas, que igualmente procesa el modelo de juego junto con el conjunto de reglas de adaptación que ha definido el autor del juego. Estas reglas de adaptación se definen en forma *condición* -> *efecto*, donde la *condición* se expresa en términos del perfil del usuario (que tenga discapacidad cognitiva) y también en términos internos del juego, para conseguir una adaptación lo más efectiva posible. En caso de que se disponga de un modelo de usuario más detallado, las condiciones de las reglas pueden tenerlo en cuenta para que la adaptación sea lo más particularizada posible a las necesidades del individuo. Por ejemplo, si se dispone de un parámetro "nivel de comprensión lectora baja" en el modelo de usuario se puede cargar una versión alternativa de los textos del juego. El *efecto* se define en términos de las adaptaciones que se deben realizar en el juego. El tipo de adaptaciones que se pueden definir dentro de los efectos de las reglas viene limitado únicamente por la capacidad expresiva de la plataforma de juegos donde se implemente.

- Por último, se complementan las adaptaciones anteriormente descritas con un conjunto de herramientas de apoyo que pueden configurarse y cargarse dentro del juego, integradas dentro de la atmósfera del mismo para no romper la inmersión del jugador. Como ejemplo concreto se plantea una herramienta magnificador que permite realizar zoom en la pantalla de una manera rápida y directa. Esta herramienta se introduce en el juego como una lupa, un objeto más que está disponible para el jugador a través del inventario.

4.1.2. Propuesta de modelo refinada. Finalización del análisis en anchura

En el artículo *Towards Universal Game Development in Education: Automatic and Semiautomatic Methodologies* (ver sección 6.4) se realiza una nueva propuesta de modelo, refinada gracias al desarrollo de dos casos de estudio (ver secciones 4.3.1 y 4.3.4). Este modelo propone dos novedades respecto al presentado en 4.1.1:

- Se refina el modelo de interfaz adaptativo propuesto para las personas con discapacidad física (ceguera, visión limitada, movilidad reducida, discapacidad auditiva), teniendo en cuenta que para conseguir la mayor usabilidad posible es necesario que la adaptación no sea automática sino semi-automática, esto es, teniendo en cuenta una cierta información de configuración adicional que el desarrollador del juego debe introducir. Esto implica un coste extra, aunque limitado.

- Se propone el desarrollo de herramientas de inspección y evaluación de problemas de accesibilidad específicas para juegos. Estas herramientas, que se presentarían al desarrollador igualmente integradas dentro de la herramienta de creación principal (eAdventure en este caso), tendrían como objetivo informar sobre potenciales problemas de accesibilidad en base a un análisis realizado sobre el modelo subyacente de juego. Con esto lo que se consigue es incrementar la concienciación del desarrollador sobre la necesidad de tener en cuenta las necesidades de las personas con discapacidad pero de una manera poco intrusiva. Este tipo de herramientas suponen una ayuda al desarrollador para configurar el motor de adaptación descrito en la sección 4.1.1 de una manera más eficaz, pues teniendo claros los problemas es mucho más fácil crear reglas que los detecten y solventen.

Con esto se completa la propuesta de modelo en anchura, pasando a ampliar el modelo en profundidad, previo estudio de evaluación de la propuesta, en base a otro caso de estudio, cuyos resultados se describen en la sección 4.3.4.

4.1.3. Ampliación del modelo en profundidad: interfaces alternativas para personas ciegas

En (Torrente, Marchiori, et al., 2012), artículo que se presenta en la sección 6.8, se proponen tres modelos de interfaz alternativos para personas ciegas, de nuevo para juegos tipo *point-and-click*:

1. Un modelo de interfaz basado en la introducción de comandos en lenguaje natural por teclado, que ya había sido propuesto anteriormente durante el análisis en anchura (ver 4.1.1 y 4.2.1 para más detalles).

2. Un modelo de interfaz basado en navegación cíclica por foco y estructurada por niveles (ver Figura 22). Esta interfaz permite al usuario recorrer los elementos interactivos (objetos, personajes, controles de la interfaz, etc.) presentes en la escena utilizando la tecla tabulador, tal y como se pueden recorrer los distintos controles de una página web utilizando el teclado. Esto es lo que se considera un *ciclo de foco* (conjunto de elementos del juego que se pueden recorrer cíclicamente pulsando una tecla). Para mejorar la usabilidad los elementos se estructuran en un árbol de ciclos de foco, de tal manera que el número de elementos en cada nivel no sea suficientemente alto como para generar frustración. Los distintos niveles de ciclos de foco se conectan a través de objetos y personajes del juego concretos (véase el armario en la Figura 22). Esta estructura en niveles no se determina automáticamente, sino que debe definirla el autor del juego a fin de que sea consistente con la semántica del mismo. Para pasar al siguiente nivel de ciclo de foco se utiliza la tecla intro, mientras que para volver al nivel anterior se utiliza la tecla escape. Las hojas del árbol están formadas por un ciclo de foco compuesto por las acciones disponibles para el elemento seleccionado (p.ej. coger, usar, hablar, etc.).

3. Un modelo de interfaz basada en audio 3D. Esta interfaz tiene como novedad para la persona ciega que propone el uso del ratón como dispositivo de entrada en lugar del teclado, un periférico que no están acostumbrados a utilizar. El cursor representa al oyente en el sistema de audio 3D. Cada elemento interactivo emite un sonido característico. Al mover el cursor la intensidad de cada sonido emitido por los elementos interactivos varía en intensidad (para dar información sobre su lejanía o cercanía al ratón), altavoz por el que se transmite (para dar información sobre la localización relativa del elemento respecto al cursor), y timbre agudo o grave (para dar información sobre la posición vertical relativa al cursor). De esta manera, el usuario recibe gran cantidad de información auditiva a fin de ser capaz de localizar los elementos interactivos en la escena con el ratón.

Cada una de estas interfaces se dirige a personas ciegas pero con características diferentes. La interfaz 2 se diseñó pensando en personas acostumbradas a utilizar la web pero que nunca han utilizado juegos, un perfil muy común dentro de las personas ciegas pues el abanico de juegos a los que pueden acceder es reducido (aunque todavía superior al de otras personas con discapacidad). Es por ello que esta interfaz es la más sencilla de utilizar, aunque también disminuye el nivel de desafío al que se enfrenta el usuario, ya que en estos juegos la exploración de la escena y el descubrimiento de los elementos interactivos supone un aliciente, lo que pone en riesgo la capacidad de atraer al jugador (Dede, 2009). En el extremo opuesto se presenta la interfaz 3, que presenta un reto mayor de lo normal al jugador por exponerle a utilizar un dispositivo inusual como es el ratón, y por tanto se presupone una interfaz más atractiva para personas acostumbradas a utilizar la tecnología con frecuencia y que tengan experiencia con juegos digitales. Estas dos interfaces se suman a la interfaz 1, incluida en el modelo de características de accesibilidad propuesto tras el análisis en anchura (ver 4.1.1). Se realizó una evaluación preliminar de las tres interfaces cuyos resultados se discuten en la sección 4.3.5.

Añadir estas interfaces al modelo propuesto complementa la aproximación basada en perfiles, cuya limitación radica en obviar las características individuales de cada persona.

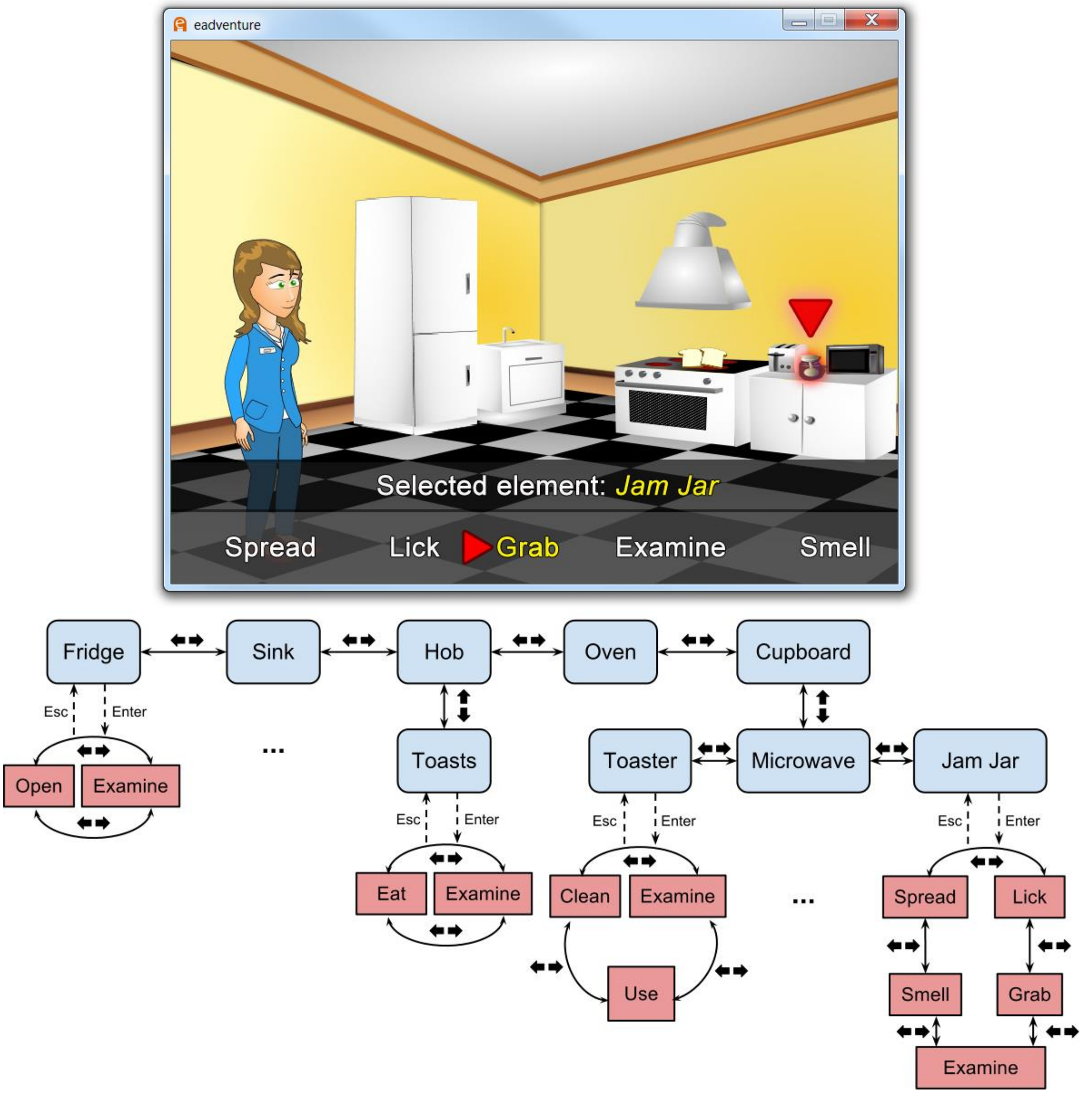

Figura 22. Ejemplo de juego con interfaz de navegación cíclica estructurada. En un primer nivel, el usuario puede utilizar el tabulador para mover el foco entre los distintos elementos interactivos que se encuentran en la escena (nevera, fregadero, placa, horno, armario). Una vez situado el foco en un elemento puede utilizarse la tecla intro para acceder al nivel inferior, si lo hubiere (por ejemplo, el tarro de mermelada que se encuentra sobre el armario). El último nivel corresponde a las acciones disponibles para ese elemento concreto.

4.2. Implementación como prueba de concepto en la herramienta eAdventure

4.2.1. Implementación del primer prototipo sobre eAdventure

En el artículo *Accessible Games and Education: Accessibility Experiences with eAdventure* (ver sección 6.2) se describe la implementación de referencia del modelo de características de accesibilidad realizado sobre la herramienta eAdventure, versión 1.5. En este artículo se describe en más detalle cómo funciona el modelo de interfaz propuesto para cada uno de los perfiles de discapacidad física considerados:

- Ceguera y movilidad reducida en las manos: los usuarios introducen comandos formulados en lenguaje natural, el sistema interpreta estos comandos y los ejecuta, si son válidos y puede determinarse su correspondencia con alguna interacción definida en el juego que esté activa, y proporciona realimentación al usuario según el resultado de dichas acciones. La diferencia es que el usuario ciego introduce estos comandos por teclado, mientras que el usuario con movilidad reducida en las manos lo hace mediante dictado. La realimentación del juego también cambia, pues para la persona con movilidad reducida ésta se proporciona mediante estímulos visuales, mientras que para la persona con ceguera se proporciona mediante estímulos auditivos, en forma de efectos sonoros y síntesis de texto a voz.

  El procesamiento de los comandos se realiza a través de una gramática regular que se genera automáticamente mediante análisis del modelo de juego, tal y como se describe en el artículo.

- Visión limitada: para los usuarios con este tipo de discapacidad se realiza una adaptación muy diferente, consistente en la aplicación de distintos filtros durante el renderizado del juego, con el objetivo de aumentar el contraste visual. Estos filtros resaltan los elementos interactivos sobre los no interactivos, facilitando su interacción con los mismos (ver Figura 23). También se adapta el tamaño de fuentes y objetos pequeños.

- Discapacidad auditiva: los juegos de aventuras *point-and-click* proporcionan la mayor parte de la realimentación al jugador en forma de texto, lo que facilita mucho el acceso a personas con discapacidad auditiva. Por tanto no se implementó ninguna adaptación automática para personas con discapacidad auditiva puesto que la propia herramienta eAdventure ya proporcionaba un soporte adecuado.

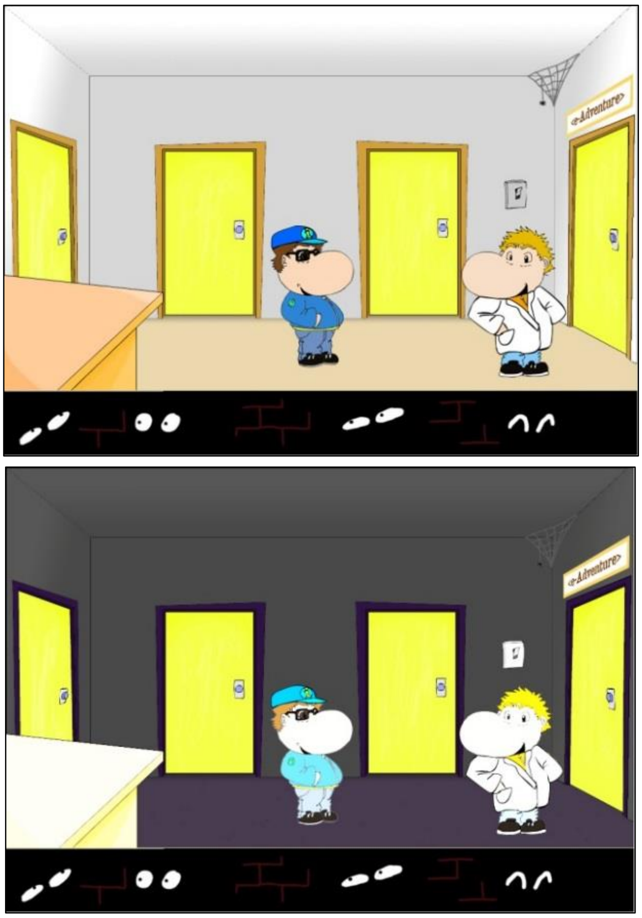

Figura 23. Ejemplo de cómo funciona la adaptación automática para personas con visión limitada (versión no adaptada arriba, versión adaptada abajo).

El desarrollo de esta prueba de concepto estuvo marcada por las limitaciones tecnológicas de la época (2009) referentes a productos de reconocimiento del habla y síntesis de voz. Hasta donde llega nuestro conocimiento, en ese momento no se disponía de productos libres de calidad suficiente, sobre todo en castellano. Tras considerar distintas opciones se decidió optar por la interfaz de voz proporcionada por *Microsoft*™, denominada *SAPI*™ (*Speech API*[53]). Esta API proporciona funcionalidad tanto de reconocimiento de voz (guiado por una gramática regular que debe proporcionarse siguiendo la especificación de *Microsoft*™) como de síntesis de texto a voz. La ventaja de esta solución es que *SAPI*™ se distribuye integrada con los distintos sistemas operativos de *Microsoft*™ desde Windows XP, por lo que solo fue necesario desarrollar un conector para poder utilizarla desde tecnología Java (lenguaje fuente de eAdventure). Esto se realizó a través del modelo COM de comunicación de interfaces de *Microsoft*™. También fue necesario integrar una voz en castellano compatible con *SAPI*™, pues *Microsoft*™ sólo proporciona soporte en inglés por defecto. Al ser necesario utilizar tecnología libre, se optó por utilizar las voces proporcionadas por el proyecto libre *eSpeak*[54], que proporciona voces compatibles con SAPI en multitud de idiomas, aunque de calidad considerablemente más baja

[53] http://msdn.microsoft.com/en-us/library/ee125663(v=vs.85).aspx
[54] http://espeak.sourceforge.net/

que los productos comerciales. Esto resultó un problema para los usuarios finales, tal y como se describe en la sección 4.3.4.

En este artículo también se describe cómo se pueden configurar estas opciones de accesibilidad a través de la herramienta de autor de eAdventure 1.5 (ver Figura 24).

Cabe destacar que la implementación final propuesta es el resultado de distintas iteraciones llevadas a cabo en base a casos de estudio y evaluaciones de usabilidad, tal y como se describe en la sección 4.3.

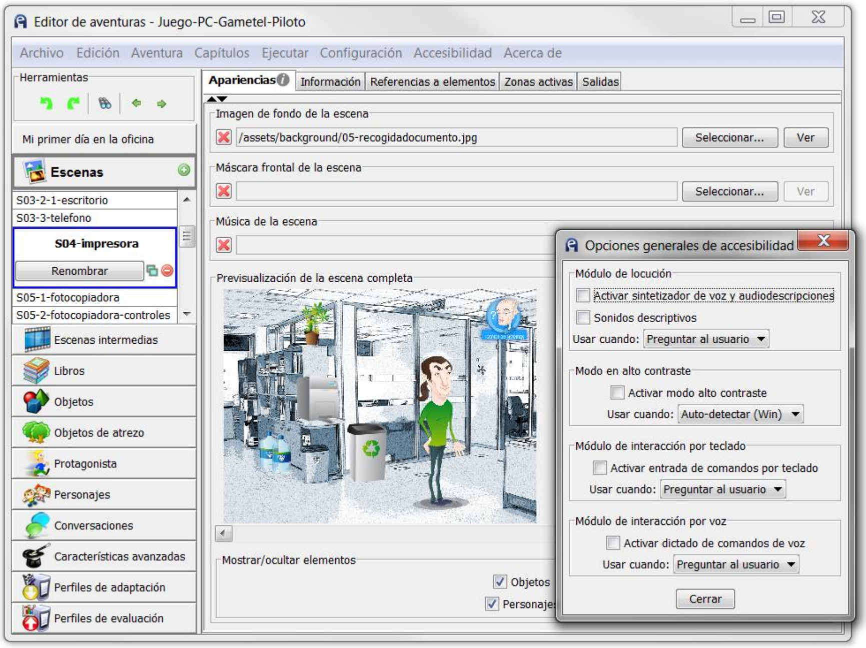

Figura 24. Captura del prototipo desarrollado sobre la herramienta eAdventure. En la ventana de diálogo que se muestra en la parte inferior derecha se pueden observar algunas de las opciones de accesibilidad configurables.

4.2.2. Propuesta de implementación en eAdventure 2.0

La prueba de concepto implementada sobre eAdventure 1.5, tal y como se describe en la sección anterior (4.2.1), estuvo marcada por la necesidad de resolver problemas técnicos complejos, necesitando adoptar una solución de compromiso para la evaluación del modelo propuesto. Es por esto que dicha implementación nunca fue publicada oficialmente ni puesta en producción. Las limitaciones relacionadas con la tecnología utilizada para desarrollar los módulos de reconocimiento de voz y síntesis de texto a voz, obtenida de terceras partes, resultaron finalmente insalvables por las siguientes razones:

- Incompatibilidad de licencias. eAdventure tiene una licencia abierta LGPL incompatible con la tecnología *SAPI*™ de *Microsoft*™.

- Baja calidad de síntesis de voz. Las voces utilizadas, proporcionadas por el proyecto libre *eSpeak* tenían una calidad insuficiente para justificar su pase a producción.

- Funcionamiento restringido a sistemas Windows. eAdventure es una herramienta multiplataforma, mientras que la tecnología *SAPI*™ sólo está disponible en sistemas con Windows.

Al ser eAdventure 1.5 una herramienta desarrollada en Java no fue posible encontrar una alternativa de garantías a la solución basada en *SAPI*™. Esta limitación no se presenta en eAdventure 2.0, nueva versión de la herramienta que está siendo desarrollada con el objetivo de que los juegos sean multiplataforma. Esto incluye tanto el escritorio (PC/Mac/Linux), mediante uso de tecnología Java, como dispositivos móviles Android y la Web mediante tecnología HTML5. Son estas dos últimas opciones las más prometedoras en materia de accesibilidad pues proporcionan soporte nativo para síntesis de voz y reconocimiento de voz utilizando tecnología de Google, de gran calidad. Debido al estado inestable del proyecto eAdventure 2.0 no han podido integrarse las soluciones de accesibilidad propuestas en este trabajo de tesis, aunque el enfoque a seguir ya ha sido planteado desde un punto de vista técnico, tal y como se describe en el artículo *Development of a Game Engine for Accessible Web-Based Games*, último artículo que se incluye en esta tesis y que puede consultarse en la sección 6.12.

4.3. Casos de estudio y usabilidad

4.3.1. Primeros casos de estudio

El primer caso de estudio consistió en una pequeña prueba realizada sobre *1492*[55], un juego desarrollado con eAdventure ya existente, y del que se adaptaron las primeras escenas para su uso por personas con ceguera y movilidad reducida. Dicho caso, de alcance reducido, se describe en el artículo *Accessible Games and Education: Accessibility Experiences with eAdventure* (ver sección 6.2). Este trabajo fue evaluado de manera informal por dos usuarios con discapacidad, uno de cada perfil, lo que sirvió para identificar distintos problemas y potenciales mejoras.

Un aspecto relevante de este caso de estudio es que tuvo presencia mediática. Una persona con discapacidad realizó una demostración de las características de accesibilidad que incluía la versión adaptada de 1492 para Radio Televisión Española (RTVE). Esta demostración fue emitida en el sexto capítulo del serial sobre las personas con discapacidad *El Mundo se Mueve Conmigo*, dentro de la sección *Tecnosoluciones*, emitido el día 12 de abril de 2010 a las 15:00. El programa puede visionarse online a través de la web de RTVE[56] y del canal que el grupo e-UCM tiene en Youtube[57].

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[55] http://e-adventure.e-ucm.es/course/view.php?id=21
[56] http://www.rtve.es/mediateca/videos/20100413/tecno-soluciones-ocio-tiempo-libre-adaptado/743483.shtml
[57] http://www.youtube.com/watch?v=ROg3pjnfi8U

Tras mejorar tanto el modelo propuesto (sección 4.1.2) como el prototipo desarrollado sobre eAdventure (4.2.1) se elaboró un nuevo caso de estudio. En esta ocasión se desarrolló un juego nuevo por completo, tal y como se describe en el artículo *Designing Serious Games for Adult Students with Cognitive Disabilities* (ver sección 6.3). Este juego fue desarrollado en colaboración con expertos en accesibilidad e integración laboral de *Technosite*, empresa del grupo ONCE.

El juego se titula *Mi primer día de trabajo* (Figura 25) y pretende servir como toma de contacto al trabajo de oficina para un trabajador con discapacidad que se incorpora a una nueva empresa. De esta manera se intenta que el juego tenga un fin educativo y social claro, además de servir como caso de estudio para evaluar la introducción de características de accesibilidad. El juego se dirige fundamentalmente a personas con discapacidad intelectual, por lo que sirvió también para explorar los aspectos de adaptación del diseño de juego para personas con discapacidad cognitiva recogidos en el modelo propuesto.

Figura 25. Detalle del juego *Mi primer día de trabajo*. En la imagen se aprecia un diálogo con uno de los personajes.

El jugador se pone en el papel de Javier Pérez, un trabajador que se incorpora a su nuevo puesto de trabajo en la empresa ficticia "ACME Social". Para finalizar el juego con éxito, el jugador debe completar los siguientes objetivos:

- Aprender a interactuar con el equipamiento de la oficina, según las necesidades específicas de cada jugador: ordenador, impresora, fax, fotocopiadora y una máquina de bocadillos.

- Adquirir conocimientos básicos sobre la aplicación de correo electrónico: qué es un mensaje electrónico, acceso a correos entrantes, envío de nuevos correos, descarga y manejo de ficheros adjuntos.

- Adquirir habilidades sociales básicas: trato respetuoso hacia los compañeros, solicitar ayuda cuando es necesario, etc.

- Conocer la estructura organizativa de la empresa, su organigrama, áreas, departamentos, personas y lugares importantes.

Para superar estos objetivos, el jugador debe completar tareas básicas asignadas por la dirección de la empresa. Para ello deberá interactuar con los objetos y personajes que se encuentre a su paso, siguiendo el estilo de las aventuras gráficas conversacionales. El juego está diseñado en primera persona para lograr una mayor inmersión del usuario en el mundo del juego.

Una vez desarrollado el juego se incluyeron las características de accesibilidad para personas con discapacidad física descritas en 4.1.1 y 4.1.2, utilizando el prototipo analizado en la sección 4.2.1, siguiendo un enfoque *a posteriori* tal y como se describe en el capítulo 3. Este enfoque permitió estimar de una manera más precisa el esfuerzo asociado a la introducción de accesibilidad utilizando el prototipo eAdventure (sección 4.4.1). La usabilidad de estas características de accesibilidad fue evaluada con 14 usuarios, tal y como se describe en la sección 4.3.3, previo desarrollo de una metodología de evaluación adecuada (ver sección 4.3.2).

4.3.2. Desarrollo de una metodología para la evaluación de accesibilidad

Tal y como se discute en los capítulos 2 y 3, no existen metodologías de evaluación de accesibilidad adecuadas para juegos. Es por ello que antes de evaluar la accesibilidad del juego *Mi primer día de trabajo* se desarrolló una metodología de evaluación apropiada. Esta metodología se describe en el artículo *Usability Testing for Serious Games: Making Informed Design Decisions with User Data* (ver sección 6.6). Ésta metodología no sólo tiene en cuenta la accesibilidad del juego, sino la usabilidad en su conjunto, siguiendo un enfoque más amplio. Además toma en consideración las particularidades de los *serious games*, tales como el valor educativo del juego. La metodología combina estrategias de los métodos de evaluación tipo *think-aloud*[58] y de la evaluación de interfaces basada en heurísticas. Las sesiones de cada usuario se graban y revisan por expertos que identifican problemas de usabilidad y los tipifican utilizando una clasificación propuesta. Cada sesión es revisada por más de un experto para mayor fiabilidad. Los diferentes expertos se reúnen y ponen en común los problemas identificados a fin de generar una única lista de problemas consensuada y proponer soluciones.

[58] Métodos de evaluación de usabilidad en los que se pide al usuario que realice una serie de tareas con el sistema software a analizar y que verbalice su experiencia en alto durante todo el proceso.

4.3.3. Evaluación de la accesibilidad del juego Mi primer día de trabajo

Tras desarrollar el juego *Mi primer día de trabajo* (ver sección 4.3.1) así como una metodología de evaluación adecuada (ver sección 4.3.2), se realizó una evaluación de usabilidad del juego en la que participaron 14 usuarios con distintos perfiles:

- 5 personas sin discapacidad física, que sirvieron como grupo de control.
- 3 personas con ceguera.
- 3 personas con visión limitada.
- 3 personas con movilidad reducida en las manos.

No se incluyeron personas con discapacidad auditiva por considerar los expertos en accesibilidad de Technosite, junto con los que se desarrolló el juego, que sus necesidades estaban cubiertas por la funcionalidad que eAdventure incluye por defecto.

El objetivo de esta evaluación era analizar el nivel de accesibilidad logrado tras introducir las características de accesibilidad recogidas en el modelo propuesto en las secciones 4.1.1 y 4.1.2. Sólo se tuvieron en consideración las interfaces generadas semi-automáticamente. Los resultados de esta evaluación se describen en el artículo *Evaluation of Semi-automatically Generated Accessible Interfaces for Educational Games* (ver sección 6.7) que se encuentra todavía en proceso de revisión. Estos resultados son alentadores, aunque muestran aspectos en los que las interfaces adaptadas semiautomáticamente todavía pueden mejorar. No obstante, la mayor parte de los problemas identificados tienen que ver con problemas de calidad de los productos de terceros utilizados (síntesis de voz, reconocimiento de voz). Además tanto el juego como las características de accesibilidad introducidas fueron muy bien acogidos por parte de los usuarios.

Con esto se dieron por validadas las interfaces accesibles propuestas, así como su generación semi-automática, principales aportaciones del modelo descrito en las secciones 4.1.1 y 4.1.2, a falta únicamente de validar las extensiones propuestas en la sección 4.1.3 para personas con ceguera.

4.3.4. Último caso de estudio. Evaluación de usabilidad de las características propuestas en 4.1.3

Las interfaces alternativas para personas ciegas descritas en 4.1.3 se evaluaron mediante un último caso de estudio. Esta evaluación se describe en el artículo *Evaluation of Three Accessible Interfaces for Educational Point-and-Click Computer Games* (ver sección 6.9).

En la evaluación participaron cuatro usuarios ciegos con distinta experiencia previa en juegos. Dos de ellos habían jugado a juegos digitales adaptados previamente. Uno de ellos incluso reconoció jugar a juegos accesibles para ciegos en su Smartphone. Los otros dos usuarios no tenían experiencia previa en juegos.

Para la evaluación se crearon tres mini-juegos de tipo aventura *point-and-click*, de estética, duración y contenido similares. Cada uno se configuró con una de las tres interfaces descritas en 4.1.3. En estos juegos se pedía a los usuarios que resolvieran un determinado crimen. Para ello tenían que inspeccionar la escena del crimen en busca de pruebas e indicios, hasta averiguar el móvil y el autor del crimen. Los cuatro usuarios jugaron a cada uno de los juegos, pero en un orden diferente.

Se evaluó tanto la usabilidad como el entretenimiento proporcionado por cada uno de los juegos. Las tres interfaces puntuaron positivamente en ambos aspectos aunque a niveles diferentes. La más usable fue la interfaz número 2, basada en navegación cíclica estructurada, por ser la más familiar para los usuarios. La interfaz que los usuarios encontraron más entretenida fue la número 3, basada en audio 3D, independientemente del perfil del usuario. Esto sorprendió a los investigadores por plantear una interacción muy diferente frente a la que suelen estar acostumbrados las personas con ceguera.

Con esta sencilla evaluación se dio por completada la fase de evaluación de usabilidad planteada en el capítulo 3.

4.4. Evaluación final

4.4.1. Análisis del coste

El último de los objetivos propuestos para este trabajo de tesis es realizar un análisis sobre el coste asociado a la introducción de accesibilidad en *serious games* utilizando las características de accesibilidad propuestas y la implementación realizada sobre la plataforma eAdventure. Esto es necesario a fin de evaluar si el enfoque general propuesto es efectivo, que trata de reducir el esfuerzo que necesitan invertir los desarrolladores para hacer que un juego sea accesible como vía para aumentar el nivel de accesibilidad de los juegos digitales en general, y de los *serious games* en particular.

Hacer estimaciones de coste en desarrollo software no es tarea sencilla, más aún si se plantea sobre juegos digitales. En este caso la complejidad aumenta por tratar de determinarse el coste asociado únicamente a un conjunto de tareas (las que tienen que ver con la accesibilidad), aisladas del resto de actividades necesarias para el diseño e implementación de un juego digital.

A fin de acotar el problema lo más posible se desarrolló un juego completo (*Mi primer día de trabajo*, ver secciones 4.3.1 y 4.3.3) y se introdujeron las características de accesibilidad después (enfoque *a posteriori*). Se contabilizaron las tareas que fueron necesarias para conseguir que el juego fuera accesible para personas ciegas, con visión limitada, movilidad reducida y discapacidad auditiva. Estas son:

1. Añadir descripciones adicionales para objetos y personajes, necesarias para el correcto funcionamiento del sistema de síntesis de voz que genera realimentación auditiva para usuarios ciegos.

2. Añadir sinónimos para referirse a objetos, personajes y acciones del juego (p.ej. coger/tomar/agarrar). Estos sinónimos, aunque no son imprescindibles, mejoran mucho la usabilidad del sistema de reconocimiento de comandos formulados en lenguaje natural diseñado tanto para personas ciegas como para personas con movilidad reducida.

3. Añadir algunos tutoriales especiales para usuarios ciegos y con movilidad reducida, a fin de reducir la curva de aprendizaje de las interfaces propuestas al comienzo del juego y hacer que el juego fuera autocontenido.

4. Recursos artísticos adicionales (efectos de audio e imágenes adaptadas). Estos recursos tampoco son imprescindibles para el funcionamiento de las versiones adaptadas de los juegos, pero igualmente mejoran la experiencia de usuario y por tanto son muy recomendables.

Posteriormente se estimó el esfuerzo[59] que fue necesario para completar dichas tareas. Este esfuerzo se calcula como una medida relativa en función del incremento del tamaño de distintos aspectos del juego tras introducir la accesibilidad. Por ejemplo, el esfuerzo asociado a la tarea 4 se calculó comparando el número de recursos artísticos (imágenes, sonidos, animaciones) que tenía el juego con el número de recursos que se tuvieron que añadir para que las distintas versiones adaptadas funcionaran correctamente.

Es importante mencionar que no todas las tareas anteriormente descritas requieren el mismo esfuerzo. Las tareas 1 y 2 conllevan únicamente la creación de texto adicional, actividad que tiene un esfuerzo bajo. La tarea 3 conlleva un esfuerzo mayor puesto que requiere de ampliar ligeramente el diseño de juego. La tarea 4, por su parte, es la que tiene un coste más elevado pues requiere además de un perfil especializado (artista gráfico).

Los resultados de dicho análisis se presentan en el artículo *Towards a Low Cost Adaptation of Educational Games for People with Disabilities* (ver sección 6.5). Un resumen de los mismos se incluye en la siguiente tabla (ver Figura 26). En el artículo se concluye que el esfuerzo necesario para introducir las características de accesibilidad fue asequible, puesto que la mayor parte del

[59] Nótese que en este contexto se utilizan los términos coste y esfuerzo casi como sinónimos. Dado que el coste del desarrollo software viene fundamentalmente determinado por el coste humano, consideramos que el coste de la accesibilidad puede estimarse directamente a través del esfuerzo (horas) que es necesario invertir.

trabajo adicional se centró en tareas de bajo esfuerzo (1-2), mientras que a las tareas más costosas (generación de recursos) apenas se les dedicó tiempo.

Tarea	Perfil(es)	Esfuerzo relativo
Descripciones adicionales para objetos y personajes	Ceguera	60,98% (líneas de texto del juego)
Sinónimos para referirse a objetos, personajes y acciones comunes	Ceguera, movilidad reducida	271,28%
Tutoriales especiales	Ceguera, movilidad reducida	10,32% (diseño del juego)
Recursos artísticos adicionales	Ceguera, movilidad reducida, visión limitada	8,86%

Figura 26. Tabla con información referente al esfuerzo relativo necesario para producir versiones adaptadas del juego *Mi primer día de trabajo* utilizando el prototipo desarrollado. El esfuerzo se estima comparando la cantidad de elementos añadidos durante el proceso de introducción de accesibilidad (momento 2) frente a los que tenía el juego tras completar la primera versión no accesible (momento 1). Porcentaje = 100 x (Cantidad 2 – Cantidad 1) / Cantidad 1.

4.4.2. ACM Student Research Competition

Finalmente, en este trabajo de tesis se incluyen otros dos artículos titulados *Reusable Game Interfaces for People with Disabilities* y *Supporting Player Diversity: Game Interfaces for People with Disabilities*, que sirven como validación final del enfoque en su conjunto así como de los principales resultados obtenidos (ver secciones 6.10 y 6.11).

El artículo *Reusable Game Interfaces for People with Disabilities* (ver 6.10) resultó ganador del certamen *Student Research Competition* del congreso ASSETS 2012 que organiza anualmente la ACM (*Association for Computing Machinery*) bajo el patrocinio de *Microsoft*™, uno de los congresos más relevantes en el campo de las tecnologías accesibles (tasa de aceptación inferior al 26%). En este artículo se presenta un resumen del trabajo realizado durante la tesis así como del enfoque seguido. En este certamen, los trabajos participantes tienen que pasar primero un proceso de revisión por pares que tiene lugar antes de la celebración del congreso. Los trabajos seleccionados son expuestos en una sesión de pósters, donde son valorados por un jurado especializado que hace una segunda selección de los mismos. Los trabajos mejor puntuados pasan a la final, en la que el jurado decide el trabajo ganador en base a la calidad de una exposición pública que cada candidato debe realizar.

Como ganadores del certamen tuvimos la oportunidad de participar con el artículo *Supporting Player Diversity: Game Interfaces for People with Disabilities* en la fase mundial (*Grand Finals*), que reúne a los ganadores de los congresos ACM de diferentes temáticas celebrados ese año. En esta segunda fase el trabajo fue revisado por un jurado formado por cuatro miembros senior de la ACM. A pesar de no ganar la final, la realimentación recibida fue muy positiva, alentando a continuar con el trabajo iniciado.

Capítulo 5: Conclusiones y trabajo futuro

En este capítulo se resumen, a modo de conclusión, las principales aportaciones realizadas en este trabajo de tesis. Además, se esbozan las líneas de investigación que quedan abiertas y que se plantean como trabajo futuro.

5.1. Conclusiones y principales aportaciones

La principal aportación de esta tesis es la propuesta de una serie de características de accesibilidad configurables que pueden integrarse en herramientas de creación de juegos digitales a fin de facilitar la creación de juegos digitales accesibles en general, y *serious games* en particular. Además se ha desarrollado una implementación sobre la herramienta eAdventure a modo de prueba de concepto, junto con tres casos de estudio. Esto tiene como principales ventajas las dos siguientes:

1. Reducir el esfuerzo que los desarrolladores necesitan invertir para hacer que un juego sea accesible para personas con discapacidad.
2. Aumentar la visibilidad del problema de la accesibilidad entre la comunidad de desarrolladores gracias a su integración en sus herramientas de trabajo diario, mejorando su concienciación.

Esto supone por tanto que el enfoque adoptado se ha centrado en el *desarrollador*, puesto que se abordan los principales problemas que tienen los desarrolladores para mejorar la accesibilidad de los juegos digitales.

Durante el trabajo también se han realizado una serie de contribuciones adicionales en el campo de los *serious games* y de la accesibilidad en juegos digitales que se describen brevemente en las siguientes subsecciones.

5.1.1. Estudio del dominio

Toda tesis tiene como subproducto un análisis del dominio en cuestión. Tal y como se describe en el capítulo 2, en este caso se ha realizado un estudio sobre el estado actual de la accesibilidad en juegos digitales en general, y *serious games* en particular, desde un punto de vista crítico. Se han identificado distintos enfoques, que podrían clasificarse a groso modo de la siguiente manera:

- Enfoques *ad-hoc*. Son aquellos en los que se toma un juego concreto como caso de estudio, ya sea uno existente o desarrollado desde cero, y se mejora su accesibilidad pensando en un conjunto de discapacidades que suele ser limitado (una o dos a lo sumo). A su vez se identifican dos subgrupos según el punto del desarrollo en el que se empieza a tener en cuenta la accesibilidad:

    - Enfoques *a priori*: la accesibilidad se toma en cuenta desde el primer momento. Esto tiene como ventaja que las potenciales barreras de accesibilidad se identifican rápidamente, lo que permite una resolución más rápida, sencilla y ágil.

    - Enfoques *a posteriori*: la accesibilidad se introduce una vez se encuentra disponible una versión completa del juego. Este enfoque suele adoptarse cuando se desea mejorar la accesibilidad de un juego publicado por terceros (caso típico en juegos comerciales).

- Enfoques generalistas. Son aquellos trabajos que abordan la accesibilidad desde un punto de vista más amplio, tratando de proponer recomendaciones, directrices y metodologías que puedan aplicarse a distintos juegos y/o discapacidades. El problema de estos enfoques es que, además de ser minoritarios, están poco desarrollados y carecen normalmente de implementaciones de referencia de gran calado.

Este trabajo tiene un espíritu fundamentalmente generalista. En primer lugar porque propone una serie de características de accesibilidad que puedan integrarse en herramientas de creación de juegos, lo que permite su reutilización en distintos juegos. Y en segundo lugar, porque considera un espectro amplio de discapacidades, poniendo el foco en las principales discapacidades físicas (ceguera, visión limitada, movilidad reducida, discapacidad auditiva) pero prestando atención también, aunque en menor profundidad por la complejidad que representan, a las discapacidades cognitivas.

Igualmente se ha realizado un análisis crítico de los principales problemas de accesibilidad a los que se enfrentan las personas con discapacidad a la hora de jugar a juegos digitales, así como de las distintas soluciones existentes. Este análisis se ha tomado como punto de partida a la hora de diseñar las interfaces generadas semi-automáticamente que constituyen el núcleo de las características propuestas (ver sección 4.1). Además ha servido para orientar el alcance de esta tesis así como para determinar las principales discapacidades con las que se iba a trabajar.

También se ha realizado un conjunto de análisis complementarios con el objetivo de contextualizar mejor este trabajo de tesis y acotar su alcance. Esto incluye las siguientes áreas:

- Estado de la accesibilidad en campos como la Web o los entornos de e-learning. Este análisis resulta fundamental para poner en contexto la escasa atención que se ha prestado a la accesibilidad en juegos digitales comparado con otras áreas.

- Diversificación del sector de los juegos digitales, así como las distintas opciones existentes con diferente valor educativo y características de accesibilidad. Este análisis permitió acotar el alcance del trabajo, centrándolo en un único género, el de las aventuras gráficas *point-and-click*, que aúnan un mayor valor educativo y menor número de barreras de accesibilidad que otros géneros.

- Herramientas y enfoques disponibles para la creación de juegos, teniendo en cuenta la diversificación actual del mercado, a fin de contextualizar la elección de una plataforma concreta para la implementación de una prueba de concepto (eAdventure).

5.1.2. Modelo de características de accesibilidad configurables para herramientas de creación de juegos

Partiendo del estudio del dominio se ha realizado una propuesta de características de accesibilidad configurables para herramientas de creación de juegos (ver sección 4.1). El objetivo es que el desarrollador encuentre integradas en su herramienta de creación de juegos un conjunto de funcionalidades configurables listas para usar. Estas funcionalidades se exponen al desarrollador al mismo nivel que el resto de funcionalidades necesarias para crear un juego, tales como la edición del mundo virtual, configuración de reglas físicas, inteligencia artificial o creación de animaciones, lo que favorece la concienciación. Cabe destacar que este modelo (ver sección 4.1), es aplicable a cualquier herramienta o entorno de desarrollo de juego.

El conjunto de funcionalidades propuestas, centrándose en los juegos de aventura gráfica tipo *point-and-click*, puede resumirse de la siguiente manera:

- Un conjunto de interfaces alternativas a la interacción *point-and-click*, generadas semi-automáticamente a partir del modelo de juego (que debe estar disponible de manera explícita) y de una cierta información complementaria que proporciona el usuario, en forma de sinónimos, descripciones adicionales, y un número limitado de recursos gráficos alternativos. Estas interfaces son las siguientes:
    - Para usuarios ciegos:
        - Interacción mediante introducción de comandos en lenguaje natural por teclado (p.ej. "abrir puerta" o "hablar con chica") y retorno de la información mediante efectos de audio y locuciones generadas por un motor de síntesis de voz.
        - Interacción mediante navegación entre los elementos interactivos utilizando el foco (similar a la interacción por teclado en formularios Web).
        - Interacción mediante ratón, ayudado por un sistema de audio 3D que proporciona información al jugador sobre la posición relativa de los elementos interactivos.

- Para usuarios con visión limitada: interacción *point-and-click* (no adaptada) sobre un esquema de renderizado adaptado mediante filtros que aumenta el contraste y el tamaño de elementos y texto.

- Para usuarios con movilidad reducida en las manos: interacción mediante introducción de comandos en lenguaje natural (p.ej. "abrir puerta" o "hablar con chica") dictados y retorno de la información mediante estímulos visuales.

- Para usuarios con discapacidad auditiva: interacción *point-and-click* (no adaptada) con retorno de la información textual (subtitulado oculto).

- Un motor de reglas de adaptación para modificar dinámicamente aspectos relacionados con el diseño, el contenido, la historia, los puzles o la mecánica de juego. Estos aspectos son poco propensos a ser adaptados automática o semiautomáticamente, por lo que las reglas debe introducirlas de manera explícita el creador del juego. Este motor puede utilizarse para satisfacer las necesidades de cualquier tipo de usuario, aunque inicialmente se considera que su uso sería especialmente adecuado para personas con discapacidad cognitiva.

- Un conjunto de utilidades adicionales de accesibilidad, integradas en la metáfora de juego para no dañar la inmersión, como puede ser una lupa. Desde un punto de vista de autoría, incluir estas herramientas no supone esfuerzo, puesto que pueden añadirse en tiempo de ejecución según la discapacidad y las preferencias del usuario.

- Un conjunto de herramientas de inspección de problemas de accesibilidad, que permitan generar informes sobre potenciales problemas, tal y como funcionan herramientas similares para la evaluación de accesibilidad en la web.

El aspecto en el que más se ha avanzado es el primero, las interfaces generadas semi-automáticamente. El resto de utilidades se proponen dentro del modelo conceptual propuesto, pero no se ha realizado una implementación de referencia.

Este modelo y su correspondiente implementación en eAdventure han sido evaluados de varias maneras:

- De manera iterativa y continua, en materia de usabilidad, a través de la realización de casos de estudio

- De manera final, en aspectos relacionados con el coste de hacer que un juego completo fuera accesible

- En última instancia, mediante revisión por expertos durante nuestra participación en el certamen *ACM Student Research Competition*, en el que el trabajo resultó ganador del primer premio de la fase local celebrada en el congreso ASSETS 2012 especializado en tecnologías accesibles.

5.1.3. Casos de estudio

Este trabajo también supone una contribución en la forma de tres casos de estudio, desarrollados en colaboración con expertos en accesibilidad de *Technosite*, empresa del grupo ONCE:

- Un primer caso de estudio, de alcance reducido, en el que se adaptaron las primeras escenas del juego ya existente *1492* (desarrollado con eAdventure) para personas con ceguera y movilidad reducida en las manos. Este trabajo obtuvo una gran difusión al aparecer en un serial de Radio Televisión Española dedicado a las personas con discapacidad.

- Un segundo caso de estudio de alcance mucho más ambicioso, en el que se desarrolló desde cero el juego *Mi primer día de trabajo*, sobre el que posteriormente se añadieron características de accesibilidad para personas con ceguera, visión limitada y movilidad reducida en las manos. Este juego es una contribución significativa en sí mismo por dos razones:

    - Por tener un enfoque educativo y social, puesto que el juego trata de facilitar la integración laboral de personas con discapacidad intelectual. Los usuarios que participaron en la evaluación del juego mostraron además un gran interés por el juego por su valor educativo y su capacidad para entretener.

    - Por servir de caso de demostración de las características de accesibilidad propuestas en el análisis en anchura para las discapacidades físicas (ver 4.1.1 y 4.1.2).

- Un tercer caso de estudio, centrado en las interfaces alternativas para personas con ceguera propuestas en el análisis en profundidad. En este caso de estudio se analiza la usabilidad así como la capacidad de captar el interés del jugador de tres interfaces con características distintas.

5.1.4. Contribuciones a la evaluación de usabilidad y accesibilidad en juegos

Finalmente, se ha realizado una serie de contribuciones significativas en materia de análisis de usabilidad y accesibilidad en juegos. Esto además de permitirnos validar las características de accesibilidad propuestas, supone una aportación en los siguientes sentidos:

- Se ha desarrollado una metodología específica para la evaluación de *serious games*, que no solo abarca aspectos de accesibilidad sino de usabilidad en general por lo que puede aplicarse de una manera más amplia. Esta metodología combina aspectos de evaluación basada en métodos *think-aloud*, heurísticas y evaluación por expertos, y permite generar datos tanto cuantitativos como cualitativos para poder realizar una evaluación más completa.

- Se ha aplicado dicha metodología para evaluar el segundo caso de estudio, el más completo y complejo realizado en este trabajo de tesis, que sirve como ejemplo de cómo se puede aplicar dicha metodología para evaluar el nivel de accesibilidad de los *serious games*.

- También se han evaluado aspectos de usabilidad en los dos casos de estudio restantes, en colaboración con *Technosite*, empresa del grupo ONCE, teniendo en consideración a expertos en accesibilidad y usuarios finales. En estos casos no se ha aplicado la metodología completa, por no disponer de suficientes usuarios finales, sino que se ha seguido un enfoque más informal.

5.2. Trabajo futuro

En toda tesis doctoral es común identificar nuevos retos y problemas a abordar según se resuelven los propuestos inicialmente, y que se dejan como trabajo futuro. En esta sección describimos brevemente las líneas de trabajo futuro que consideramos más relevantes separadas en dos grupos claramente diferenciados: líneas de investigación, y tareas de implementación y desarrollo.

5.2.1. Líneas de investigación

Las líneas de investigación que consideramos más prometedoras que surgen a partir de este trabajo son las siguientes, expuestas sin ningún orden concreto:

- Desarrollar la propuesta de herramientas de inspección y evaluación de accesibilidad, propuestas en 4.1.2, y que por limitaciones de tiempo no pudieron llegarse a desarrollar. Además esta tarea será algo más fácil de abordar según vayan madurando y ganando consenso las directrices disponibles sobre accesibilidad en juegos digitales, lo que la convierte en una línea de investigación muy prometedora de cara al futuro.

- Abordar el problema de la accesibilidad de las propias herramientas de autoría. No sólo existen jugadores con discapacidad, sino que también hay desarrolladores con discapacidad. Es por tanto relevante realizar propuestas sobre cómo se puede mejorar la accesibilidad de unas herramientas tan complejas y visuales como son estas.

- Realizar un análisis en profundidad sobre otras discapacidades, al estilo del trabajo realizado para las personas con ceguera en este trabajo, a fin de proponer interfaces adecuadas para las características personales de cada individuo.

- Explotar la adaptación en tiempo real de las interfaces. Sería interesante aplicar tecnologías actuales como los agentes software o sistemas de recomendación basados en casos para conseguir que las interfaces generadas automáticamente aprendan a través de la interacción con el usuario y se adapten a sus características específicas.

- Ampliar el modelo propuesto a otro tipo de juegos, que tengan o no valor educativo, y teniendo en cuenta otras herramientas y enfoques de creación de juegos. Ésta es quizá una de las principales limitaciones del presente trabajo, puesto que sólo se ha abordado una plataforma y un tipo de juegos, por la necesidad de limitar el alcance.

- Profundizar en el trabajo con los desarrolladores. Para que este enfoque tenga impacto es imprescindible dar difusión al problema de la accesibilidad así como a las soluciones existentes. Obtener realimentación por parte de la comunidad de desarrolladores de juegos (de la que nos consideramos parte) de una manera aún más amplia ayudaría mucho a refinar el enfoque así como las propuestas realizadas en este trabajo de tesis.

- Aplicar técnicas de *learning analytics* (Ferguson, 2012) y *game analytics* (Hullett, Nagappan, Schuh, & Hopson, 2011) para recopilar datos sobre el uso de los juegos que posteriormente puedan ser analizados a fin de detectar problemas de accesibilidad, permitiendo de esta manera mejorar las interfaces propuestas.

- Profundizar en la aplicación de juegos en poblaciones envejecidas, así como en personas con discapacidad cognitiva, por el potencial que estos tienen para mejorar las condiciones de vida de estas personas.

5.2.2. Desarrollo e implementación

A continuación se enuncian algunas de las líneas de trabajo relacionadas con el desarrollo e implementación de prototipos relacionados con esta tesis, también sin ningún orden específico:

- Continuar con la línea de trabajo iniciada en 4.2.2, referente a la reimplementación de todas las características propuestas esta tesis en eAdventure 2.0, la nueva versión de eAdventure, a fin de aprovechar las características de accesibilidad que tanto las plataformas móviles como la web ofrecen en la actualidad.

- Desarrollar una nueva versión del juego *Mi primer día de trabajo* integrando los comentarios de mejora que proporcionaron los usuarios durante su evaluación, y portarlo a la versión 2.0 de eAdventure para eliminar las limitaciones referentes al uso de tecnología *SAPI*™ que impiden su libre distribución.

- Implementar las características de accesibilidad propuestas en otras herramientas de creación de juegos digitales que tengan un mayor peso específico en la comunidad de desarrolladores, a fin de maximizar el impacto del trabajo. En este sentido *Unity* parece la plataforma idónea, aunque la complejidad es mayor al no disponer de una representación explícita del modelo subyacente de juego.

- Desarrollar más juegos con características de accesibilidad y tratar de evaluarlos con un conjunto de usuarios más amplio.

Capítulo 6: Resumen amplio en inglés (Extended abstract in English)

Cumpliendo con la normativa actual, en este capítulo se proporciona un resumen extendido de la presente tesis doctoral en inglés que abarca los capítulos anteriores.

In compliance with the regulations that determine the structure of this PhD dissertation, in this chapter we provide an extended abstract that summarizes the most relevant aspects of all the previous chapters.

6.1. Introduction

Access to education is a universal right recognized by the 26th article of the Universal Declaration of Human Rights (United Nations, 1948). This includes people with disabilities too, whose right to education has also been explicitly recognized by United Nations through the 24th article of the Convention on the Rights of Persons with Disabilities (United Nations, 2006). However, it is also generally accepted that people with disabilities face multiple barriers worldwide when accessing services such as health and education, as expressed by the World Report on Disability developed by a joint effort of the World Health Organization (WHO) and the World Bank (2011). This may be seen as a secondary problem that affects just a minority, but the fact is that more than one billion people in the world are estimated to have some sort of disability (data from the WHO), defined as an umbrella term encompassing any temporary or persistent injury affecting body functions or structures that limits the full participation of the person in daily life. This figure is expected to keep growing as a consequence of aging populations and the growth of chronic diseases, increasing the importance of finding solutions that guarantee sustainable access to all kind of activities and services for everybody, regardless of the possible presence of a disability.

The increasing need to cater for accessibility also has implications in education, where the growing penetration of technology increases the existing risk of a digital divide. This implies the need to consider the accessibility of new technologies that are introduced in the classroom as a *must*, in order not to jeopardize the rights of persons with disabilities.

This should be the case of the so-called *serious games*, term referring to those digital games that are developed with a purpose beyond entertainment (Sara de Freitas & Oliver, 2006). The term comprises the application of digital games in diverse fields as health (Akl et al, 2013; Arnab, Dunwell, & Debattista, 2012; Brox, Fernandez-Luque, & Tøllefsen, 2011; Rosser et al, 2007), marketing (Pempek & Calvert, 2009) and crowd research (Cooper et al, 2010). However, education is one of the main applications of *serious games* at the moment, where they are proposed as an effective means to get students engaged in their own learning (MD Dickey, 2005; Kirriemur & McFarlane, 2004; Michael & Chen, 2006), which ultimately results in a more meaningful and even higher academic performance (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Hwang & Wu, 2012; Perrotta, Featherstone, Aston, & Houghton, 2013), among other benefits. Their effectiveness when designed and implemented appropriately is supported with experimental evidence (Annetta, Minogue, Holmes, & Cheng, 2009; Barzilai & Blau, 2013; Cheng, Su, Huang, & Chen, 2013; Hainey et al., 2013; Papastergiou, 2009; Tuzun, Yilmazsoylu, Karakus, Inal, & Kizilkaya, 2009). This last meaning, which associates the *serious games* term to the educational field, is the one used throughout this PhD dissertation.

Therefore, it is surprising that little attention has been paid to ensuring the full accessibility of *serious games* and other multimedia materials (Abrahams, 2010), taking into account that the use of *serious games* is expected to keep growing in the next years (Johnson et al, 2013;. Johnson, Adams, & Cummins, 2012). Moreover, the accessibility of digital games in general remains low regardless of their purpose, as several authors have argued (Bierre et al, 2004, 2005; Westin, Bierre, Gramenos, & Hinn, 2011; Yuan, Folmer, & Harris, 2011).

The low accessibility of digital games is related to the impact it has on *game developers*. First, dealing with accessibility poses an extra burden on the developer's shoulders, from both design and implementation perspectives, which results in an increased production cost. Games are highly interactive pieces of software, which makes dealing with accessibility more difficult than for other applications (Grammenos, Savidis, & Stephanidis, 2009). Besides, accessibility introduces major complications in game design, an art that requires equal doses of experience and creativity to achieve a well-balanced combination of different strategies and mechanics to reach players with different motivations (Egenfeldt-Nielsen, 2007). For example, there are players whose motivation to play a particular digital game lies in overcoming all primary and secondary challenges the game poses (*achievers*), while others seek socialization with other players or are attracted by the underlying narrative of the game (Yee, 2006). Each person with disabilities may also have different needs and/or require personalized adaptations, including but not limited to the general difficulty of the puzzles, the language used or the underlying narrative that supports the game, laying out a scenario of diverse needs that is hard to deal with. For this reason, few of the scant accessible digital games available include support for more than two or three types of disabilities. Moreover, it is also necessary to solve technical challenges such as the integration and/or development of complex and expensive technologies (e.g. text-to-speech or voice recognition modules) or the production of special hardware (e.g. adapted game controllers) (Bierre et al. 2004).

The extra costs accessibility involves may be affordable in large projects, usually related to the field of entertainment, but rarely in projects related to education, where the budget is limited. In fact, there are voices that advocate that *serious games* development must be driven by austerity and cost optimization strategies to achieve greater penetration (FAS, 2006).

Another factor that is provided to explain the low accessibility of digital games is the lack of adequate training and awareness of developers (Heron, 2012). Only then can it be understood that games are often released to market with intermittent accessibility or usability barriers that could be easily avoided (Archambault, Gaudy, Miesenberger, Natkin, & Ossmann, 2008; Ossmann, Archambault, & Miesenberger, 2008).

This PhD project aimed at contributing to address these two limitations developers face regarding accessibility: (1) the extra effort and cost they must invest, and (2) their lack of awareness. In this regard, the main contribution of this PhD dissertation was the proposal of a set of configurable accessibility features (conceptual model) that can be integrated in popular digital game creation tools, in order to facilitate the development of accessible digital games in general, and *serious games* in particular. A prototype of this conceptual model was developed and integrated into the eAdventure tool, which was also used to produce three case studies evaluated by users and experts alike. Overall, this approach has the following main benefits:

1. To reduce the effort that developers need to invest to make a game accessible for people with disabilities.

2. To raise awareness among the developer community about the special needs of people with disabilities.

6.2. State of the art

A detailed analysis of the state of the arte was conducted as part of this PhD project, including various aspects that are relevant to the topic and approach followed and which are summarized in this section.

First, the field of digital game creation was addressed, with particular emphasis on existing tools and methodologies. This analysis was necessary to get a better understanding of the tools game developers use and to determine the most promising ones for this project. This study reflects the diversification digital games have experimented in recent years, whose ubiquitous influence in modern culture has resulted in the emergence of a wide market of game development tools of every shape and condition. There are game development tools for people with different profiles, ranging from AAA tools oriented to large professional development studios, which are complex and costly, to simple tools for amateur developers and game enthusiasts, more limited in functionality but also easier to use. This is the case of the eAdventure platform, a simple *serious game* development authoring tool that was chosen to develop most of the proof-of-concept prototypes for this PhD project.

Second, the state of the art of accessibility in Web and e-learning environments (application of information and communication technologies to education) was analyzed. This discussion is useful for comparing the level of accessibility of digital games and *serious games* with other popular technologies. This analysis reveals that a lot of progress has been achieved in making the Web more accessible, mostly due to the joint efforts of advocators, communities of disabled users, and dedicated organizations like the W3C Consortium. This worldwide recognized organization leads the Web Accessibility Initiative (WAI) that has developed specifications that address how to develop accessible Web Content (W3C, 2008), Rich Internet Applications (W3C, 2014), User Agents (i.e. browsers) (W3C, 2002) and Web Content Authoring Tools (W3C, 2013). Most of these specifications are now considered stable and mature standards in the community, and there are different support tools available that help developers evaluate the level of accessibility of their contents and/or produce more accessible content. There are also some initiatives that have addressed the accessibility of e-learning environments, like the *IMS Access for All* initiative.

An analysis of the different approaches to accessibility in digital games was also conducted, concluding that two main approaches coexist. The most usual is to devise specific solutions *ad-hoc* for a limited number of disability profiles and a particular game. The second approach, less frequent, encompasses guidelines, recommendations, frameworks and tools that could be applied to a wider number of games and/or disabilities, allowing developers to reuse previous efforts across games. This analysis was complemented with a study of the main barriers users with five types of disability have (blindness, reduced mobility, limited vision, hearing disability and cognitive disability) and different strategies available for them.

The analysis of the state of the art ended with a study of how accessibility can be evaluated for digital games. The most relevant conclusions out of all this work were the following:

1. **Accessibility in digital games is still an incipient and immature field compared to Web accessibility**. As previously discussed, Web accessibility has been pushed for years by the W3C, a highly influential organization, and there are currently numerous widely accepted standards and tools to support it. In the field of accessibility in digital games there are important initiatives, but these are much less mature and consolidated.

2. **Digital game developers have little support and information for creating accessible games**. The two analyses conducted on game creation tools and accessibility initiatives in games show a clear lack of support. As a result, the effort required to make a game accessible increases significantly, which hinders wider adoption of accessibility in games. This lack of support and information is also a factor that explains the lack of awareness identified in game developers.

3. **Not all disabilities have received the same attention**. The supply of accessible games available for each disability profile is also variable. Blindness is the profile that has received most attention within physical disabilities. It is, undoubtedly, the profile more case studies have focused on. Cognitive disabilities have also received more attention than other disabilities, although this comparison is unrealistic for the latter group comprising a wide set of disabilities. Besides, most of the work done for cognitive

disabilities was grounded in the field of rehabilitation and education, leaving entertainment in the background.

4. **There is a strong need of new evaluation methodologies to formally validate the accessibility of digital games**. Current practices are insufficient for formal usability and accessibility evaluation of digital games and especially *serious games*, because they either fail to consider the need to evaluate the educational value of the games or the special needs of people with disabilities.

6.3. Goals and scope

6.3.1. Scope

This PhD project approached *serious games* accessibility from a practical perspective. It was centered in the figure of the developer, trying to provide solutions to the most relevant problems that developers experience. We believe that any approach focused on the developer must have a practical nature since purely theoretical models that do not provide good support tools are doomed for not presenting a real advantage for the developer. Those problems are, as described above: (1) the increased effort and development cost, which is unaffordable in many cases, and (2) the lack of awareness.

This work focused on the tools used by developers to create games. One of the most relevant strategies proposed to reduce the cost associated with accessibility (though not the only one) is the automatic (or semi-automatic) adaptation of the game, or at least its user interface. The generation and automatic adaptation of user interfaces is a field with decades of history and it has provided good results in various areas, including education (Boutekkouk, Tolba, & Okab, 2011; Chen & Magoulas, GD, 2005; Falb et al., 2009). Such techniques have also been applied to digital games, where there is a considerable challenge given the complexity of their user interfaces (Robin, 2005). In this PhD project we essentially combined aspects of Natural Language Processing with adaptations in the rendering pipeline.

Given the complexity and heterogeneity of the area in which this thesis is framed, we followed an iterative methodology driven by case studies, which allowed for the progressive refinement of the accessibility features and prototypes proposed. A total of three iterations were completed, each one with a different case study.

Several actions were taken to limit the scope of the project. First, we focused on a particular game genre: *point-and-click* adventures, which combines good educational features (Amory, Naicker, Vincent, & Adams, 1999; MD Dickey, 2005; Garris, Ahlers, & Driskell, 2002), and a lack of some of the most frequent accessibility problems as they include time pressure less frequently in their game mechanics. Second, we narrowed the study to five types of disabilities: blindness, reduced mobility, limited vision and cognitive disabilities.

6.3.2. Goals

The main objectives identified for this thesis were:

1. To propose a set of accessibility features that can be integrated into game creation tools to facilitate the introduction of accessibility features in *point-and-click serious games* (conceptual model).

To achieve this goal, we first proposed solutions to the major needs of the most common types of disabilities identified for this PhD project. Then, we explored different alternative solutions for a particular type of disability (blindness).

The second and third objectives were built upon the conceptual model proposed:

2. To implement a proof of concept of the conceptual model on a specific game creation tool (Implementation).

3. To assess the suitability of the proposed model (see Objective 1) by developing case studies and further analyze their usability with disabled users (Usability).

Finally, we identified the need to estimate the cost (in terms of effort) associated to the introduction of accessibility features in a particular game. This goal was formalized as follows:

4. To analyze the cost associated w the introduction of the accessibility features proposed in a real game, in order to assess whether the approach yields a significant effort reduction (Final Evaluation).

The most relevant contributions on each of these four goals are described in the next section (6.4).

6.4. Summary of contributions

Based on the study of the state of the art, we made a proposal of configurable accessibility features for game creation tools, focusing on *point-and-click* adventure games. The objective was to provide the developer with ready-to-use accessibility features integrated into their game creation tools. These features are exposed to the developer at the same level as the other aspects needed to create a game, such the virtual world, physics, artificial intelligence or animations, which enhances visibility and raises awareness.

The proposed set of features can be summarized as follows:

- A set of alternative interfaces to the classic *point-and-click* interaction that are semi-automatically generated taking as input the game definition (which must be available for processing) and some additional information provided by the author, like synonyms, additional descriptions, and a limited number of alternative graphic assets. These interfaces are:

  - For blind users three interfaces were explored:
    - Input through natural language commands introduced with the keyboard (e.g. “open the door" or "talk to girl"), and feedback provided through audio effects and phrases generated by a text-to-speech engine.
    - Interaction through interactive items using the focus (similar to keyboard interaction in Web forms).
    - Input provided only with the mouse, aided by a 3D audio system that provides information to the player about the relative position of the interactive elements.
  - For users with limited vision, classic *point-and-click* interaction is still used, and an adapted rendering scheme is applied, which increases the contrast and size of elements and text.
  - For users with reduced hand mobility, input is provided by entering commands formulated in natural language (e.g. "open the door" or "talk to girl") that are dictated to the computer. The game provides feedback using visual stimuli.
  - For users with hearing disabilities: classic *point-and-click* interaction is enhanced with additional textual feedback (closed captions).

- An adaptation engine based on rules that dynamically modify aspects related to the game like the design, content, history, puzzles or gameplay mechanics. These aspects are less likely to be adapted automatically or semi-automatically, so the rules must be explicitly introduced by the game author. This engine can be used to meet the needs of any user, although it is considered particularly interesting for people with cognitive disabilities.
- A set of additional accessibility tools, integrated into the game atmosphere to avoid hurting the immersion, as for example, a magnifying glass the player can use to better inspect the game scene.
- A set of tools for inspecting accessibility issues that can report potential problems, similar to the tools available for the evaluation of Web accessibility.

We implemented this model into the eAdventure *serious games* creation tool. Both the conceptual model and the implementation into eAdventure have been evaluated from different angles:

- In terms of usability, through the development of three case studies

- In terms of cost, by estimating the effort required to make a full *serious game* accessible.

- Ultimately, through peer review during our participation in the ACM Student Research Competition, held at the ASSETS 2012 conference, where our work was awarded the first prize.

This work also contributes three case studies developed in close collaboration with experts in accessibility from Technosite, a company of the ONCE group:

- In the first case study, of limited scope, we adapted the first scenes of an existing eAdventure game (*1492*) for blind people and people with reduced mobility in hands. This work was broadcasted in the Spanish Public Broadcasting System (http://youtu.be/ROg3pjnfi8U?list=UUsqlQuEzeSxydA7nHYu9VEA).

- In the second case study, with a more ambitious scope, we developed from scratch the game '*My First Day at Work*', which we enhanced with accessibility features for people with blindness, limited vision and reduced mobility in hands. This game is a significant contribution for two reasons:

    - It has an educational and social purpose, since the game tries to facilitate the integration of people with cognitive disabilities into the workforce. Users with other types of disability who also participated in the evaluation of the game showed great interest in the game for its educational and entertainment value.

    - It showcases the accessibility features proposed in this PhD thesis to deal with physical disabilities.

- In the third case study we focused on the evaluation of alternative interfaces for blind users that we had proposed. In this case study, the usability and engagement of three similar games configured with the three interfaces was analyzed with a cohort of blind users with diverse background and gaming preferences.

Finally, this PhD project makes the next contributions in the field of usability and accessibility evaluation in games:

- We have developed an evaluation methodology especially optimized for *serious games*, which not only covers aspects of accessibility but also usability in general, so it can be applied more broadly. It combines aspects from think-aloud methodologies, heuristic evaluation techniques and peer review, and it produces both quantitative and qualitative outcomes in order to allow for a more detailed assessment.

- The methodology has been applied to evaluate the second case study, which serves as an example of how you can apply this methodology to assess the level of accessibility of serious games.

Capítulo 7: Artículos presentados

En este capítulo se incluyen los 12 artículos editados que se aportan como parte de esta tesis doctoral.

7.1. Implementing Accessibility in Educational Videogames with <e-Adventure>

7.1.1. Cita completa

Torrente J, Del Blanco Á, Moreno-Ger P, Martínez-Ortiz I, Fernández-Manjón B. **Implementing Accessibility in Educational Videogames with <e-Adventure>**. Primer ACM international workshop on Multimedia technologies for distance learning - MTDL '09 [Internet]. Pekín, China: ACM Press; 2009. p. 55–67. Disponible en línea en: http://portal.acm.org/citation.cfm?doid=1631111.1631122.

7.1.2. Resumen original de la publicación

Web-based distance education (often identified as e-learning) is being reinvented to include richer content, with multimedia and interactive experiences that engage the students, thus increasing their motivation. However, the richer the content, the more difficult it becomes to maintain accessibility for people with special needs. Multimedia contents in general and educational games in particular present accessibility challenges that must be addressed to maintain e-learning inclusivity. Usually the accessibility of multimedia content in courses is addressed with the definition of simpler but more accessible content that diminishes the benefits of the richer content. Hence we need new, accessible multimedia technologies that guarantee that the learning experience is motivating and engaging to all students. We will focus our work on educational games, trying to leverage their engaging narratives to produce educational experiences that are attractive to all students, including people with special needs. Nonetheless the development of accessible games is a major challenge, due mostly to the additional development cost it involves. In this paper we present how the <e-Adventure> game platform facilitates the development of educational videogames for e-learning, simplifying the introduction of accessibility from the design stage of the game development process.

Implementing Accessibility in Educational Videogames with <e-Adventure>

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ABSTRACT
Web-based distance education (often identified as e-learning) is being reinvented to include richer content, with multimedia and interactive experiences that engage the students, thus increasing their motivation. However, the richer the content, the more difficult it becomes to maintain accessibility for people with special needs. Multimedia contents in general and educational games in particular present accessibility challenges that must be addressed to maintain e-learning inclusivity. Usually the accessibility of multimedia content in courses is addressed with the definition of simpler but more accessible content that diminishes the benefits of the richer content. Hence we need new, accessible multimedia technologies that guarantee that the learning experience is motivating and engaging to all students. We will focus our work on educational games, trying to leverage their engaging narratives to produce educational experiences that are attractive to all students, including people with special needs. Nonetheless the development of accessible games is a major challenge, due mostly to the additional development cost it involves. In this paper we present how the <e-Adventure> game platform facilitates the development of educational videogames for e-learning, simplifying the introduction of accessibility from the design stage of the game development process.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, graphical user interfaces (GUI), natural language, screen design*;

K.3.1 [**Computers and Education**]: Computer uses in education – *distance learning, computer-managed instruction*;

K.8.0 [**Personal Computing**]: General – *games.*

D.1.7 [**Programming Techniques**]: Visual programming;

General Terms
Design, Economics, Human Factors.

Keywords
Accessibility, <e-Adventure>, e-learning, distance learning, game authoring tools, game-based learning, online learning, videogames.

1. INTRODUCTION
For the last decades, information systems in general and the Internet in particular have experienced rapid expansion. These systems have become a fundamental tool in daily life, but this advance sometimes signifies a marginalization for people with special needs who cannot access the content that new technologies provide (be it as a consequence of personal characteristics or contextual issues). This has caused an increasing effort in the development of the technologies that enhance the accessibility of information systems for people with special needs.

Nevertheless, the creation of accessible technologies has focused unequally on different fields of software development. While the accessibility of websites is reasonably covered, other areas such as interactive multimedia (and especially videogames) are still trying to find the most suitable way to create accessible products. While it is true that there are some videogames that include accessibility characteristics, the high cost involved in acquiring some of these features is hindering their widespread adoption. One of the possible interventions is to provide all the information, even the small details, through several alternative channels at the same time, which is usually achieved by combining subtitles and sound/voices. However, this approach requires a considerable investment in gathering all the audio recordings (a videogame may have hundreds or thousands of information lines), which often makes this approach unaffordable in contexts where the budget is limited.

These problems are especially important in educational videogames. The need for enhanced accessibility in any kind of educational content is more pressing than in purely entertainment-driven developments (and even more in e-learning environments). According to the 2007 US Census Bureau[1], 18% of the US population and 11% of children from 6 to 14 have some level of disability, with 12% of the total population having a severe

[1] http://www.census.gov

disability. If videogames are to play a role in education, accessibility cannot be left aside. In addition, the higher cost of accessible games is harder to assume in an educational videogame, given that most educational gaming projects often have a limited budget, which makes the issue far more serious. These contexts require methodologies, design patterns, and tools that facilitate the creation of accessible videogames, without compromising the cost. In contrast, a survey of the domain reveals that such elements are rare and have received scarce attention in the literature.

In fact, game-based learning is still an emerging field being discussed in academic environments, with both supporters and detractors [1]. Therefore, developers are still more concerned with creating appropriate games for learning than in making them accessible, assuming that accessibility could be eventually addressed in the future. However, we consider that educational videogames, and especially web-oriented games, should take accessibility aspects into account from the very beginning if they are to become a real alternative or complement to other educational approaches.

The aim of our work is to create a system based on natural language processing to allow the introduction of accessible features in the development of educational videogames without compromising development costs. The system offers different pre-made input/output modules such as a voice interface for recognizing voice commands, a text interface for recognizing text orders, and a voice synthesis module for transmitting audio feedback without additional development efforts. The system has been integrated into <e-Adventure>, a game authoring platform designed to facilitate the creation of educational *point-and-click* adventure games for e-learning environments.

This work is structured as follows: Section 2 provides some context, focusing on the potential issues and current trends in accessibility, games and education. Section 3 describes a general framework for web-oriented accessible games in education, which has served as a base for the integration of accessibility features into the <e-Adventure> platform, as described in section 4. Section 5 presents a concrete case study, in which a pre-existing game is enhanced with accessibility features using <e-Adventure>. Finally, section 6 presents some conclusions and future lines of work.

2. CONTEXT: ACCESSIBILITY, GAMES AND EDUCATION

The accessibility of information systems is rapidly becoming a key issue, since it is one of the potential sources of digital division. In this context, the accessibility of educational technologies can seriously affect the future opportunities of individuals with limited means of access. While traditional teaching methods are often able to cope with accessibility aspects (often through the effort of dedicated instructors), the current trend towards increasingly complex educational technologies is continuously growing the challenge.

2.1 Web Accessibility

The emergence of the World Wide Web (WWW) and the posterior interest in e-learning environments was initially disruptive in this sense, leaving students with special needs unable to access these systems. Screen-reading tools partially resolved that issue. However, parallel to the evolution of the Web, e-learning environments grew more complex and started to include advanced multimedia content that increased the importance of accessibility measures.

To that end, these e-learning web-based tools can benefit from the ongoing efforts fulfilled by different public and private organizations to improve WWW accessibility. Highly influential organizations as the W3C are presenting the necessary requirements to create accessible web content [2, 3], along with webmaster-oriented tools to check the accessibility of web-based content [4].

There are also initiatives that specifically deal with digital educational contents for web environments. A very thorough approach was undertaken by the IMS Global Consortium in their *IMS AccessForAll* set of specifications [5, 6]. Unfortunately, these efforts are principally focused on the most common types of educational content (including many forms of multimedia content), but do not adequately cover highly interactive content such as educational games.

2.2 Input Device Adaptation for Videogames

The most common approach to increasing the accessibility of videogames is to seek their compatibility with assistive technologies [7]. Some examples would be screen-reading tools, mouse emulators or virtual keyboards. There are also tools that can be used to substitute the usual gamepads provided by game consoles (e.g. vocal joysticks or tongue sensors).

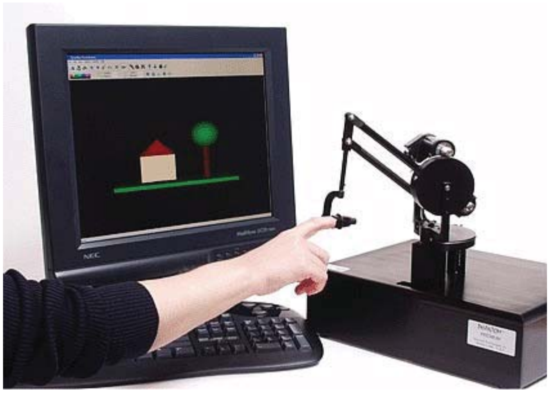

Fig 1. The *PHANToM™* device, created by SensAble Technologies Inc.

In this line, the work presented in [8] shows the use of the *PHANToM™* device (Figure 1), as an example of how *haptic* devices (which provide human-computer interaction based on body movements and the sense of touch) can increase accessibility. This approach not only facilitates access to the games for a wide range of people with impaired mobility (controlling the videogames with easy movements of one finger), but can also be useful to visually impaired people because the device offers them the possibility of perceiving 3D objects by means of movements of a device.

Another approach consists of adjusting the games without requiring specific devices (e.g. adding subtitles). However it is possible to bring both conceptions together. In this line we find *auditory games*, (also known as "audio - games") [9] which are specially designed for people with visual impairments, where the information from the game is transmitted through audio [10]. In some of those games the indications are given with abstract sounds, but the games with major acceptance are those which give users voice descriptions reproduced through text synthesizers.

Another way to provide audible information is with descriptive sounds. Specific sounds, which are used intensively throughout the game, are given special meanings so it is easy to remember the association between sounds and meanings. Other games receive input through voice or by means of specific devices [11].

2.3 Methodologies, Tools and Design Patterns for Accessible Videogames

Other works, such as [12], have focused on providing some design guidelines such as how to design interfaces or some simple methodologies for accessible videogame development [9, 13]. There are also design patterns and web initiatives providing indications on how to create accessible videogames, although they have not been translated into broadly accepted standards or specifications yet.

The *International Game Developers Association* (IGDA) has a *Special Interest Group* that focuses on accessibility issues[2] and published a white paper which provides a good analysis of the field [14]. This document provides a general overview, covering what accessibility in games means, why it is necessary, and what kind of disabilities can be tackled at the videogame creation stage. That work also gives some indications about how to adapt an already created game to improve its accessibility through adding subtitles and customizing text fonts, or how the textual information and subtitles can be recorded or synthesized. Along with these ideas, they encourage the use of other approaches to gather user input such as use voice recognition or other specific devices. However, the report does not propose any concrete pattern or methodology to create accessible games.

A unique approach from a technological point of view is proposed by *FORTH* (Foundation for Research and Technology - Hellas) [13], and is based on the *Unified User Interface Design* (UUID) [15]. UUID proposes a design pattern where the game tasks are initially considered in an abstract device-independent way. In later design phases, the interaction for each game task is designed and includes the selection of input/output devices. Several games have been developed following these guidelines, achieving accessibility for people with a wide range of special needs. These are the universally accessible games (*UA-Games*). An example is *Access Invaders* [16], which supports different game settings depending on the potential disabilities of each player, such as blindness (in which case the game will be loaded with the appropriate characteristics of the Audio-Games), damaged vision, cognitive disabilities or motor disabilities.

As far as development tools are concerned, the market is populated with many authoring environments for the development of videogames. There are development frameworks for game programming (such as *Microsoft XNA*™[3]), game development environments which allow people without technical knowledge to develop their own videogames (like *Game Maker*™[4] or *Unity3D*™[5]) and even simple editors oriented to specific game genres like *The FPS Creator*[6] or *Adventure Game Studio*[7]. However, none of these initiatives includes pre-configured features targeting game accessibility. This means that accessibility has to be implemented from scratch for every individual game.

2.4 Accessibility in Commercial Videogames

There are some commercial videogames that implement features to enhance accessibility or that have been modified after being published for this purpose. The creators of *Half Life 2*™ introduced accessibility for people with hearing problems during the development process after they received some complaints concerning the first issue of the saga. The reason is that in *Half Life*™ certain information that was essential to complete the game was transmitted across cut-scenes (videos) without subtitles, making it impossible for people with hearing impairments to reach the end of the game [17].

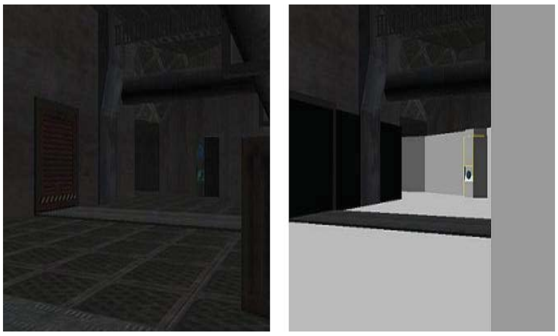

Fig 2. *Terraformers* game: left image shows normal mode, and right image shows the same scene with high contrast.

Terraformers™ was directly designed with accessibility features at an early stage. It includes a normal mode in which visual graphics are reproduced as usual in first-person 3D games, but it also has an accessible mode. In that mode, a sonar is activated to tell players what is in front of them and the contrast of the graphics is increased for vision-impaired people [18]; this mode also allows the player to select objects from the inventory orally.

3. DESIGNING ACCESSIBLE VIDEOGAMES FOR E-LEARNING

There are several considerations that must be taken into account when designing accessibility for a videogame. If the game is to be embedded in an e-learning scenario, some additional peculiarities must be considered. For instance, dealing with cognitive impairments, which is rarely covered in entertainment-driven videogames, becomes a very important issue in education as cognition and learning are closely related. In this section we will discuss these and other general considerations. First we will discuss the user model to be used to model the needs of each student (that is, what the user can or cannot do). Then we will discuss what to adapt in the games according to the user model. Finally we will discuss some other relevant issues such as the choice of appropriate game genres.

[2] http://www.igda.org/accessibility/

[3] http://www.xna.com/

[4] http://www.yoyogames.com/make

[5] http://unity3d.com/

[6] http://www.fpscreator.com/

[7] http://www.adventuregamestudio.co.uk/

3.1 Input Data for Accessibility. User model definition

The first issue that must be considered when designing accessibility for a videogame is to identify the data that will serve as input to adapt the game. The most obvious (and probably most important) is the *user model*. That is, what the system knows about the user. This is a crucial factor as the game will need to know what the special needs of each student are in order to adapt the game experience.

But adaptation cannot be limited to students' impairments that are not expected to change over time. Even though the term accessibility is usually associated with personal disabilities, it can also be a result of the environment (i.e. context). A hearing impaired person is as challenged by audio content as any other person in a loud environment without earphones. Therefore the *environment settings* must also be taken into account. The adaptation will be more effective if the input data provided is focused on *what the user can or cannot do in that precise moment and context.*

The user model should also include some *user preferences* that may help to make the game accessible to the student, including *preferred and forbidden settings*. This is indispensable to facilitate access to the games for students with "minor" needs that might not be able to play a game due simply to small details that could be easily fixed by adapting the configuration of the game slightly. If students are able to play the game but only with great effort, they could get frustrated after a while. For instance, color-blind students may not be able to read a text or recognize an enemy approaching when a specific combination of colors is used.

Most of the information about accessibility that the user model should contain can be classified in four categories according to the group of impairments of a particular student in a particular context. Those are visual, hearing, mobility and cognitive impairments. Table 1 represents a fragment of a simple user model, including a categorization of the user (compulsory) and some preference attributes (optional) under each category. Although this is a simplified example, it illustrates some of the most relevant situations.

Table 1. Accessibility-attributes for the user model

Group	Attribute	Accepted values
Visual impairments	Vision level	*Low-vision* (unable to read normal text but who would be able to read it with some aids); *Complete impairment* (unable see anything on the screen).
Visual preferences	Preferred color combination	Preferred text and background colors for the student
	Forbidden color combination	Text and background colors that would impede or make the student's access to the game the difficult.
Hearing impairments	Hearing level	*Low hearing* (able to hear background sounds, requires subtitles for conversations); *Complete Impairment* (requires full subtitles for every event)
Hearing preferences	Preferred sound level	0-100
Mobility impairments	Hand-arm mobility level	*Difficulties using mouse*; *Difficulties using keyboard*; *Cannot move hands*

Note that, as previously indicated, this information is not fixed for each student and can change in runtime to cover environmental or context issues.

3.2 Maintenance and Persistence of the User Model

An important design issue is how (and when) to produce and maintain the data that will be used for accessibility. For a desktop game, the persistent data about the user can be obtained directly from the student when the game is installed, by storing the information on disk for further execution of the game (or other similar games). In these cases, the student is responsible for providing and maintaining the information.

In some other games, the instructor may be aware of the special needs of a group of students, and pre-configure the game before distributing it to the students.

Finally, in web-based e-learning environments, it would make more sense to keep the data about the user in a central location independent of the student's computer. The current e-learning environments have evolved into the so-called Learning Management Systems (LMS), such as *Moodle*™, *Sakai*™ or *Blackboard*™, with features far more sophisticated than the initial content repositories used in web-based e-learning. A modern LMS stores information about the students and their progress, and can deliver customized information to each client. These systems can thus store the user models centrally and deliver it to the clients each time the game is executed.

Thus, depending on the context, the user model may be maintained by the students themselves, by the instructor, or stored in a centralized location, with all three approaches presenting different advantages for different scenarios. However, environmental restrictions cannot be computed a priori in any approach. These restrictions should either be automatically inferred or introduced by the student at the beginning of each execution of the game.

3.3 What to Adapt

An accessible game will require some modifications that typically will be different for each user and context. However, in most cases, the adaptations focus on game-user interaction channels. That is, the *input* and *output* systems of the game. Since a game is mostly an interactive experience, these adaptations can pose a significant challenge.

The multiple input/output scenario forces game designers to design game tasks and activities in a device-independent manner [13]. All the aspects of game design must be considered abstractly, with no explicit or implicit binding to any input/output mechanism.

Adapting input and output systems in a game could involve two different tasks. Sometimes it would require providing alternative input/output systems according to the user and environmental models previously defined. The game will decide at runtime what input/output alternatives are used. This is the typical case for visual, hearing and mobility impairments. To design these alternatives methodologically, game designers first need to think about the input/output system that will be provided for each attribute. Then they need to define the input/output systems that will be enabled or disabled in any case.

However, in many other cases, accessibility issues can be addressed by simply adjusting some game parameters. Some "minor" visual, hearing and mobility impairments will fall into this category. For instance, people with reduced hand mobility may not be able to control a mouse or the keyboard fast enough to cope with the quick reaction times often found in action games. In these cases, it would be enough to adjust the time pressure to allow impaired students to interact with the game at their own pace.

Nevertheless, there are cases where adapting the input and the output will not be enough and the own game structure will require adaptation. Cognitive and mental impairments may require lessening the difficulty of the game, skipping some activities, adjusting the text or speech speed, etc. Just as happens with other educational approaches, this is the most challenging accessibility adaptation, and possibly requires changes in the core of the game experience. These challenges are difficult to address in a systematic manner, and the specific approach will be dependent on the specific topics presented by the game.

3.4 Deciding the Game Genre

Accessibility requirements are very different depending on the game genre. In educational gaming, game genre is always a crucial factor, as not all games are equally appropriate for learning. Given that some game genres are more suitable for accessibility than others, the choice of a game genre becomes even more relevant.

As described in the previous, activities in games must be designed abstractly without committing to any specific device or input/output system. Thereby, when possible, it is better to focus on game genres where engagement and immersion are obtained thanks to the attractiveness of game tasks, activities and the flow of the game itself, moving away from some features such as being visually attractive or providing intensive action. Educational games must capture the attention and motivate students even when their accessibility features are activated. Otherwise, their positive effects for learning will be lost.

Point-and-click adventure games, such as the classic *Monkey Island*© or *Myst*© sagas, meet these requirements. This kind of games captures the players' attention by developing an engaging and motivational plot narrative that players unblock as they advance in the game. Graphics, sounds, or special effects are part of these games as well, but only as peripheral features to enhance immersion in the game. In addition they promote reflection instead of action, which is very convenient for people with motor impairments, who have plenty of time to solve puzzles with no time pressure. Besides, *point-and-click* adventure and story-telling games are especially adequate for education [19]. In our opinion, adventure games are a good candidate when planning the development of an accessible educational game, as they are adequate both for educational purposes and for introducing accessibility.

3.5 General considerations

Finally any development of an accessible game must be carried out following some general design guidelines. The adaptation that is performed in the game must be as user-customized as possible. If different alternatives may be feasible for a certain kind of disability, the optimum one must be chosen, while considering aspects such as which one best preserves engagement and immersion factors in the game or which alternative will make the game less effort-consuming for people with that disability. A possible methodology to achieve this would be completing a cross-table that matches all the possible disabilities identified in the user model with all the possible adaptations, indicating if each option is optimum, valid or not valid at all [13].

Besides, settings in the game must be as flexible as possible. Either by direct action of the user or by automatic inference, the game should permit the easy configuration of the text font settings (color, size, etc.), audio settings, time response gaps, and input/output settings (e.g. screen size and resolution).

Another important consideration is that an accessible game must always be compatible with adapted input/output devices, especially if the game is to be accessible to people with severe mobility impairments.

Tutorials on how to use the games for each possible adaptation setting must be designed, implemented and embedded in the game to ensure that all the students will be able to play.

Finally, how the game is going to be delivered, installed and accessed must be considered as well. Accessible games should be extremely easy to install and execute. In e-learning settings we can take advantage of the web to deliver and distribute the games. Accessing a game that is embedded in a web page would be easier for students with special needs as it does not require any installation and they usually have hardware or software aids to navigate the web.

4. THE <E-ADVENTURE> APPROACH

We have implemented the ideas presented in this paper in the <e-Adventure> platform. <e-Adventure> [20] is an educational game platform developed by the <e-UCM> research group at the Complutense University of Madrid (Spain) which has been used in the development of several educational games [21, 22]. The platform is composed of two applications: a game authoring editor (used to create the educational games) and a game engine (used to execute the games). The editor is completely instructor-oriented; hence it does not require any technical background or programming skills to be used [23].

The platform has some features to facilitate accessible game development, especially for e-learning applications. First, it is focused on the *point-and-click* adventure game genre, which is one of the specially suited types of games for accessibility, as discussed in section 3.4. As well, <e-Adventure> provides instructors with special features that enhance the educational possibilities of the platform, including a mechanism to adapt the game experience to the needs of different students [24]. These adaptations can focus on adapting the content (to suit different learning objectives or different levels of initial knowledge) or adapting the interaction modes to support users with special needs.

Finally <e-Adventure> games can be deployed via web and integrated with an LMS [25], which makes the platform ideal to integrate accessible educational games in e-learning courses.

4.1 General Architecture

The <e-Adventure> platform includes several *pre-configured input/output modules* to facilitate the inclusion of accessibility in the games. The idea is that game authors should be able to define various interaction mechanisms that coexist in the game, so that people with special needs can play easily. In addition <e-Adventure> includes some *in-game tools* that can be included in the games as an aid for impaired people. These modules are activated/deactivated by means of a user model.

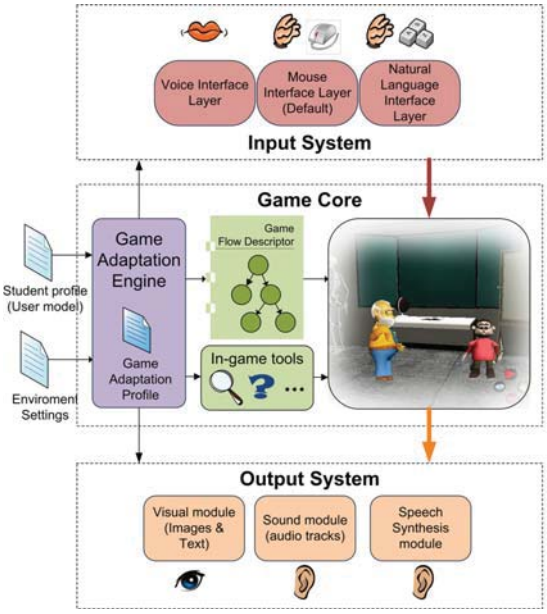

Fig 3. Architecture of the game engine (game application).

<e-Adventure> contemplates a user model which contains information about the student. The game engine expects to receive a user model which can be integrated with the game through the <e-Adventure> editor, imported from the e-learning environment or gathered from the student before the game starts. The model is separated into two parts. The *student profile* contains all the information concerning the permanent special needs of the student (i.e. things that are not expected to change in time such as the impairments of the student). The *environment or context settings* describe circumstantial needs that are related to the scenario where the game is going to be played (e.g. the environment is noisy or sound is not allowed) or momentary special requirements of the student (e.g. the student has a broken arm). Next sections present in detail all the input/output modules in the <e-Adventure> platform.

4.2 Description of the Input/Output Modules

The input modules supported by the <e-Adventure> platform are three: the *Mouse Interface* module (MI), the *Voice Interface* module *(VI)* and the *Natural Language Interface* module *(NLI).*

The MI is the classical interaction mechanism in *point-and-click* adventure games, where students usually need to point the mouse over NPCs (Non-Player Characters) and objects they find on their way in order to trigger any kind of in-game interaction. Therefore students need to be able to move the mouse and to see the elements on the screen in order to play the games, which may make them inaccessible to students with visual or mobility impairments. The VI is controlled by speech so students only need to be able to speak to control the games. Using a microphone, students can directly "give orders" to trigger any interaction in the game (e.g. "go to the library" or "grab the notebook"). The VI does not depend on the student's voice to work so students do not need to train the system, which is always an excruciating task. Besides, the VI accepts diverse synonymous orders for the same action (e.g. examine the scene or describe the scene) so students do not really need to learn how to use the VI, which is a typical problem in voice recognition. Table 2 shows an example of typical orders that the system would recognize in an <e-Adventure> game.

Table 2. Example of natural language commands that the VI and NLI modules recognize

Order	Description
Examine the table	The game will provide a description of the object "table", if it exists in the scene.
Go to the left	The student's avatar in the game will move in that direction, discovering new items that were still hidden.
Grab the pencil	The game will take out the object "pencil" from the scene and put it in the student's inventory[8].
Name items in the scene	The game will tell the student which items have already been discovered so he or she can interact with them.

The NLI accepts the same orders as the VI, but uses the keyboard as the input device. Thus students can interact with the game using text in natural language, which is helpful if students have speech and visual impairments or they are not allowed to speak due to environment circumstances (e.g. at a library). Table 3 summarizes all the input modules according to the special requirements they can cover.

Likewise, <e-Adventure> includes three output modules: the *visual* module, the *sound* module and the *speech synthesis* module. The visual module is not only used to print images on the screen (the background image for the scene, for the characters and objects, etc.) but also text. Text is a key element in *point-and-click* adventure games, as most of the information is provided through conversations with other characters which are usually textually represented on the screen. Accessibility could be added to conversations by recording all the dialogues by using the sound module (which can play audio tracks in mp3 format), but it would significantly increase the cost of the games, which is a problem when the budget is very limited (as is usually the case for many educational projects). This is why the speech synthesis module is helpful, as it allows the introduction of accessibility for visually impaired students at a low cost. Nonetheless higher-budget projects can use the standard sound module (which plays mp3 files) for increased sound quality.

Table 3. Summary of input/output modules

Input/output module	Senses Required	Adequate for…
Mouse Interface		Speech impaired students.

[8]The inventory is an element that is usually present in point-and-click adventure games. Players use the inventory to store objects they find on their way and keep them for a later use.

Voice Interface		Visually and/or mobility impaired
Natural Language Interface		Visually, speech impaired

4.3 The Game Adaptation Engine and In-Game Tools

Although adapting the input and output systems of the game can cover several physical or contextual impairments, other students will require different approaches. Such is the case regarding cognitive impairments. In these situations it is the game flow which needs to be adapted. Some students will need to lower the difficulty of the games, skip some tasks, receive additional guidance, etc. The <e-Adventure> platform supports this kind of adaptation through the definition of *flags*, which are used to establish conditions that block or unblock game elements or arcs in the game flow [20]. The game author can define a set of adaptation rules (i.e. *adaptation profile*) using data about the student as conditions (e.g. cognitive impairments in this case).

Fig 4. Example of the in-game tool "screen magnifier" in the *1492* <e-Adventure> game.

<e-Adventure> also provides game authors with other interesting tools for accessibility issues. For instance, game authors can provide students with a screen magnifier. To avoid breaking the game-immersive atmosphere, it is represented as an object that is put into the student's inventory (Figure 4). The student can use it to turn the mouse pointer into a magnifying glass that can move around in the game.

In addition, <e-Adventure> allows for a flexible configuration of visual items (e.g. text color) and time interaction gaps, and provides mechanisms for introducing simple hints and aids in the games. All these elements are very effective for making the game accessible to students with slight impairments, such as color-blindness, poor vision or slight cognitive impairments.

All the adaptation processes that <e-Adventure> supports (i.e. input/output adaptation, game flow adaptation and in-game tools) are carried out by a special module in the game engine core, the *Adaptation Engine*. The adaptation engine is configured through the *game adaptation profile*, which defines the set of adaptation rules. This profile includes the definition of the adaptation measures supported by the game, and receives as inputs the *student profile* and the *environment settings* previously described.

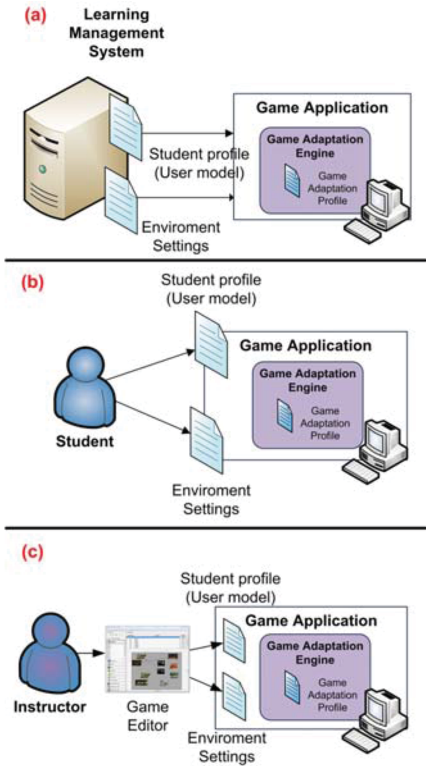

Fig 5. Three different mechanisms for providing input for the adaptation engine

The adaptation profile is defined by the game author, using the game editor just like any other resource file for the game. Therefore it is always distributed within the game package. The inputs that guide the choices from the adaptation profile (student profile and environment settings) can however be received in diverse manners according to the scenarios outlined in section 3.2. Both elements can be defined with the game editor and be included within the game package along with all the other resources of the game (e.g. art assets, game description files, etc.), or they can be delivered by an LMS or introduced manually by the student when the game is executed (Figure 5).

All three input methods are appropriate for different situations, which adds flexibility to the platform. For instance, packaging the inputs along with the game will be adequate for creating standalone versions of the game to be played offline. The inconvenience is that each student with special needs would require that the instructor create a custom version of the game for them. The second option is appropriate for situations where a LMS is available, as the game can be adapted without requiring any intervention of the student. Finally the third option allows game authors to produce a single offline version of the game, but students will need to introduce the input data manually each time they play the game.

4.4 Using the Game Editor to Introduce Accessibility

Authoring an accessible adventure game with the <e-Adventure> game editor is a very simple task. Moreover, the <e-Adventure> game editor can be used to introduce accessibility in existing games with little effort.

The first step is obviously to design and develop the game. It is recommended not to relegate the decision about accessibility to the last instant, but to think about the accessibility features that are going to be introduced in the game during the design phase, especially if they will require adapting the game flow, which would involve providing alternative paths, dealing with difficulty settings or providing additional aid in some situations.

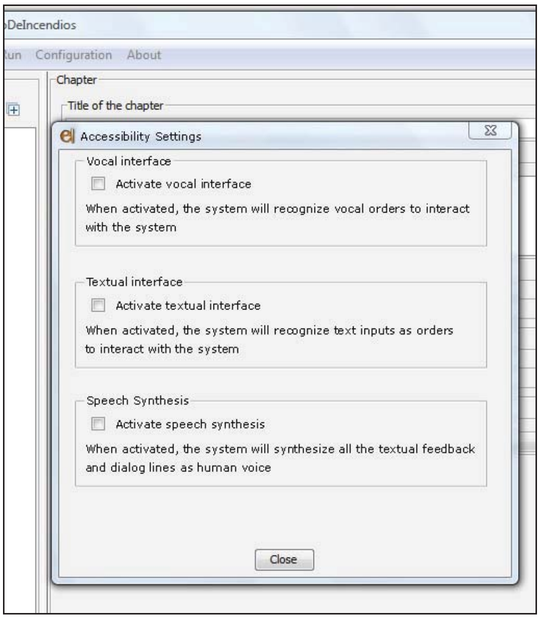

Fig 6. Edition of the Input/Output settings with the <e-Adventure> editor.

When the game is designed, the game authors must select the input/output modules and the in-game tools that they want to be active in the game. The game editor uses these settings to optimize the exportation process so no unneeded modules will be packaged within the game.

If visual accessibility is considered, it is very important that all the visual elements of the game receive an alternative description. When the player enters a scene the game engine will use these descriptions along with some extra information that it computes from the game definition (e.g. number of elements in the scene) to create a complete description of what the student is supposed to see. The complete description is synthesized and played using the audio system.

Finally, game authors need to create the game adaptation profile which will determine under which circumstances the game must be adapted, and how the adaptation must be carried out.

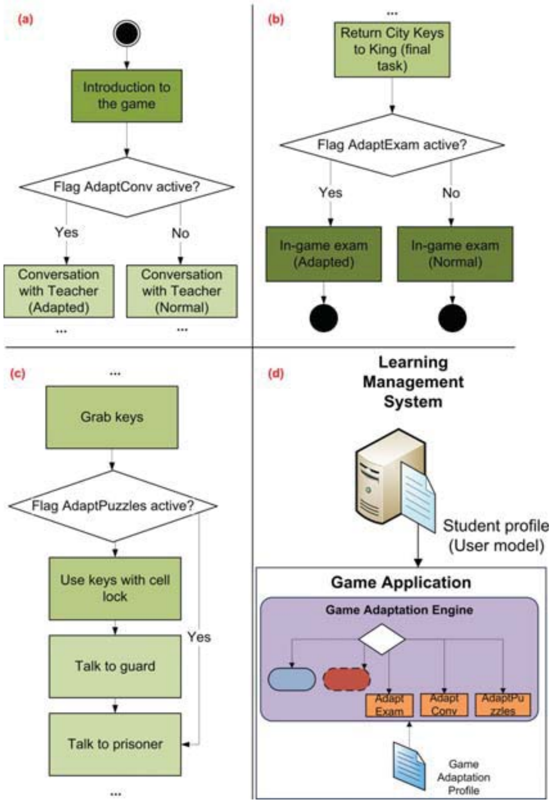

Fig 7. Figures (a), (b) and (c) are examples of how adaptation for cognitive impairments is carried out in the game flow using flags for the game 1492. Figure (d) depicts how the adaptation engine will activate or deactivate flags according to the adaptation rules (game adaptation profile) and the student profile with the disability information (input).

5. CASE STUDY

As a case study to test <e-Adventure> accessibility features we introduced accessibility in a pre-existing game. Following the ideas described in section 4, we introduced accessibility for people with different degrees of visual, hearing and mobility impairments in the game *1492*, an educational game about Spanish history [26]. *1492* focuses specifically on the feats occurring in 1492, such as the discovery of the American continent. These are notable events in the history of Spain, so it is a compulsory subject in primary education, which is an additional, strong motivation to make the game accessible. However, the purpose of the experiment was not to test how the accessibility implemented in <e-Adventure> works in a real scenario with actual students (e.g. check student satisfaction or learning outcomes), but to check its feasibility and effectiveness from a technical perspective (e.g. measure voice recognition accuracy).

1492 was not initially designed as an accessible game. However, it is simple to add accessibility using <e-Adventure>. The first step was to decide what impairments (and what severity level) we were going to target and then activate/deactivate the necessary input/output modules and/or in-game tools using the game editor. For this case study we considered visual, hearing, mobility and simple cognitive adaptations.

As cognitive impairments are very complex and may require very different adaptations, we just considered two possibilities in order to test the game adaptation system: students with low memory capacity, and students with non-severe reasoning problems. In the first case we defined alternative conversations that lessened the amount of information that the student gathers at any moment, thus increasing the focus on relevant information and reducing the amount of "superfluous" information. In the second case we defined alternative game paths with simpler riddles and *puzzles*. Besides, the original *1492* game included an in-game multiple-choice examination at the end of the game through a conversation between the main character (a student called Cristobalín) and his teacher. For both types of cognitive impairments, we provided an alternative, less difficult exam.

In order to cover the rest of potential special requirements, the game is distributed with all of the input/output modules and the screen magnifier. For this to work, we also had to provide alternative descriptions of the visual elements found in each scene, so that they could be passed to the speech synthesizer. This increased attention to descriptions brings the game closer to interactive story-telling games, which often do not have graphical interfaces but intense narrations that engage players.

Finally we produced the rules that adapt the game when the student profile (which is received in the game as input) requests any of the adaptations discussed above. In this case the most difficult task is to define the adaptation rules related to cognitive impairments. This is an issue that is closely related to the game's semantics and flow, so it cannot be abstracted easily. This was achieved by providing alternative versions of several elements in the game (original and adapted conversations, original and adapted puzzles, and original and adapted exams) that are enabled or disabled when the corresponding adaptation rules are triggered.

The resulting game serves as the prototype of an accessible game, and its development helped us to assess the potential and limitations of the accessibility features offered by <e-Adventure>. The most important result is that adding accessibility features that covered a wide range of potential impairments required very little effort and no programming at all. The platform facilitated the creation of a fully-captioned game, where every action can be triggered through a voice command and where feedback can be delivered through a speech synthesizer. The adaptation system allows the creation of a single game that can be played with different levels of cognitive difficulty, including fine-grained adaptations that can be controlled separately, giving the author great control over which sections are modified.

6. CONCLUSIONS AND FUTURE WORK

The current trend in learning technologies towards increasingly complex multimedia and interactive contents presents a significant accessibility challenge. Even though there is an ongoing effort to reduce accessibility barriers in information systems, some of the most innovative media (such as complex interactive multimedia contents or educational videogames) are not receiving enough attention. Entertainment driven games can afford to ignore accessibility concerns, but educational games should be inclusive and available to everyone regardless of their individual conditions.

Nevertheless, the development of accessible games comes at a cost. In educational settings, with limited budgets and markets, the problem becomes greater. In addition, accessible videogames are a relatively new idea, and the existing research in the field is still young and isolated. In this work we have presented the foundations of our approach to accessible educational gaming, which proposes a general framework for accessible videogames and provides a tool to facilitate the inclusion of those accessibility features in educational videogames.

However, the system is still in the prototype stage, and the quality of the results depends on the effectiveness of the supporting technologies. For example, <e-Adventure> is supported by different opensource tools (FreeTTS, Sphinx, Stanford Parser), and the quality of the results is highly dependent on their strengths and weaknesses. Fortunately, these supporting tools are evolving rapidly, and their improvement will bring benefits to the accessibility of any kind of content.

At this stage, our future lines of work will focus on facilitating the process of inputting and maintaining the data from the user model and the context. An interesting approach would be to detect when a student is being challenged excessively by the game or if the student repeatedly fails to react to some outputs from the game, and then load the adaptation features required to compensate those problems.

Finally, our next research will also include coping with cognitive impairments more explicitly. It is an important issue which is rarely covered in the development of accessible IT systems due to its high complexity. Although the effects of ignoring cognitive impairments in entertainment-driven developments might be affordable, they cannot be left aside in educational settings where all the students need to achieve the learning goals. Moreover dealing with cognitive impairments in videogames is interesting as it could improve significantly the learning outcomes of students with such needs, given the close relation between cognition and learning.

7. ACKNOWLEDGMENTS

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7.2. Accessible Games and Education: Accessibility Experiences with eAdventure

7.2.1. Cita completa

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7.2.2. Resumen original de la publicación

The increasing importance of the video game entertainment industry has prompted different efforts to promote the inclusion of accessibility features in them. While the academic field has produced relevant and promising results, mainstream producers are still reluctant to invest in access for all. However, in the academic field there is also a growing trend towards introducing games and game-like activities in educational settings, usually labeled as serious games, in an attempt to explore other learning approaches and to improve the students' engagement. And while entertainment games can (arguably) opt to ignore accessibility, educational games must be inclusive and cannot afford to ignore accessibility. In this work we present our approach to promoting accessible educational games. To reduce the barriers and costs of creating accessible educational games we are exploring the use of game creation tools with built-in accessibility features, as opposed to adding ad hoc accessibility features to existing educational games.

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Accessible Games and Education: Accessibility Experiences with *eAdventure*

The increasing importance of the video game entertainment industry has prompted different efforts to promote the inclusion of accessibility features within games. Whilst the field of academia has produced relevant and promising results, mainstream producers are still reluctant to invest in access-for-all. However, in the field of academia there is also a growing trend towards introducing games and game-like activities in educational settings - usually labeled as 'serious games' - in an attempt to explore other learning approaches and to improve the engagement of students. Yet while entertainment games can (arguably) opt to ignore accessibility, educational games must *be inclusive and cannot afford to ignore it. In this paper, we present our approach to promoting accessible educational games. To reduce the barriers and costs of creating accessible educational games, we explore the use of game creation tools with built-in accessibility features, as opposed to adding accessibility features* ad hoc *to existing educational games.*

1. Introduction

Along with the increasing demand for improved educational processes, recent years have seen an increase in the application of new technologies and media formats to support new pedagogical strategies in order to prepare students for the challenges demanded by our rapidly changing society. Within the academic field of Technology-Enhanced Learning, there is an emerging trend to provide more dynamic and interactive content for students such as in the form of video games, which have been particularly highlighted because of their potential as learning tools (Gee, 2007; Kirriemuir & McFarlane, 2004; Michael & Chen, 2006).

However, the technology of video games is still an emerging and rapidly growing one. Other technologies - especially the Internet - have also experienced rapid expansion, but these fast-paced advances often entail a marginalization of people with special needs who cannot access digital content. This can be a consequence of a personal disability (e.g. blindness, deafness, reduced mobility, learning disorders etc.) or even be due to contextual and technological issues (e.g. noisy environments where sound cannot be heard or connectivity is limited, language barriers, etc.).

As a consequence, there has been increasing development of technologies that enhance the accessibility of information systems for people with special needs. Nevertheless, the creation of accessible technologies has been unequally focused on the different fields of software development. Whilst Web accessibility is reasonably well catered for, including multiple initiatives, tools, standards and guidelines, developers involved in other technological areas such as interactive multimedia (and especially video games) are still trying to find the most suitable way to create accessible products (Abrahams, 2010).

Focusing on the specific topic of games, whilst it is true that there are some video games that include accessibility features, the high costs involved in incorporating some of these features in the game post-production is hindering their widespread adoption. Moreover, some of the projects that include accessibility features have been introduced as a result of other motivations (e.g. including in-game voice command support to enhance the gaming experience). Commercial games tend to pay little attention to these accessibility issues, partly because the industry perceives that the return on any investment is marginal. Due to a lack of specific regulations governing accessible commercial games, many publishers opt to ignore the aspect of accessibility.

However, when we focus on educational games, these problems and the discussion relating to the potential return on the investment budget must be examined differently. The need for enhanced accessibility in any kind of educational content is more pressing than in developments that are purely entertainment-driven. According to a recent report on disability jointly produced by the WHO and the World Bank, more than a billion people in the world today experience disability (World Health Organization, 2011). According to this report, the estimated number of children experiencing "moderate or severe disability" ranges from 93 to 150 million, depending on the survey. If educational video games are to play a role in education, accessibility must be considered.

Accessibility for educational video games needs to address a diverse range of issues. Video games provide engaging experiences that are far more complex than other information systems which simply grant users access to data. As such, approaches which bring accessibility to the Web and other information systems are not fully scalable to video games, as these approaches may hinder the games' immersive and engaging atmosphere. In addition, when it comes to the educational field, it is harder to assume the higher cost of accessible games, given that most innovative educational gaming projects often have a limited budget. These contexts require methodologies, design patterns and tools specially devised to facilitate the creation of accessible educational video games. In reality, such elements are rare and have received scant attention in the surrounding literature.

The aim of our work is to facilitate the introduction of accessible features into the development of educational video games without compromising development costs. Integrating accessibility features into the tools used to create the games would free developers from having to implement ad-hoc accessibility solutions for their games. With this objective in mind, we have introduced a set of accessibility features into *eAdventure*, a game-authoring platform designed to facilitate the creation of educational *point-and-click* adventure games.

This paper is structured as follows: Section 2 presents some related work, focusing on the potential issues and current trends in the fields of accessibility, games and education. In section 3 we discuss some design issues especially relevant to educational gaming. Section 4 describes the accessibility features of the *eAdventure* platform. Section 5 presents a case study, in which a pre-existing game is enhanced with accessibility features and the approach evaluated. Finally, section 6 presents some conclusions and potential future lines of research.

2. Related Work

The accessibility of information systems is rapidly attracting the attention of national authorities and IT professionals, since it is one of the potential sources of a digital divide. In this context, the accessibility of educational technologies can seriously affect the future opportunities of individuals who have limited means of access. While traditional teaching methods are often able to cope with aspects of accessibility through the efforts of the instructors, the current trend towards increasingly complex educational technologies is continuously increasing the challenge. In this section, we discuss the relevant topics for state-of-the-art accessibility in Technology-Enhanced Learning in general, and in particular in educational gaming.

2.1 Accessibility in e-Learning Environments

As e-Learning environments are mainly web-based systems (e.g. Learning Management Systems - LMS - such as Moodle™, Blackboard™ or Sakai™), the current state-of-the-art accessibility for e-Learning is very closely related to Web accessibility in general.

E-Learning environments have profited from the ongoing efforts of different public and private organizations to improve WWW accessibility. Highly influential organizations such as the W3C are presenting the necessary requirements for creating accessible web content through the Web Accessibility Initiative (WAI). WAI includes guidelines and techniques for the development and evaluation of multiple types of accessible applications related to the Web (W3C, 2002, 2008, 2011a, 2011b). Along with this initiative, different webmaster-oriented tools have been created which are devoted to checking the level of accessibility of web-based content and applications (W3C, 2006). Besides this, assistive technologies such as screen-readers or screen magnifiers have partially helped to improve the level of accessibility of the Web.

There are also initiatives that specifically deal with digital educational content for web environments. A very thorough approach was undertaken by the IMS Global Consortium in their IMS AccessForAll set of specifications (IMS Global Consortium, 2003, 2004). This initiative tries to define a set of data to describe the needs of students with disabilities and to tag the materials (Learning Objects) accordingly. The content that is delivered to the students could therefore be aligned with their special requirements. A similar approach is the ISO/IEC 24751-1:2008 standard, developed by the International Organization for Standardization (ISO). Other initiatives focus on the analysis of the level of accessibility of popular e-Learning systems (Freire et al., 2009; Minovic, Stavljanin, Milovanovic & Starcevic, 2008) or on enhancing accessibility of e-Learning systems (Sclater, 2008).

2.2 Special and Adapted Game Devices

The most common approach to increasing the accessibility of video games is to seek their compatibility with assistive technologies (Kearney, 2005). This includes compatibility with adapted and special hardware, but also with software. Some examples are screen-reading tools, mouse emulators and virtual keyboards. There are also tools that can be used to substitute the usual gamepads provided by game consoles (e.g. vocal joysticks, head gamepads or tongue sensors).

Following this line of research, the work presented by Sjöström & Rassmus-Gröhn (1999) shows the use of the PHANToM™ device as an example of how haptic devices (devices which provide human-computer interaction based on body movements and the sense of touch) can increase accessibility. This approach not only facilitates access to the games for a wide range of people with reduced mobility (controlling the video games with easy movements of one finger), but can also be useful for visually impaired people because the device offers them the possibility of perceiving 3D objects by means of the movements and vibrations it produces.

Another approach consists of adjusting games without requiring specific devices (e.g. adding subtitles). However, it is possible to bring both concepts together. For instance, there are games that allow the player to combine screen-reading tools, mouse emulators and virtual keyboards. In the same vein, we find auditory games (also known as "audio - games") (Friberg & Gärdenfors, 2004). These are games specially designed for people with visual disabilities where all the information from the game is transmitted via audio (Röber & Masuch, 2005). Specific sounds with special meanings are used intensively throughout the game so it is easy to remember the association between sounds and their meanings. In some of these games, the indications are given with abstract sounds, but the games most widely accepted are those which give users vocal descriptions reproduced through text-to-speech synthesizers. Other games receive input either vocally or by means of specific devices (Targett & Fernström, 2003).

2.3 Accessibility in Entertainment-Driven Commercial Video Games

There are some commercial video games that implement features to enhance accessibility from development or that have been modified after publication for this purpose. The creators of *Half Life 2*™ introduced accessibility for people with hearing problems during the development process after they received complaints concerning the first game of the series (*Half Life*™). The reason for this is that in *Half Life*™, certain information that was essential in order to complete the game was transmitted through cut-scenes (videos) without subtitles, making it impossible for people with hearing disabilities to reach the end of the game (Bierre et al., 2005).

Another example is *Terraformers*™, a game that was directly designed to include accessibility features from an early stage. It has a normal mode in which visual graphics are reproduced in the usual manner of first-person 3D games, but it also has an accessible mode. In the latter mode, sonar is activated to tell players what is in front of them and the graphic contrast is increased for visually-impaired people (Westin, 2004). This mode also allows the player to select objects from the inventory using voice commands.

Other academic papers have focused on providing guidelines about how to design interfaces or methodologies for accessible video game development (Friberg & Gärdenfors, 2004; Grammenos, Savidis & Stephanidis, 2007). As yet, there are no broadly accepted standards or specifications in this regard, but there are a few web-based initiatives that provide broad guidelines as to how to develop video games with accessible features. These initiatives must be translated into standards in order to unify the criteria and make the way to create accessible games more clear and facilitate the reuse of successful practices.

The International Game Developers Association (IGDA) has a Special Interest Group which focuses on accessibility issues. This group is active in producing state-of-the-art reports and analysis covering accessibility in games. One of their early works (Bierre et al., 2004) provides a general overview of the field, covering what is meant by accessibility in games, why this is necessary, what kind of disabilities can be tackled at the stage of video game creation, and the most frequent adaptations that developers concerned with accessibility usually perform. The document also outlines how to adapt existing games to improve their accessibility through the addition of subtitles and customizing text fonts, and how the textual information and subtitles can be recorded or synthesized. Along with these ideas, the authors encourage the use of other approaches to gather user input, such as the use of voice recognition or other specific devices. However, the report does not propose any concrete patterns or methodologies for creating accessible games.

From a technological point of view, a unique approach is proposed by FORTH (Foundation for Research and Technology - Hellas), based on the Unified User Interface Design (UUID) (Savidis & Stephanidis, 2004). UUID proposes a design pattern where game tasks are initially considered in an abstract device-independent way. In later design phases, the interaction for each game task is designed, including the selection of input/output devices. Several games have been developed following these guidelines, achieving accessibility for people with a wide range of special needs. These are the universally accessible games (UA-Games). One example is *Access Invaders* (Grammenos, Savidis, Georgalis & Stephanidis, 2006), which supports different game settings depending on the potential disabilities of each player. These include blindness (in which case the game will be loaded with the appropriate characteristics of the Audio-Games), damaged vision and cognitive or motor disabilities.

As far as development tools are concerned, the market is populated with many authoring environments for the development of video games. There are development frameworks for game programming (such as Microsoft™ XNA™), game development environments which allow people without technical knowledge to develop their own video games (such as Game Maker™ and *Unity3D*™), and even simple editors oriented to specific game genres (such as *The FPS Creator and Adventure Game Studio*). However, none of these initiatives include pre-configured features which target game accessibility or which are oriented to facilitate universal design. Therefore, accessibility has to be implemented from scratch for each individual game and, depending on the flexibility and possibilities for expansion provided by the platform, it may eventually be unfeasible to introduce certain accessibility features (e.g. a text-to-speech engine is not available).

3. Design Strategies For Accessible Educational Video Games

Video games are very different in comparison to other materials (e.g. web-based content), as they pose accessibility barriers that must be thoroughly analyzed. Some of these can be addressed with a slight increase in development cost if they are considered from the beginning, but the investment may grow alarmingly if they have to be implemented a posteriori. For instance, a flexible configuration tool for the game parameters (font settings: color, size etc., audio settings, time response gaps and input/output settings) is something "cheap" to implement and effective for the accessibility needs of many common disabilities.

Other perspectives may be the importance of taking into account the compatibility with special or adapted game devices, or the importance of including special tutorials and documentation within the games (Bierre et al., 2005). Many different recommendations regarding the design of video games can be discussed, but in this section we focus on three issues that are especially relevant to educational video games: the choice of an appropriate game genre, the need for fine-grained adaptation support and finally the distribution and deployment of the games.

3.1 Appropriate Genres for Accessible Educational Video Games

Accessibility requirements are very different depending on the game genre. Moreover, not all game genres have the same educational potential.

In order to make them accessible, game experiences must be designed abstractly without committing to any specific device or input/output system. Therefore, where possible, it is better to focus on game genres in which engagement and immersion are obtained thanks to the attractiveness of game tasks, activities and the flow of the game itself, rather than from features such as the game being visually attractive or providing intensive action. Educational games must capture the attention of students and motivate them even when their accessibility features are activated. Otherwise, their positive effects on learning will evaporate.

Point-and-click adventure games, such as the classic *Monkey Island* (1990 -) and *Myst* sagas (1993.2005), meet these requirements. This kind of game captures the player's attention by developing an engaging and motivational plot that players uncover as they advance through the game. Elements such as graphics, sounds and special effects are also part of these games, but only as peripheral features to enhance immersion. They promote reflection instead of action, something which is very convenient for people with motor disabilities as it allows them to solve puzzles with no time pressure. As such, *Point-and-click* adventure and story-telling games are particularly appropriate for education (Dickey, 2006).

3.2 Fine-grained Adaptation vs. Coarse-grained Adaptation

The adaptation performed on a game to make it accessible must be fine-grained, that is as finely-tuned to each player as possible. Whilst relying on stereotypes may solve some of the problems, they may exclude some users. If different alternatives may be applicable in the case of a certain student, the optimum option must be always the choice, whilst considering aspects such as which alternative best preserves the engagement and immersion factors of the game or which will make interacting with the game less difficult and/or time-consuming. This approach differs from typical coarse-grained approaches to web-based content which are built on rough categorizations of students according to their disabilities. As opposed to with other kinds of content, within video games it is possible to provide much more finely-tuned adaptive experiences (Houlette, 2004; Magerko, 2008).

3.3 The Distribution and Deployment of Educational Video Games

The processes of delivering, installing and running games must also be accessible. This presents an extra burden in educational settings. Video games usually consume a lot of machine resources and require top-of-the-range computers that are not always present in schools. To tackle this, we could take advantage of current e-Learning systems to ease game delivery and distribution (Torrente, Moreno-Ger, Martínez-Ortiz & Fernández-Manjón, 2009).

Accessing a game that is embedded in a webpage would be easier for students with disabilities, as it does not require any additional setup and they usually have hardware or software aids with which to navigate the Web. This sets a design restriction on the games, as they have to be webdeployable (e.g. using Java technologies or Adobe Flash) and small in size in order that they can be easily distributed via the Internet.

4. The eAdventure Approach

eAdventure is an educational game platform developed by the <e-UCM> research group at the Complutense University of Madrid (Spain) which has been used in the development of different educational games (Moreno-Ger, Blesius, Currier, Sierra & Fernández-Manjón, 2008; Moreno-Ger et al., 2010). The platform is composed of two applications: a game authoring editor (used to create the educational games) and a game engine (used to execute these games). The editor is instructor-oriented and does not require any technical background or programming skills.

Before beginning this work, the *eAdventure* platform already had some features that could facilitate the development of accessible games, especially for e-Learning applications. Firstly, it is focused on the *point-and-click* adventure game genre. Secondly, an audio file can be attached to any text string in a conversation. Thirdly, *eAdventure* includes mentoring mechanisms to help students when they become stuck on puzzles or other challenges. Finally, *eAdventure* allows the configuration of aspects such as the time at which each message is displayed.

In addition, *eAdventure* provides instructors with special features that enhance the educational possibilities of the platform, including mechanisms to track the performance of each user and to adapt the game experience to the needs of different students (Torrente, Moreno-Ger & Fernández-Manjón, 2008). Finally, *eAdventure* games can be deployed via the Web and integrated into a Learning Management System such as Moodle™.

In the following sections we describe the modifications made to the platform to facilitate the development of accessible educational games. The goal of developing this prototype was not to provide a holistic accessibility solution, but rather to investigate the feasibility of implementing accessibility in a game platform directly at the authoring tool level. Multiple simplifications were therefore made, targeting some of the most common disabilities: blindness, deafness, reduced mobility, low vision and some cognitive disabilities.

4.1 Combination of Input/Output Modules

The *eAdventure* platform includes different pre-configured input/output modules to facilitate the inclusion of accessibility in the games. The idea is that game authors should be able to include multi-modal interaction in their titles in order that people with special needs can play them easily by simply using functionalities included in *eAdventure*. In addition, *eAdventure* provides a number of in-game tools that can be included in the games as extra accessibility aids. These modules can be activated/deactivated automatically at the author's discretion.

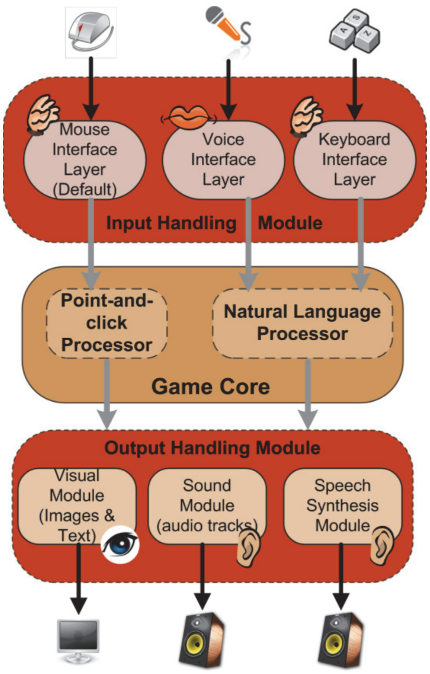

Figure 1: The architecture of the *eAdventure* game engine, with separate layers for input and output.

The *eAdventure* game engine is organized into three layers, with a core layer that handles the game interactions and monitors the state of the game and two separate layers which handle input and output. When the game is launched, it is possible to enable different modules within the input/output layers, selecting the most appropriate combination for the specific needs of each user.

The game core has two separate modules to influence and report the internal state of the game. There is a classic *point-and-click* input processor that was originally available in *eAdventure*. This processor is capable of handling mouse interactions, drawing on-screen graphics and managing simple sound effects. There is also a new Natural Language Processor capable of receiving audio or written input, processing it according to a regular grammar that defines valid commands for the game and using it to modify the state of the game. This module can also produce language output, using pre-recorded audio tracks or a speech synthesis module.

4.2 Input Modules

There are three input modules supported by the *eAdventure* platform: the Mouse Interface Layer, the Vocal Interface Layer and the Keyboard Interface Layer.

The Mouse Interface Layer is the classic interaction mechanism of *point-and-click* adventure games already present in *eAdventure*. Using this interaction mechanism, students usually need to point the mouse over the characters and objects they find as they proceed through the game in order to trigger any kind of in-game interaction. Students therefore need to be able to move the mouse over the screen to discover interactive elements in order to play the games, which may render them inaccessible to students with visual or mobility disabilities.

The Vocal Interface Layer was implemented to allow students with reduced mobility in hands to control games using speech commands. Using a microphone, students can directly “give orders” to trigger any interaction in the game (e.g. “go to the library” or “grab the notebook”). The Keyboard Interface Layer accepts the same orders as the Vocal Interface, but uses the keyboard as the input device. When this layer is activated, a text box appears at the bottom of the screen to allow the user to input commands. Students can thus interact with the game in their natural language, something which can be helpful for students with reduced mobility (using their voice) or visual disabilities (using the keyboard).

Order	*Description*
Examine the table (1)	The game will provide a description of the object "table", if it exists in the scene.
Go to the door (1)	The student's avatar in the game will move towards the place "door".
Grab the pencil (1)	The game will take out the object "pencil" from the scene and put it in the student's inventory[1].
Use ingredient with mixer (1)	The game will combine the objects "ingredient" and "mixer"
Name items in the scene (2)	The game will tell the student which items have already been discovered so that he or she can interact with them.
Open options menu (2)	Pause the game and show the options menu.
Describe (the) scene (2)	The game will provide a description of the scene as a hint for the student.

Table 1: Example of natural language commands available during gameplay. Examples tagged with (1) would be dynamically defined for each scene. Examples tagged with (2) are common to all scenes and games.

Both the Vocal and Keyboard Interfaces were based on the same kind of interaction in order to reduce the implementation cost of the approach and improve the ease of maintenance of the system. Both layers are therefore connected to the same processor (the Natural Language Processor) which receives the commands and maps them onto the game semantic.

The regular grammar that defines game commands combines this kind of dynamically generated rules with some that are constant for all the scenes and games. These rules are used to define basic interactions with the game (e.g. open menus, exit game, skip dialogue lines etc.). Another important aspect is that in order to enhance usability, the Natural Language Processor accepts diverse synonyms for the verbs and nouns that are fixed (e.g. 'examine the scene' or 'describe the scene' are both permitted). Table 1 shows some examples of typical orders the system would recognize in an *eAdventure* game.

1 The inventory is an element that is usually present in point-and-click adventure games. Players use the inventory to store objects they find on their way and keep them for a later use.

4.3 Output Modules

eAdventure has likewise been provided with three output modules: the Visual Output Module, the Sound Output Module and the Speech Synthesis Module.

The Visual Module is not only used to display images on the screen (the background image for the scene, the characters and objects etc.) but also text. Text is a key element in *point-and-click* adventure games, as these games commonly provide information through conversations with other characters which are usually written on screen.

The visual module can also be enhanced with two additional features. Firstly, game authors can provide students with a screen magnifier. To avoid disrupting the immersive atmosphere of the game, this is represented as an object that is included in the student's inventory (Figure 2). The student can use it to turn the mouse pointer into a magnifying glass that can be moved around in the game. Similarly, the player can also activate or deactivate a special high-contrast mode that highlights the interactive objects and partially hides the background (Figure 3).

Figure 2: Example of the in-game "screen magnifier" tool in an *eAdventure* game.

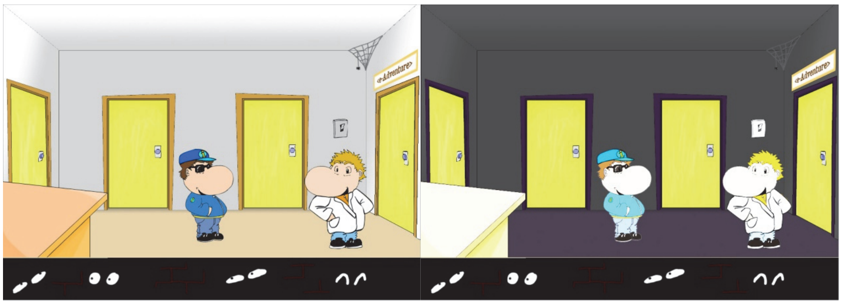

Figure 3: A game scene in regular view (a) and in high-contrast mode (b).

In turn, the Sound Module is capable of playing pre-recorded sounds, and it is possible to use it to add accessibility features to in-game conversations and texts by recording all the dialogues (the sound module can play audio tracks in MP3 format). However, this significantly increases the cost of the game, requiring voice actors to record each individual utterance. This is often a problem when the budget is limited (as is usually the case for most educational projects).

This is where the Speech Synthesis Module can be a helpful addition, as it allows the introduction of accessibility for students with visual disabilities at a low cost. When this module is enabled, any text to be written on the screen will be automatically reproduced through the Speech Synthesis Module. Higher-budget projects can still use the standard sound module (which plays mp3 files) for increased sound quality. In either case, these modules can also read special accessible descriptions that can be attached to each scene in the game.

The regular Sound Output Module is also used to play descriptive sounds as an alternative feedback for the user. For instance, when the Keyboard Interface is activated and the user introduces a command, the system uses special beeps to indicate whether or not the command was a valid one. Analogously, other actions such as entering or leaving the options menu have been associated with other specific beeps.

4.4 Configuring Accessibility Features with the eAdventure Game Editor

The first step to create an accessible adventure game is obviously to design and develop the game with the *eAdventure* game editor. It is recommended not to leave the decision about accessibility to the last moment, but to instead think about the accessibility features that are going to be introduced in the game during the design phase. This is especially true if these will require adapting the game flow as this would involve providing alternative paths, dealing with difficulty settings or providing additional aids in some situations.

When the game is designed, the author must select the input/output modules and the in-game accessibility tools (such as the screen magnifier) that will be active in the game. The game editor uses these settings to optimize the exportation process so that no unnecessary modules will be packaged within the game.

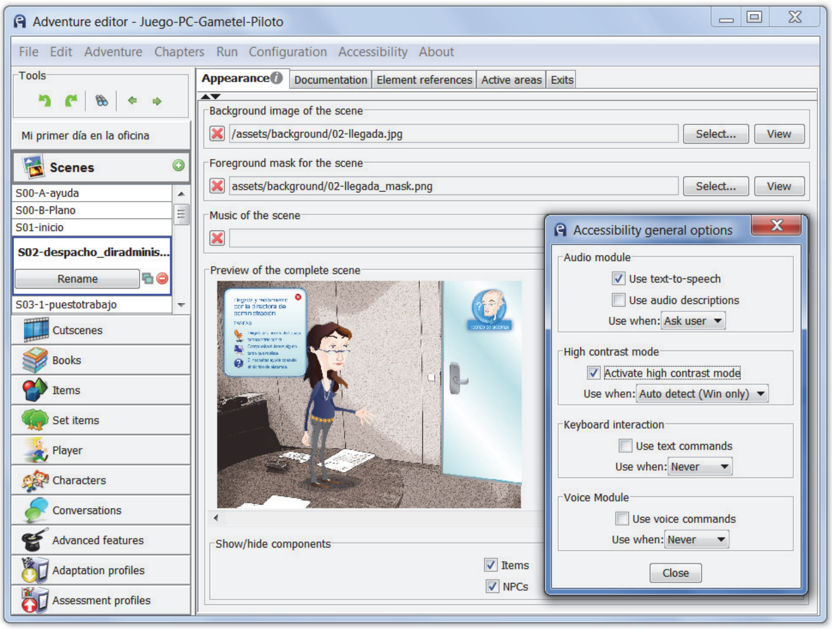

Figure 4: Edition of the Input/Output settings with the *eAdventure* editor.

If visual disabilities are considered, it is very important that all the visual elements of the game receive alternative descriptions. When the player enters a scene, the game engine will use these descriptions along with some extra information that it computes from the game definition (e.g. the number of elements in the scene) to create a complete description of what the student is supposed to see. The completed description is synthesized and played using the audio system. Authors can redefine this behavior by introducing a list of available descriptions for each scene and set the conditions that will trigger each description.

The next step is providing captions for cut-scenes (videos and slides). This feature is currently only supported for slide-scenes in *eAdventure*[2]. Finally, game authors need to create the game adaptation profile which will determine under what circumstances the game must be adapted, and how the adaptation must be carried out.

5. Case Study

As a case study to test the new *eAdventure* accessibility features, we introduced accessibility into a pre-existing game. Following the ideas described in section 4, we introduced accessibility for people with different degrees of visual, auditory, motor and cognitive disabilities in the game *1492*, an educational game about Spanish History[3]. *1492* specifically focuses on the events that occurred in 1492, such as the Granada War and Columbus' expedition (Figure 5). These are notable events in the history of Spain and are thoroughly covered in primary education, which is a strong additional motivation for making the game accessible.

2 A slide-scene is a special type of cut-scene that displays a sequence of static images, rather than full-motion video.

3 The original version of the game can be downloaded from the eAdventure game repository: <http://e-adventure.e-ucm.es/course/view.php?id=26>. Video produced by Spanish Public Broadcasting System, available on Youtube: <http://youtu.be/ROg3pjnfi8U>

Figure 5: A screenshot from the game 1492. Cristobalín is exploring King Boabdil's palace looking for the stolen ceremonial Key to the City.

5.1 Adaptation of the 1492 Game

1492 was not initially designed as an accessible game. The first step was to decide the target disabilities and to then activate/deactivate the necessary input/output modules and/or in-game tools using the game editor. For this case study we considered visual, auditory, mobility and cognitive problems.

As cognitive disabilities are very complex and may require very different adaptations, we considered just two possibilities in order to test the system: students with low memory capacity and students with non-severe reasoning problems. In the first case we defined alternative conversations that lessened the amount of information that the student is required to gather at any one moment, thus increasing the focus on relevant information and reducing the amount of "superfluous" information. In the second case, we defined alternative game paths with simpler puzzles and riddles. Furthermore, the original 1492 game included an in-game multiple-choice examination at the end of the game by means of a conversation between the main character (a student called Cristobalín) and his teacher. For both types of cognitive disabilities, we provided an alternative, more linear exam.

In order to cover the rest of potential special requirements, the game is configured with all of the input/output modules and the screen magnifier. The high contrast mode was not used. To allow the modules to describe the game, we also had to provide alternative descriptions of the visual elements found in each scene, as well as of the scenes themselves, so that these could be passed to the speech synthesizer.

5.2 Preliminary Evaluation

The preliminary evaluation phase so far conducted involved two end users. In this session, the game was played for 20 minutes by a blind user and a user with reduced mobility in hands. Both users had prior experience interacting with computers both for work and entertainment (they liked to play some accessible video games). For the visually impaired user, the system was configured with the Keyboard Interface and the Speech Synthesis Module activated. For the user with motor disability, the Vocal Interface was activated as the interaction method. During the experience, we observed and documented the reactions of both participants. The most relevant conclusions obtained from this session are as follows:

The blind user had some initial trouble interacting with the game. Apparently he did not find the mechanism for interaction intuitive. He expected to be able to navigate through the game elements using the keyboard arrows and select the interactions from a menu as he would typically do when navigating the Web. After a while, he began managing to interact with the game without making major errors. In this regard, the auditory feedback provided by the system (speech synthesis and special sound effects) seemed to be appropriate. Nevertheless, it was sometimes difficult for the user to identify which character was speaking as not all the characters' voices were different. This person did not need any assistance from the researchers and could complete the game session on his own.

The person with motor disability had some initial problems with the pronunciation of the commands. It was noted by the researchers that the shorter the pronounced commands, the more efficient the voice recognition. Nevertheless, the user did not realize this and became quickly frustrated and he therefore required some help from the researchers to understand how he was expected to interact with the system. Following this, the accuracy of the vocal interface began to increase, allowing him to complete all the three scenes of the game included in the evaluation session plan (in the case of the second user, the full game was not tested in order to keep the session as short as possible). The main issue with the vocal interface was the vocabulary that the player needed to use in order to activate the game commands. As a result of this experiment, we realized that it is necessary to add flexibility to the vocabulary (e.g. introducing more synonyms from a thesaurus) for the different game actions.

6. Conclusions and Future Work

The current trend in learning technologies is towards increasingly complex multimedia and interactive content and this presents a significant accessibility challenge. In this regard, while entertainment-driven games can to some extent afford to ignore accessibility concerns, educational games should be inclusive and available to everyone regardless of their individual conditions.

Nevertheless, the development of accessible games comes at a cost. In educational settings, with both limited budgets and markets, the problem becomes greater. In addition, accessible video games are a relatively new idea and the existing research in the field is still at an early stage. In this work, we have presented the foundations of our approach to accessible educational gaming, which provides a tool to facilitate the inclusion of accessibility features in educational video games.

However, the system is still at the prototype stage. The evaluation thus far performed has proven the feasibility of the approach, as end users were able to interact with the system. Nevertheless, the results obtained show that there are still open issues that should be dealt with before incorporating the features into a production environment. In this regard, according to the results of the evaluation, it would be necessary to reduce the learning curve, as end users become frustrated the first time they interact with *eAdventure* games using the vocal and keyboard interfaces. This may be solved by including further guidance and an in-game tutorial that explains how the user is expected to interact with the game. Once they are stable enough, we are planning to integrate the accessibility features described throughout this paper into the main release of the open source *eAdventure* platform for use by the general public. This will probably be when the second generation of the platform (*eAdventure* 2.0) is released, which is initially scheduled for late 2012.

Another aspect that will require further attention is the evaluation of our approach for users with cognitive disabilities. While the case study was designed to cope with some cognitive disabilities, it has yet to be tested with target users. Finally, further testing is required in order to measure whether the introduction of accessibility in the games had a negative impact on the user's immersion and engagement. While the users who tested the system felt positive about the experience, the engagement with the regular version of the game compared to the accessible one has not been formally evaluated.

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7.3. Designing Serious Games for Adult Students with Cognitive Disabilities

7.3.1. Cita completa

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7.3.2. Resumen original de la publicación

Digital games have a great potential to improve education of people with cognitive disabilities. However, this target audience has attracted little attention from industry and academia, compared to other segments of the population. As a consequence, there is little knowledge available about how to de-sign games that are usable by people with cognitive disabilities. In this paper we discuss how the eAdventure game platform can support their special needs. This tool has been used to develop two games to improve profession-al education of people with cognitive disabilities. Lessons learnt from these experiences are presented to serve as a first step to support further research in this field.

Designing Serious Games for Adult Students with Cognitive Disabilities

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Abstract. Digital games have a great potential to improve education of people with cognitive disabilities. However, this target audience has attracted little attention from industry and academia, compared to other segments of the population. As a consequence, there is little knowledge available about how to design games that are usable and enjoyable by people with cognitive disabilities. In this paper we discuss how the eAdventure game platform can support their special needs. This tool has been used to develop two games to improve professional education of people with cognitive disabilities. Lessons learnt from these experiences are presented to serve as a first step to support further research in this field.

Keywords: accessibility, digital games, eAdventure, education, e-Learning, Game-Based Learning, social inclusion.

1 Introduction

The educational potential of digital games is rapidly being accepted within the academic community, as more experimental research that proves the effectiveness of this paradigm has became available recently. This body of research validate, at least partially, the hypothesis of academics who discussed unique characteristics of games that make them interesting for education [1].

Some of these features could be especially advantageous for students with cognitive disabilities. For example, digital games provide a virtual world that can be used as a safe test environment that students can freely explore, at their own pace, trying out hypothesis and receiving immediate feedback. Students get immersed in this virtual world, where they can rehearse and improve their abilities and knowledge but without taking any risk. In addition, digital games are able to capture students' attention more effectively than other contents, keeping them in the zone of optimal flow for knowledge creation. This characteristic may be especially beneficial for students with intellectual disabilities, as they usually suffer from attention deficit, which is a significant drawback for learning.

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Despite this potential, there are few games directed to people with cognitive disabilities [2, 3]. This deficiency is motivated by multiple causes, but one of the most important is that designing serious games for people with cognitive disabilities is an extraordinary challenge. Making games is always a complex activity requiring wide doses of creativity and highly specialized technical skills. Cognitive disabilities are complex and heterogeneous, difficult to categorize and model, requiring an individualized approach in many cases. Therefore, when the game design must also cope with these special needs the difficulty of the task increases, involving an additional development cost.

Specialized authoring tools can facilitate game development for this target population. High level tools like Unity or Game Maker facilitate the creation of games by providing code abstraction, automation of frequent tasks, built-in modules and game parts that are ready to use. However, it is necessary that these tools accommodate the special needs of people with disabilities to be really effective. But for this to be feasible, it is necessary to understand what are the requirements of this understudied population for interacting with games.

In this paper we discuss how the eAdventure game authoring tool can be used to create games for people with cognitive disabilities. We present two case studies of developing games to educate adults with cognitive disabilities:"My first day at work" and "The big party". The goal in both games is to improve their education as means to increase their opportunities for employment. Finally we discuss lessons learnt for designing games for this target population.

2 Digital Games for People with Cognitive Disabilities

Despite the ever-growing expansion of digital games, the collective of people with cognitive disabilities has not attracted too much attention yet. As recent literature reviews on accessibility in games reveal, there are few games available that cater for the needs of people with cognitive disabilities [2, 3]. Still, some interesting examples can be found, like Ilbo [4], where players navigate through a 3D maze by using their weight while sitting on a chair. Other games are oriented to facilitate collaboration among peers and improve social and communication skills [5], although in some cases the presence of game elements is limited to a 3D virtual world [6].

Most of the limited research reported on games for cognitive disabilities is concentrated on rehabilitation and therapy, usually combined with virtual reality techniques. For example, in [7] virtual reality games developed for the Nintendo™ Wii® are used to improve motor and cognitive skills of children with a diagnosis of Down Syndrome. Despite of research done, this field is also considered to be in its infancy, lacking of proper understanding of what causes the effectiveness of computer and virtual reality games for rehabilitation [8].

Some studies have addressed the potential of digital games to improve education of people with cognitive disabilities. For instance, in [9] computer games are used to teach safety knowledge to children with cognitive disabilities. This study also demonstrates that knowledge constructed in the virtual world can be transferred to persistent skills in the real world. In [10], a puzzle game for training children with autism is described. A relevant study for the topic of this paper is the GOET project, whereby several games were developed to educate students with cognitive disabilities to improve their chances for employment [11].

Generally speaking, research on serious games for people with cognitive disabilities is still in its infancy, compared to other types of disabilities. It is necessary to conduct a deeper analysis of how game design can be tuned to cater for the special needs of this audience.

3 Point and Click Adventure games. eAdventure

Choosing a right type of game is important to minimize the number of accessibility barriers that must be dealt with. *Point-and-click* adventure games is a genre where many of the most frequent accessibility issues are not present. Besides, this genre has been signaled by academics for having significant educational potential. It is a genre where reflection predominates over action. In fact, time pressure is rarely used to get players engaged. Other elements are used instead, as an appealing story or puzzles that players must solve by applying reasoning and problem solving skills. As a consequence, these games are usually low-paced, which is a desirable characteristic for people with cognitive disabilities [13]. Besides, *point-and-click* interaction is usually simple, requiring a minimum amount of input as controls are mouse clicks that could also be replaced by one-switch devices [3].

eAdventure is a game authoring tool especially devised for educational applications [12]. It is oriented to teachers as end users, providing a simple interface and educational features such as a tracking and assessment system. eAdventure supports the development of games accessible for people with cognitive disabilities in several ways. First, eAdventure is focused on *point-and-click* adventure games. Second, eAdventure includes an adaptation engine that adds personalization and flexibility to the game experience. This system can be used to adapt content and puzzles, reducing complexity and the number of objects as needed [14]. Besides, experimental development to improve the accessibility of the platform has been conducted.

4 My First Day at Work

The educational game "My first day at work" aims to facilitate the incorporation of a worker with a cognitive disability to a new company. The game assumes the player has already got his/her first job, and it covers competences and skills needed for daily work and achieve a successful integration into the team:

- Usage of standard equipment and materials used in the office: computer, printer, fax and a copy printer.
- Fundamentals of the e-mail system used in the company: how to access incoming messages, how to compose and send new messages, download files and use attachments.

Besides, the game covers transversal competencies that people with cognitive disabilities have problems to develop frequently:

- Basic social interaction skills, such as how to address colleagues with respect, ask for help when needed, etc.
- Structure of the company and the physical distribution of its headquarters.

The game has the form of an adventure quest where the player must complete different tasks that are assigned by the company's management board. To complete these tasks he/she must interact with different objects and characters.

Additionally, the game "My first day at work" includes accessibility features oriented to overcome potential barriers for students with a visual disability or limited mobility in hands. Therefore the game can be played using the mouse, the keyboard or speech commands, and the return of information is produced either visually or by audio. The game also includes a high contrast mode for people with limited vision. This visualization mode applies an alternative rendering mode to backgrounds and interactive elements, with the purpose of increasing the contrast of such a highly graphical application.

The game was developed in collaboration with Technosite, a company that belongs to the ONCE group (Spanish National Organization for the Blind). Experts in game accessibility, therapists and social workers were involved in the development of the game. A usability evaluation was performed with 15 users that were exposed to the game for one hour. Participants with the slightest disabilities were able to complete the game without further guidance or intervention from researchers. However, participants with severe disabilities had problems to remember short-term goals, which suggested the need for a "task list" feature that could be accessed at all times. Participants showed interest in the game and considered it a good asset to improve their education.

Fig. 1. Screenshots of the game "My first day at work"

5 The Big Party

The game "The Big Party" was designed to train a specific set of social and self autonomy skills and concepts in adults with a cognitive disability.

The topic of the game is to attend a social dinner organized by the company the player works for. The game covers a wide range of issues, from personal hygiene and choosing appropriate clothes for the occasion to addressing other colleagues.

When the game starts, the player chooses his/her gender on the game. This choice will be used by the game to adapt configuration of the resources, clothes, and hygiene habits displayed. The game covers the next specific competences:

- Personal hygiene: processes related to hygiene including showering, brushing teeth, applying cologne and deodorant, combing one's hair, etc. Tasks related to personal care must be executed in a specific right order (for example, cologne should not be applied before taking a shower).
- Preparation before leaving home: adequate dressing for the event.
- Take public transport to reach the event and dealing with unexpected issues (e.g. request help from underground's staff).
- Use of common resources and items in public places and transport vehicles (ticket vendor machines, control points, automatic elevator, etc.).
- Correct use of language in formal occasions.
- Basic rules of behaviour in public places, including interaction with peers, like give greetings, say good bye, bringing up conversation topics that may be of interest for other people or resolution of conflicts (e.g. stepping a colleague by accident). Aspects related to self control and moderate eating and drinking are also considered.

The game is linear, with a specific number of tasks to be completed in a specific order. Thus, completing the game implies succeeding in all game tasks. For that purpose, the player is provided with convenient feedback when he/she fails to complete a task. The player is allowed as many retries as needed.

The game has been developed in collaboration with the Prodis foundation, whose mission is to prepare adult students with cognitive disabilities for professional development. The game has been evaluated in two Living Labs with teachers of special education and also with students with Down Syndrome. The purpose of this evaluation was to identify potential improvements or modifications for enhancing its usability and guarantee usefulness for this particular educational context.

Fig. 2. Pictures of evaluation sessions during development of "The Big Party" (living lab with educators on the left, usability evaluation with students on the right)

6 Lessons Learnt from the Case Studies

Having a flexible and highly configurable game experience was very important in these cases. This is also a requisite identified by previous work in this field [11]. The one-size-fits-all principle does not usually fit games, where players have different motivations and even play styles. In special education this requisite is even more important, as each user is unique and requires personalized attention. In this sense digital games are more suitable than other kind of contents as digital games are flexible and easy to configure.

A good example is the high contrast mode developed for the game "My First Day at Work". Although this mode was developed in collaboration with people that normally use high contrast settings to interact with technology, not all people that participated in the evaluation felt comfortable with the interface. Through the feedback participants provided, researchers noticed that each user had a particular way to interact with the computer. In the case of "The Big Party", diverse aspects were added a posteriori to facilitate understanding and use by people with intellectual disabilities, like allowing multiple retries to complete a task, indication of possible solutions after a failure or mistake, etc. In this manner students could play the games and learn at their own pace.

Another problem found was that many people with intellectual disabilities have difficulties to identify themselves in the games [11]. Finding a solution to this problem is essential or many students would not be able to play as they would not understand what is going on in the game. In this sense, the ideal solution would be to use students' own image to set up a virtual avatar, but from a technical perspective this is quite complex to implement. In the case of "My First Day at Work", the workaround was to provide the player with a finite set of avatars with varied abilities and characteristics to choose from. Hence players could choose the avatar that was more close to their own characteristics and abilities. In "The big party" game students experienced the game in first person, limiting their choices to a simple selection of gender. The preliminary evaluation proved that any improvement in this aspect would be beneficial for the overall usability of the game.

Broadly speaking, design guidelines followed in the development of both games can be repurposed and applied to effectively develop other games for students with intellectual disability. For example, language style should be simple, clear and direct. It is also highly desirable to provide information using multiple modalities (e.g. complementing visual feedback with descriptive sounds, using subtitles but also speech recorded by actors. This feature will also make the games more accessible for students with other disabilities. It is important to gauge game's pace to ensure that players have enough time to read all dialogues, analyze all information provided by the game and take decisions according to options available. The eAdventure platform that was used to develop the games provided ready-to-use solutions that facilitated dealing with this issue (e.g. management of timing, progress in dialogs and interactions).

Reaching the highest level of realism possible is also a recommended practice. This facilitates the acquisition of new knowledge and abilities by students with abstract reasoning deficiencies. For this reason both "My First Day at Work" and "The

Big Party" have been developed combining photos and videos from real environments with cartoon-like designs. This also helps to limit the number of graphic assets required, which reduces the production cost.

Both games were developed following a user-centered methodology, using living labs to identify potential barriers. This methodology allowed for a rapid detection of poor design strategies and supported an agile requirements capture process, which facilitated development and reduced the overall cost. This aspect was crucial for success as how this target population interacts with games is rather unknown and therefore it cannot be anticipated.

These case studies were useful to identify potential improvements in the eAdventure authoring tool. For example, people with Down Syndrome are slower at executing goal-directed tasks/activities compared to typically developing peers. Games usually set out a number of primary goals to entice the player that have to be completed in the long term (e.g. defeat the master boss of a level or unlock all possible levels) and are not prone to change frequently. These are complemented with secondary goals, whose completion is required to progress in the game and achieve the primary goals (e.g. unlock a certain weapon to beat the master boss). Secondary goals are set out frequently, and are used to keep the player challenged and engaged at all times. This structure of primary and secondary goals was also present in both case studies, and resulted to be too complex for some users with Down Syndrome as they were unable to remember short-term goals and had problems to distinguish between primary and secondary goals. This problem could be addressed by developing configurable tasks lists in eAdventure that could be accessed by the player at all times.

7 Conclusions and Future Work

The field of digital games has reached a considerable status of maturity and stability, both in its recreational and serious forms. However, there are areas that have not been thoroughly explored yet. This is the case of games for people with cognitive disabilities. The design of games for this audience is a challenge as classic solutions may not be applicable, given the diversity of this understudied target group that brings together multiple disability profiles with heterogeneous needs. Besides, the potential of games to improve the lives of people with cognitive disabilities remains almost unexplored. Research on digital games should address both issues systematically in the next years.

In this paper we have discussed how the eAdventure game authoring tool can support the needs of students with cognitive disabilities. We have presented the main lessons learnt from designing and developing two games for this purpose with eAdventure, in the aim that they may be useful for other serious games developers. However, this is just a first step. The guidelines discussed in this paper are still general and superficial, based on two examples. It is necessary to carry out a deep analysis of the successful strategies found in these games and others in the literature to produce more concrete guidelines that could be applied in the development of new games but also to improve eAdventure and other game authoring platforms.

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7.4. Towards Universal Game Development in Education: Automatic and Semiautomatic Methodologies

7.4.1. Cita completa

Torrente J, del Blanco Á, Serrano-Laguna Á, Vallejo-Pinto JA, Moreno-Ger P, Fernández-Manjón B. Towards Universal Game Development in Education: Automatic and Semiautomatic Methodologies. Advances in Web-Based Learning - ICWL 2012. Springer; 2012; Lecture Notes in Computer Science 7558:160–9.

7.4.2. Resumen original de la publicación

Serious games are increasingly being used in education to support the development of skills that future professionals and citizens require. However, the inclusion of games in the curricula can threaten the universal right to education for students with disabilities if they are not designed to be accessible. In this paper we discuss the need for tools that assist educators and educational content providers in producing games that are equally accessible for all. The goal is to minimize the cost and effort needed for introducing accessibility in serious games. We discuss to what extent the process of making a serious game accessible can be automated and supported by software tools that minimize human intervention. We conclude that there is a set of common accessibility barriers, especially those related to interaction and physical disabilities, that can be addressed systematically in a high proportion and therefore could be dealt with by software. Other problems, especially those more close to structure, storyboard and design, still need direct intervention from the game authors, but could be facilitated with appropriate methodologies and auditing tools.

Towards Universal Game Development in Education

Automatic and Semiautomatic Methodologies

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Abstract. Serious games are increasingly being used in education to support the development of skills that future professionals and citizens require. However, the inclusion of games in the curricula can threaten the universal right to education for students with disabilities if they are not designed to be accessible. In this paper we discuss the need for tools that assist educators and educational content providers in producing games that are equally accessible for all. The goal is to minimize the cost and effort needed for introducing accessibility in serious games. We discuss to what extent the process of making a serious game accessible can be automated and supported by software tools that minimize human intervention. We conclude that there is a set of common accessibility barriers, especially those related to interaction and physical disabilities, that can be addressed systematically in a high proportion and therefore could be dealt with by software. Other problems, especially those more close to structure, storyboard and design, still need direct intervention from the game authors, but could be facilitated with appropriate methodologies and auditing tools.

Keywords: accessibility, educational games, serious games, universal design.

1 Introduction

Education is a universal right, and this adds an imperative to consider accessibility as a high priority requirement whenever new technologies are brought into the educational process. Otherwise we may be threatening the equality of opportunities for all students. This should be the case of educational games (a.k.a. serious games), which are rapidly gaining acceptance, and will probably become a relevant educational tool for enthusiastic teachers in the next few years [1]. But actual level of accessibility in videogames (both commercial and educational) is still low compared to other kind of technologies and digital static contents like the web [2].

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One of the main arguments to explain the few attention that accessibility receives in games is that it means an extra burden for the developers and an increase factor of the investments. Firstly, design complexity increases. Games are intricate, heterogeneous and highly interactive applications that provide unique experiences depending on who is playing and what title is being played [3]. Designing an engaging, appealing and meaningful game for a wide number of users is an art that requires loads of expertise and creativity. When designers have also to cope with the special needs of users with disabilities the difficulty of the job increases substantially. And secondly, developers are faced with extra implementation challenges. Dealing with accessibility usually requires integrating (or even developing) complex and expensive technologies, such as text-to-speech or voice recognition. And it may even require producing special hardware (e.g. adapted game controllers).

All these overheads may be affordable for large entertainment game development projects, and even then most entertainment games tend to ignore accessibility concerns. However, educational games do not typically have large budgets, with many initiatives being led by enthusiastic educators and organizations with little resources. To avoid leaving accessibility concerns out of these projects, making accessible game-based educational content should be as seamless and cost-effective as possible. To accomplish this goal, we advocate for making the process as automated and straightforward as possible, limiting human intervention when possible in order to alleviate the cost overhead. To achieve the objective, it would be necessary to integrate accessibility tools and technologies in educational games development software, thus facilitating the implementation of accessibility features. This would facilitate design by providing game authors (i.e. educators) with reusable components and interfaces that are ready to use, resulting in significant savings.

This paper aims to answer the question of to what extent the introduction of accessibility in educational games can be automated. We build on our previous experiences developing accessibility solutions for educational games that we have tried to integrate in the eAdventure game platform.

2 Related Work

2.1 Approaches to Accessibility in Games

Traditionally, accessibility in games has been addressed individually in most of the cases, either adapting a specific title to meet the needs of a particular user profile [4–6], or developing games for a specific community of users with disabilities [7–9]. Audio games, for example, are designed for users with a visual disability [10]. However, other approaches have adopted a more general and holistic perspective, proposing frameworks and methodologies that consider the needs of different profiles of users that could also be applied to different types of games [11].

For example, in [12] the authors propose Unified User Interface Design, a methodology for designing universally accessible games where game tasks are devised without considering a specific modality or interaction device. In further design phases, alternative interaction methods are designed for each task depending on the needs of the target audience. Therefore the game design is extensible, facilitating the subsequent inclusion of accessibility features to cater for the needs of other users.

2.2 The eAdventure Educational Game Platform

eAdventure [13] (formerly <e-Adventure>) is a game authoring platform especially oriented to education[1] [14]. Although eAdventure's capabilities support the creation of a variety of 2D games, it was originally focused on point-and-click adventure games. This decision was driven by the consideration that these are the most appropriate genres for education because of their strong narrative underpinnings and predominance of reflection over action [15]. From an accessibility perspective, this genre does not pose barriers such as time pressure or fast-paced action, although a variety of barriers related to modality remains (they are highly visual, require moving a mouse for identifying objects, etc.).

There are two components in eAdventure: a game editor used to create the games and a game engine, used to run them. The typical workflow is to create and test the games with the editor, and then use editor's exportation features to produce a distributable package bundling all the assets that the game engine needs to process the games, which are a set of XML documents that describe the game and art resources (images, sounds, videos, etc.). The game editor includes education-oriented features and tries to simplify the game creation process as much as possible.

The game universe in eAdventure games is defined by composing elements of different types: characters, items, active areas, and the game scenarios (a.k.a. scenes), which are composed by a 2D background image and a set of interactive elements.

3 Experiences Developing Accessible Interfaces with eAdventure

We have used eAdventure to explore the automatic generation of accessible interfaces for two games that we present in this section as case studies. Upon the eAdventure source code, we built components that adapted the user interface depending on a given user profile. In this section we will elaborate on the level of automation achieved in each case. For each case, we have evaluated the usability from the end user's perspective, by asking different users to interact with each type of resulting accessible interface. Further technical details on the implementation of these interfaces can be found on previous publications [17, 18].

The official eAdventure distribution complies out-of-the-box with a certain level of accessibility for users with hearing disabilities, as all the information provided by audio can also be displayed with text. It is also accessible for users with a cognitive disability as it integrates an adaptation engine that allows game authors to tailor the game experience to each user capabilities (e.g. alternative contents or puzzles or skipping complex parts). For that reason, our work has focused more on improving accessibility for users with visual and motor disabilities.

[1] `http://e-adventure.e-ucm-es`

3.1 Fully Automatic Adaptation of Interfaces - The case of 1492

In a previous work we have described a prototype built upon eAdventure v1.0 [18] that supported alternative modalities through a combination of input and output modules. Two user profiles were considered: blind users and users with a motor disability. Among the wide variety of levels of visual impairments, we characterized the blind user profile as users that needed the aid of screen reading software to use a computer. We considered users with a motor disability as those needed of using voice recognition software to interact with a computer due to reduced or lack of mobility. Both user profiles encounter barriers when interacting with point-and-click applications as they are not able to use the mouse.

The game author was only allowed to enable or disable the modules during the exportation process. All the adaptation to the user profile was performed automatically by analyzing the game description XML files and art resources (see Fig. 1).

The results were two new modalities which had common inner workings. The interaction was performed through short commands formulated in natural language (e.g. "grab the notebook" or "talk to the character"). An interpreter received the commands, executed them if they were correct, and provided feedback about the results using the appropriate channel for the active user profile (auditory for the blind user through a built-in text-to-speech engine, text for the user with a motor disability). Blind users introduced the commands using the keyboard, while users with a motor disability used speech.

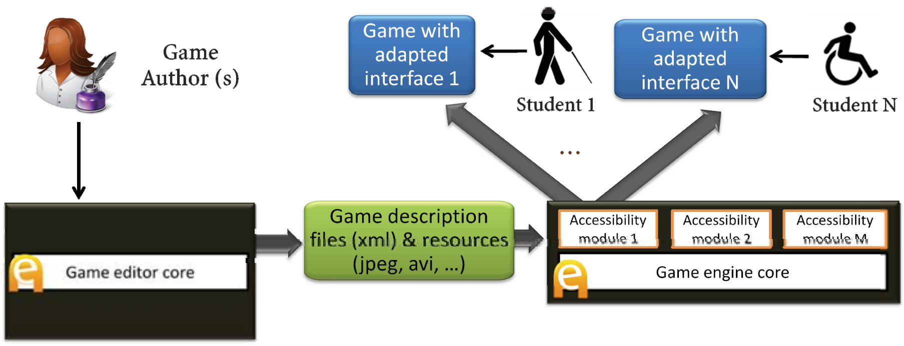

Fig. 1. Basic accessibility architecture. Accessibility was provided by specific input/output modules integrated with the engine, which are activated when the game was exported.

Command processing was directed by a regular grammar combined with a fixed list of synonyms for relevant verbs (actions) and nouns (interactive elements). The regular grammar was automatically generated from the description of the game, taking the actions defined for the interactive elements available in each game scenario. During game play, the number of actions and interactive elements available in eAdventure games is susceptible to change at any time as they depend on the value of a number of variables that vary dynamically according to the rules the game author specifies (this is the mechanism that eAdventure provides to define the game structure and flow). To deal with this issue the grammar was rebuilt each time an internal variable changed and also each time the scenario was reloaded.

This approach was applied to the 1492 game (available from the eAdventure website). It was evaluated by two users, one of each profile. Users were able to interact with and complete the accessible version of the game in the experiment (around 20 minutes of game play), but the system presented several usability flaws. The most important was that the user's vocabulary did not always match the system's vocabulary, defined by a list of synonyms that included at least 4 equivalent words for each keyword. As a result, command recognition accuracy was low, having little chances of succeeding if the game had taken longer to complete. Natural language processing techniques, combined with a well-defined ontology containing a wider vocabulary may overcome this type of issues. Such ontology could effectively cover most of the vocabulary related to actions, as these are common for most eAdventure games (e.g. grab, use, talk, examine, etc.). However, the nouns used for the game items cannot be anticipated as these are user-defined, requiring the game author to provide additional synonyms. Other usability problems found may be solved by improving the implementation of the system (e.g. delays in the auditory feedback generated).

3.2 Semiautomatic Adaptation - The Case of "My first day at work"

Building upon the experience of the 1492 game, we conducted another experiment which resulted in the game "My first day at work", developed in collaboration with Technosite, a company of the ONCE (National Organization for the Blind in Spain) group. We refined the process to address the limitations found (see Fig. 2) by improving flexibility of the accessibility features that now could be configured with the game editor.

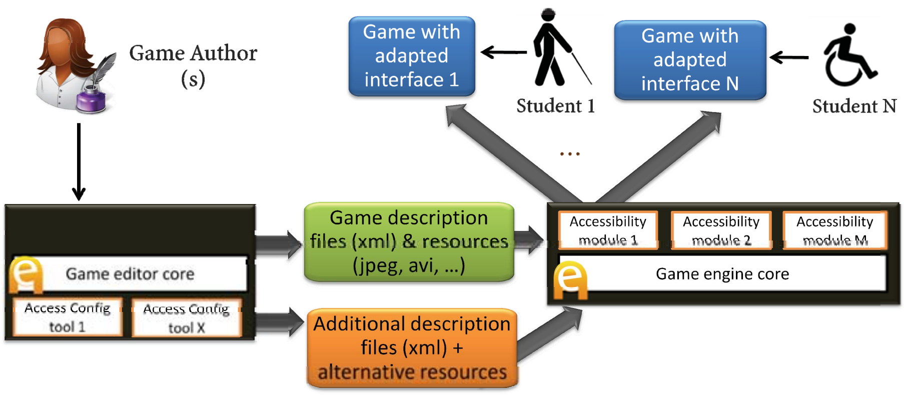

Fig. 2. Improved architecture and workflow. The accessibility features are now configurable from the editor to match different user profiles. The editor also produces automatically additional description files and resources.

In addition to the blind and motor disability profiles, a new user profile was considered: users with low vision. Colleagues from Technosite identified the adaptations this profile needed, which included screen and text magnification and use of a high contrast color scheme. Low vision users were expected to have problems to inspect the game scenes and find interactive elements as for them shapes and images blur with the background of the scene or with other elements.

We tried to keep the human work needed to accommodate the needs of these users to a minimum. The approach followed was to develop a low vision mode in the game engine. We started by developing an alternative rendering mode that improved the contrast of the interactive elements over the background of the game scenarios. This kind of technique has been applied to improve the accessibility of other games in the past [9], although focus has been placed on a single title instead of trying to build a generic and reusable system. This kind of adaptation introduced the novelty of modifying the rendering pipeline (i.e. how the game is painted), in contrast to blind users and users with a motor disability that required adapting the modality. The game engine automatically applied a light green filter to the interactive elements which increased their brightness and a dark purple filter to decrease the brightness of other areas, facilitating the identification of those interactive elements. Font sizes and colors used for cursors, buttons and menus were also automatically adapted.

However further adaptations were needed. Through early prototypes we found out that some scenes could not be adapted by automatically applying a filter, like those using images with text embedded. In these cases, authors should produce alternative graphic resources and include them in the game manually.

Although "My first day at work" was focused on meeting the needs of the three bespoken profiles (blind, motor disability and low vision), we also tried to make it accessible to users with cognitive disabilities (e.g. Down and Asperger syndromes). We wanted to explore the kind of adaptations these users require, who usually experience difficulties to understand complex language, memorize large pieces of information or present attention deficit disorders.

Dealing with these problems is much more complicated and there is little room for automation. The eAdventure adaptation engine was used to provide alternative paths in the game with different levels of difficulty, or alternative versions of text intensive components such as conversations.

The game was evaluated by 10 users with a disability (3 blind users, 4 with low vision and 3 with reduced mobility). Apart from minor usability problems that could be solved by researchers during the experience, all users were able to complete the game (around 60 minutes of game play).

4 Discussion

In the case studies presented the kind of adaptations that were required to meet users' needs varied across profiles. These adaptations affected diverse aspects of the game and were achieved with different levels of automation.

4.1 Level of Automatic and Semi-automatic Adaptation

Table 1 shows a summary of the adaptations performed. Adaptations related to the modality, how the user interacts with the game or perceives the game feedback are prone to be automated (e.g. interfaces for blind users and users with reduced mobility). This does not mean that solutions are straightforward, but that current state-of-the-art in technologies like text-to-speech or voice recognition allows building interfaces that can be used by a high number of users. Once these interfaces have been built, they can be reused across different games with little extra work.

Table 1. Summary of adaptations performed for each profile. Table reflects what aspect of the game were affected and the level of automation achieved.

Profile	Aspect	Adaptation (s)	Automation
Blind	Interaction / modality	New interaction and adapted return of information	High
Motor disability	Interaction / modality	New interaction	High
Low vision	Interface / rendering pipeline	High contrast rendering filters, magnification, alternative images and color schemes	Medium
Cognitive disability	Game design and content	Lessened difficulty of puzzles, alternative version of texts	Low

Other types of disability require adapting how the game is rendered (e.g. users with low vision). The process can be automated to some extent, as the rendering pipeline in game engines can be configured to apply transformations over specific elements, like applying filters, using alternative color schemes (for example to deal with color blindness) enlarging images or providing a magnifier. However, there is a point where alternative versions of art resources may be needed, having a greater impact on the cost of the game. In the case of the game "My First day at work", it was necessary to produce 647 art resources in first instance, including images, animations for characters, videos and sounds. To make it accessible for users with low vision it was needed to produce alternative versions of 53 art resources, an increase of 7,57%. Although this value is not very high it could increase exponentially if more profiles were considered (e.g. users with color blindness), so it is important to keep the number of manually crafted alternative resources as low as possible.

4.2 Non-automatic Adaptations and Auditing Tools

Other accessibility profiles (e.g. those related to cognitive disabilities) may not be subject to automatic adaptation and therefore are harder to address. The adaptations they require are related to the design of the game, which is difficult to analyze and modify without requiring the intervention of the game author. Some AI techniques could be explored to solve some of the problems, like using automatic text analysis to simplify the language used if the user has a cognitive disability, but it is unlikely to achieve similar levels of automation to those previously described in section 3.

In these cases other approaches could be followed. Game authors could be provided with tools to perform accessibility auditing over the games, following the guidelines of the W3C ATAG recommendation [19]. These tools would work as accessibility evaluation tools for the web, searching the game structure for potential accessibility barriers (e.g. complex language, too many interactions available in a game scene, use of time pressure, etc.).

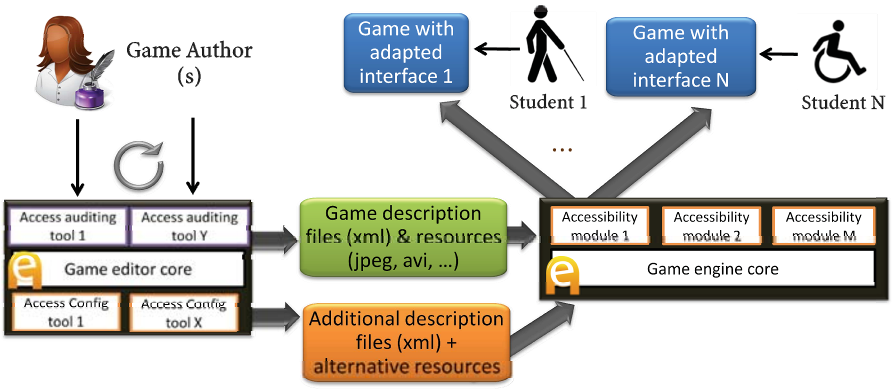

Fig. 3. Final architecture and workflow. Auditing and feedback tools are added, forming an iterative process of accessibility improvement.

An additional benefit of inspection and auditing tools is that they are educational, as they can recommend solutions to the game author and give further details about why problems encountered may endanger access for users with disabilities. The results of the auditing process could be presented in a human readable report, but could also be displayed in their context while the game runs to maximize the educational value. However, developing auditing tools is only feasible if the structure of the game is explicitly defined, as it is in eAdventure and most game authoring software, but not in game engines or frameworks where the game structure emerges or is implicitly defined. The final diagram of editing and running accessible games would look like the one Fig. 3 shows.

5 Conclusions and Future Work

Educational games should be as accessible as possible to avoid a potential digital divide when they are brought into the classroom. To achieve this it is necessary to reduce the overhead needed to make the games accessible, especially in education where budgets are usually limited. Cost reduction can be reached by integrating accessibility tools in game development software. In this paper we have gathered different previous experiences creating accessible games with reusable tools, analyzing the strengths and limitations of each technical approach.

Based on these experiences, we have summarized the lessons learned during the process, ending up in the proposal of an architecture and workflow for the creation of accessible educational games. The focus of the study has been to identify what kind of accessibility adaptations can be performed automatically or semi-automatically, as these are the ideal approaches to keep the cost down.

We conclude that there are adaptations that can be performed mostly automatically, (e.g. generation of alternative interfaces) and have a significant impact in the accessibility of the games. Other adaptations can be performed semi-automatically, like having the tool try to create automatically alternative graphic resources (using filters and special rendering effects), and having a human provide alternative resources only in those cases when the automatic process was not enough.

On the contrary, when these processes cannot be automated, or when there is need for additional insight on the performance of the automated processes, we propose developing accessibility auditing tools to educate, detect barriers and propose solutions to improve the process of introducing accessibility. Nonetheless this is just a proposal that we expect to develop further in future research.

Finally, it should be noted that these automatic adaptations were designed specifically for educational games, where the tradeoff between cost and accessibility is critical, and accessibility should not be ignored. We consider that entertainment games may also benefit from this type of automatic and semi-automatic approaches, even though the game industry tends to favor specific developments for each game, due to the rapidly changing technology required to be competitive in that space.

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7.5. Towards a low cost adaptation of educational games for people with disabilities

7.5.1. Cita completa

Torrente J, del Blanco Á, Serrano-Laguna Á, Vallejo-Pinto J, Moreno-Ger P, Fernández-Manjón B. **Towards a low cost adaptation of educational games for people with disabilities**. Comput Sci Inf Syst [Internet]. 2014; 11(1):369–91. [Syst [JCR-SCI 0,549 2012; 97/132 Categoría *Computer Science, Information Systems*]. Disponible online desde:
http://www.doiserbia.nb.rs/Article.aspx?ID=1820-02141400013T

7.5.2. Resumen original de la publicación

In this paper we analyze how to increase the level of accessibility in videogames by adding support for it in game authoring software. This approach can reduce the effort required to make a game accessible for people with disabilities, resulting in significant savings. A case study is presented to support the approach based on the eAdventure educational game authoring platform, which allows semi-automatic adaptation of the games. The game, "My First Day At Work", was made accessible for students with different disability profiles, mainly blindness, low vision and limited mobility, although hearing and cognitive disabilities are also considered. Results show that the effort needed to make the games accessible is moderate in comparison to the total effort dedicated to game development. Although the specific solutions proposed are optimized for educational games, they could be generalized to other game frameworks and purposes (e.g. entertainment, advertising, etc.).

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Towards a Low Cost Adaptation of Educational Games for People with Disabilities

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Abstract. In this paper we analyze how to increase the level of accessibility in videogames by adding support for it in game authoring software. This approach can reduce the effort required to make a game accessible for people with disabilities, resulting in significant savings. A case study is presented to support the approach based on the eAdventure educational game authoring platform, which allows semi-automatic adaptation of the games. The game, "My First Day At Work", was made accessible for students with different disability profiles, mainly blindness, low vision and limited mobility, although hearing and cognitive disabilities are also considered. Results show that the effort needed to make the games accessible is moderate in comparison to the total effort dedicated to game development. Although the specific solutions proposed are optimized for educational games, they could be generalized to other game frameworks and purposes (e.g. entertainment, advertising, etc.).

Keywords: accessibility; educational games; serious games; universal design.

1. Introduction

Education is a universal right. This implies the need of considering accessibility as a high priority requirement whenever new technologies are brought into the educational process. Otherwise we may be threatening the equality of opportunities for all students. This should be the case of educational games (a.k.a. serious games), which are rapidly gaining acceptance and will probably become a relevant educational tool for enthusiastic teachers in the next few years [1, 2]. But current level of accessibility in videogames (both commercial and educational) is still relatively low compared to other kind of technologies and digital static contents like the web [3–5].

One of the main arguments to explain the little attention that accessibility receives in games is that it means an extra burden for the developers and an expense increase factor. Firstly, the game increases in design complexity. Games are intricate, heterogeneous and highly interactive applications [6] that provide unique experiences depending on who is playing and what title is being played [7]. Designing an engaging, appealing and meaningful game for a wide number of users is an art that requires loads of expertise and creativity. When designers have also to cope with the special needs of users with disabilities the difficulty of the job increases substantially. And secondly, developers are faced with extra implementation challenges. Dealing with accessibility usually requires integrating (or even developing) complex and expensive technologies, such as text-to-speech or voice processing modules. And it may even require producing special hardware (e.g. adapted game controllers) [8].

All these overheads may be affordable only for large entertainment game development projects, and even then most entertainment games tend to ignore accessibility concerns. Educational game development should be driven by austerity and cost optimization to achieve wider adoption [9], an axiom that clashes with increasing budgets to accommodate accessibility. To avoid leaving accessibility concerns out of these projects, making accessible game-based educational content should be as seamless and cost-effective as possible. Our proposal is to increase the support that game authoring software provides to the author to make accessible games resulting in a reduction of the effort required. This involves enhancing game tools with new components that adapt the game to suit the needs of the player with a minimum amount of author input.

However, automatic adaptation of games is a serious challenge [10], especially if the goal of the adaptation is to meet the special needs of people with disabilities. Gameplay experience is so dependent on the design of the game that general purpose approaches are hard to envision. For that reason, this paper narrows the scope to a particular game authoring platform, eAdventure, that is optimized for the development of 2D *point-and-click* games [11]. Through a case study we discuss to what extent it was possible to reduce the effort (and thence the cost) needed to make a game accessible.

This paper is structured as follows: in section 2 we provide an overview of several initiatives aimed at improving the accessibility of digital games. In section 3 we discuss the adaptations required to make a game accessible for different profiles of disability. In section 4 we briefly describe the approach followed to introduce accessibility in the eAdventure game editor. In section 5 we describe, as case study, an accessible game developed using the prototype described in the previous section. In section 6 we discuss the usability achieved with the adaptations performed on the game. Section 7 discusses the effectiveness of the approach in terms of cost and effort reduction. Finally, section 8 draws conclusions and outlines future lines of research.

2. Related Work

Although research on game accessibility has not received as much attention as other fields, there are several approaches that deserve recognition. In this section we provide an overview of how different authors have adapted videogames for people with disabilities (section 2.1), and other comprehensive proposals to add accessibility to a wide range of games (section 2.2), whose spirit is more similar to our approach. We recommend reading works by Yuan and Westin for a detailed literature review [4, 5].

2.1. Ad-hoc approaches

Making games accessible is a very complex issue that requires taking different actions across multiple aspects of the game, like producing adapted versions of the art resources, integrating universal design principles in the game design, or extending the functionality of the underlying game technology (e.g. a game engine) [12]. The process of adapting a game is highly dependent on the game genre and the specific types of disabilities being considered [13]. Moreover, in many cases adaptations performed for a game do not adequately scale to other games of the same genre or similar nature. Thus, accessibility has been usually addressed game by game.

Different works have explored how to design and implement games to accommodate the needs of players with one or more disabilities [14–16]. In these situations, accessibility is considered *a priori*. Considering accessibility *a priori* is frequently advised by experts in the field [13]. In early stages of development it is easier to modify the game design (e.g. dialogues, technology, puzzles, interface design, etc.) or the underlying technology (e.g. game engine, text-to-speech support, etc.), which facilitates personalizing the user experience to the needs of players with disabilities. As a drawback, *a priori* accessibility may complicate development and increase the costs, depending on the case, as it requires concurrent development of different game versions (or branches). For that reason, accessibility is not considered since the beginning very often. To address this shortcoming several works have explored the adaptation of a specific title to meet the needs of a particular user profile [17–19] *a posteriori*, once a fully-functional prototype is available. However, these approaches rarely address multiple disabilities (e.g. blindness, deafness, low vision, etc.) at the same time since making modifications in the core of the game is much more complicated once development has been completed.

Ad-hoc solutions are necessary to increase understanding on what is needed to make playful experiences that are accessible to everyone, as they allow approaching the problem in a stepwise way and from multiple perspectives, exploring alternative solutions for a particular disability and/or game genres at a time. However, it is necessary to build general models that can be widely applied to accessible game development.

2.2. General approaches

Building on some of the ad-hoc solutions above presented, other approaches have adopted a more general and holistic perspective, proposing guidelines, frameworks and methodologies that consider the needs of different user profiles that could also be applied to different types of games [4, 8, 20–22].

One of the first initiatives with a broad scope was the game accessibility guidelines produced by the Special Interest Group on accessibility of the International Game Developers Association [8]. In this white paper published on 2004, a set of practical recommendations were proposed to avoid most of the common accessibility barriers that were identified in popular games of the time. Building upon this document, the MediaLT group published a more detailed set of recommendations and guidelines grouped by profiles of disability [21]. Recently, a new set of good practices has been published targeting developers, which provides examples of how recent games have solved some of the problems. This set of good practices is structured in levels of detail (basic, intermediate and advanced) to support a stepwise approach to the problem, which resembles to the accessibility conformance levels proposed by the W3C consortium [23]. However, game accessibility guidelines are still far from being as mature, agreed-upon and widely adopted as the W3C recommendations are. First, many W3C recommendations have the consideration of standard, being their use mandatory in several environments. The use of game accessibility guidelines has not been explicitly supported by any standardization body yet. Second, there are numerous support tools available for the W3C recommendations, dedicated to evaluate the level of compliance of websites, and also to support content creation that complies with the W3C. In contrast, there is nothing equivalent for game accessibility guidelines.

With a more academic tone, in [20] the authors propose Unified Design of Universally Accessible Games (UDUAG), a methodology for designing universally accessible games where game tasks are devised without considering a specific modality or interaction device. In further design phases, alternative interaction methods are designed for each task depending on the needs of the target audience. Therefore the game design is extensible, facilitating the subsequent inclusion of accessibility features to cater for the needs of other users. The UDUAG methodology has been used in the development of several accessible games, like UA Chess [24] or Access Invaders [25].

The drawback of these general approaches is that most of them do not provide a reference implementation that could facilitate the work of the developer. One exception is a system called Blindstation [26], which separates interface and logic components to facilitate interoperability with different input/output devices. Other technology developed with a similar purpose is described in [27]: an audio-only 3D game engine which provides a software architecture to make immersive games for people with visual disabilities.

3. Strategies for Adapting Games for Players with Disabilities

Regarding the type of disability, the number of accessible games is not distributed evenly, as not all the needs require the same effort to be accommodated. In this section we provide a concise description of how game accessibility has been approached for different profiles of disabilities.

Classification of disabilities is a controversial topic where the terms are used differently depending on the context and who is speaking. For the scope of this paper, we consider the next types of disabilities, based on the kind of adaptations required in each case:

- *Blindness:* As blind users we refer to people that need the aid of screen reading software (e.g. JAWS) to use a computer.
- *Low vision*: Users with low vision are those that usually need screen and text magnification tools and use of a high contrast color scheme.
- *Motor disability*: Users that need to use voice recognition software to interact with a computer due to reduced or lack of mobility in their hands.
- *Hearing disability*: Users that require replacing or complementing audio return of information with visual stimuli.

- *Cognitive disability*: Users that require adapting the pace, the complexity of the story, puzzles, dialogues, instructions, levels or mechanics.

3.1. Blindness

The blind are among the profiles of disabled users that have gathered more attention. For example, the Audio Games community provides lots of titles of audio-based games designed for users with a visual disability [28]. Some of the games, like *Papa Sangre* [29], even avoid incorporating graphical support. The games that blind gamers can play are usually more varied than for other users with disabilities, including racing games, FPS, Role-Playing Games (RPG), Puzzle, Arcade or Music games. Most of the games available to blind users are oriented to leisure, but occasionally their use as educational tools has also been explored. This is the case, for example, of the game described in [30, 31], which used a virtual reality game with haptic feedback to improve navigational skills of blind people.

Barriers found by blind players are usually related to perceiving feedback provided by the game. For that reason, adaptations are usually related to the replacement of visual stimuli with audio [28, 32], haptic feedback in several forms [33, 34], or more often a combination of both [14, 18, 35, 36]. Audio-based techniques are the most varied, being easy to find different strategies in the literature, like using *auditory icons* and *earcons* to associate information to sound. The main difference between the two is that, while *auditory icons* are recognizable and designed to resemble to real sounds, *earcons* are structured musical messages [37]. Both techniques have been applied in several games like *Tim's Journey* [28] or *Os & Xs*. Other games use more sophisticated audio solutions, like spatial or 3D sound [38].

In many cases blind users may also find barriers in providing input, for example if the game is controlled with the mouse. In these cases, it is also necessary to provide an alternative modality, like allowing to control the game using a keyboard (which is the most common approach) [30], or special hardware [15].

3.2. Low vision and Color Blindness

Users with low vision usually encounter problems when the objects or the font sizes are too small in the game [8]. Using color codes to convey information is also an issue, especially for users with color blindness. Another important barrier is having low contrast causing interactive elements or game objects blend in the background, or if visually tracking a moving element is essential to advance in the game at any point [39].

To address these issues, three types of adaptations are the most frequent. Firstly, the accessible game provides functionality to increase the size of the font and the elements, and/or provide a screen magnifier to enlarge parts of the screen. Secondly, the game provides alternative ways to convey information that do not depend only on color (e.g. using also symbols) or at least offers several color schemes that the player can choose from. Finally, some games provide a high contrast mode that affects the rendering pipeline [22]. The typical behavior is to apply a black-and-white filter to make easier to distinguish important elements from the background and enhance the contrast of the text over the background, like in the PowerUp game [39]. Another alternative is to alter the luminosity of the elements, for example having darker characters and brighter backgrounds and vice versa. This can be achieved by producing alternative versions of the art resources when the game is created or by applying filters at runtime. This technique is used, for example, in the Terraformers game [16].

3.3. Limited Mobility

Users with limited mobility in the hands usually have trouble playing with standard game controllers (e.g. joysticks or gamepads). This problem can be addressed with *software* or *hardware* solutions. Software approaches rely on speech recognition programs that convert voice commands into game actions. *Hardware* approaches focus on producing new game controllers suited for people with disabilities, or adapting standard gamepads. Special input devices available are varied, having for example brain controllers [40], tongue controllers [41] or eye trackers [42]. However, switches that allow interaction with simple taps of the hand, head or other parts of the body, are probably the most common [25].

Users with reduced mobility would also require tweaking the game to limit the amount of input that is needed to play it. Even if the user has an adapted controller or input mechanism, probably she will need a slower game pace to have enough time to make choices and respond to game events. For example, in [43] a classic Tetris game is made accessible for people with a motor disability using two different interfaces: one based on humming and other based on pure speech. In [44] a Sudoku is played using one of two alternatives to control the game: one using either speech or a single switch/button system, and the other making use of a scanning system that changes the focused object automatically at a predefined time rate and following an order that is known to the user. This allows users interact with the game using only one control (e.g. a switch).

3.4. Hearing disability

Barriers experienced by users with a hearing disability arise when effects, essential information or parts of the plot are conveyed only using audio. This kind of barriers could be solved replacing audio with visual information. The most common approach is to replace the audio information with text using techniques like subtitling or close captioning [45, 46]. This was the case of the popular Half Life© game, released in 1998 by Valve Studios. The title gathered a lot of criticism from communities of deaf gamers as information required for finishing the game was provided in uncaptioned cut-scenes. Critics had definitely an impact on Valve's, as its sequel, Half Life 2©, was 100% deaf gamer friendly [47].

Even if no essential info is conveyed in audio-only format, gamers with a hearing disability can be in disadvantage, especially in games where fast reaction to stimuli is required (e.g. First Person Shooters). For example, missing gunfire audio cues may result in a deaf gamer being shot [5]. In these cases the most common approach is to replace the audio with visual cues. For instance, GarageGames' Torque Game Engine©

supports, along with closed captioning, displaying a sound radar that visually identifies the direction and intensity of sound sources in the scene [48].

Alternatives to visual conveyance of audio information are less frequent, but can also be found. Two examples are CopyCat and SMILE, two educational games developed for deaf children. CopyCat is a game that recognizes sign language gestures [49], and it was developed to help young deaf children practice American Sign Language (ASL). SMILE was developed to teach science and maths to students with hearing problems [50]. In this case students also use ASL to interact with the game.

3.5. Cognitive disability

Cognitive disabilities are complex and diverse and the number of barriers that these players may encounter is varied and highly dependent on the type of disability, even on the abilities of each individual player [8].

Most common problems for these players are related to the design, content and mechanics of the game. This includes aspects like the complexity of the puzzles the player is challenged with, the language registry used, or not having enough time to decide the next move on the game in response to a given stimuli. Common strategies adopted include reducing time constrains, the amount of stimuli or input [5], and providing alternative difficulty levels [51].

A considerable number of educational games for people with cognitive disabilities of all ages is available in the literature [52–55]. This contrasts to the relatively low number found for students with physical disabilities. Different genres are used, although virtual reality and 3D environments are preferred. For example, in [56] a Web multi-player game is used to foster development of social skills in autistic children. In [57] a drill-and-practice 3D game is used to instruct fire and street safety skills in children with developmental disabilities, showing a positive impact.

4. Coping with Accessibility in the eAdventure Educational Game Platform

eAdventure [58] is a game authoring platform especially oriented to education[1] [59]. Although eAdventure supports the creation of a variety of 2D games, it was originally focused on *point-and-click* conversational adventure games. The genre was initially chosen because it has interesting traits for education, like strong narrative underpinnings and predominance of reflection over action [60–62].

eAdventure has two components (Fig. 1): a game editor used to create the games and a game engine, used to run them. The typical workflow is to create and test the games with the editor, and then use an editor tool to produce a distributable package. This package contains the game engine and all the assets needed to run the game (XML documents describing the game, images, sounds, videos, etc.). The game editor includes features especially devised for education and tries to simplify the game creation process as much as possible.

[1] http://e-adventure.e-ucm.es

The universe in eAdventure games is defined by composing 2D elements of different types: characters, items, active areas, and the game scenarios (a.k.a. scenes).

Accessibility was introduced in eAdventure at platform level, which makes the approach more similar to those described in section 2.2. Instead of focusing on making a single game accessible, our goal was to provide other game authors with features that would help them to make more accessible games. Although these features are currently a proof-of-concept, they will be eventually integrated into the official public distribution. Further implementation details can be found on previous publications [11, 63]. These features can facilitate dealing with accessibility, but their use is left to the solely discretion of the game author. Hence there is no guarantee that a game will be accessible if the creator does not take into account the special needs of people with disabilities.

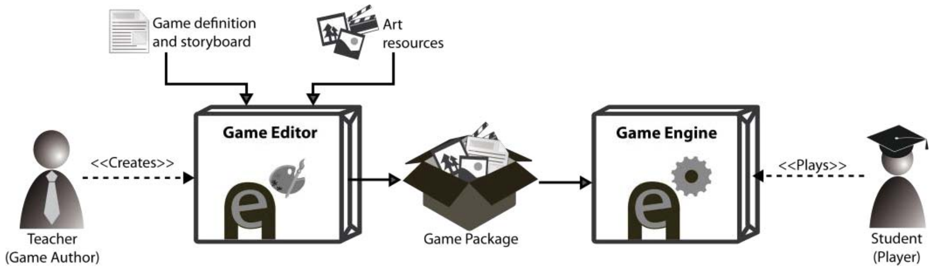

Fig. 1. Diagram of eAdventure applications. The Game editor is used to create the game, while the game engine runs it.

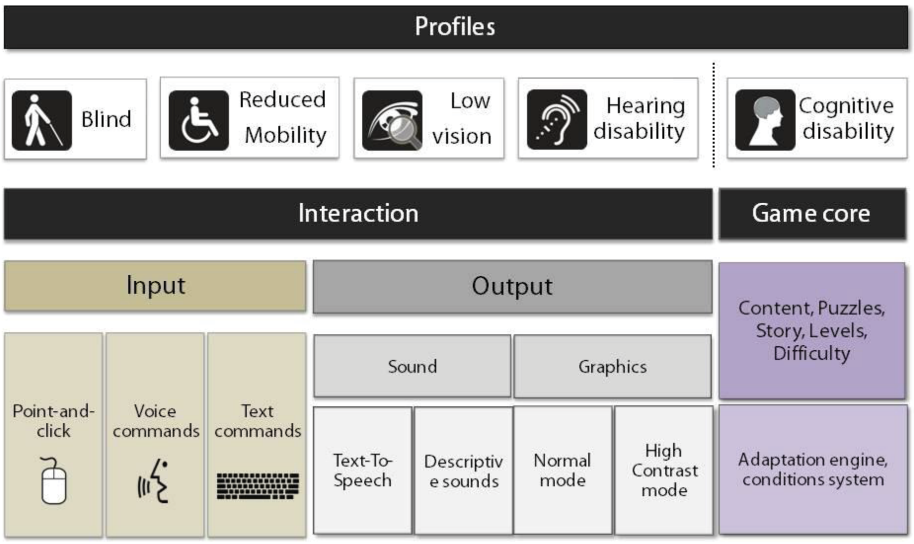

Fig. 2. High level view of the components produced to adapt the interaction for each user profile.

Fig. 2 provides an overview of the features supporting accessibility. For physical disabilities (vision, hearing, limited mobility), which require adapting the modality, alternative input/output mechanisms are provided. The game author can activate these features in the game. After loading, the game displays an accessibility menu where the player can select which features she would like to use.

To deal with cognitive disabilities, game authors can use the eAdventure adaptation engine, built upon a system of flags and variables that facilitates personalization of the game content, puzzles, and difficulty.

Next subsections describe how eAdventure provides game authors with functionality to deal with each type of disability.

4.1. Blindness and Limited Mobility

In eAdventure, both blind users and users with limited mobility encounter barriers that are related to the use of a point-and-click interface, as they are not able to use the mouse. Thus, an alternative interaction mechanism was developed to accommodate their needs, but using different input devices for each profile: blind players introduce the commands using the keyboard, while players with a motor disability use speech.

With this alternative interaction mechanism, the player formulates short commands in natural language to play (e.g. "grab the notebook" or "talk to the character"). An interpreter reads the commands, executes them if they pass a syntactic and semantic validation, and provides feedback about the results using the appropriate channel (auditory for the blind user through a built-in text-to-speech engine, text for the user with limited mobility).

Table 1. Example of natural language commands available during gameplay. Examples tagged with (1) would be dynamically defined, as they depend on the specific configuration of each scene. Examples tagged with (2) are common to all scenes and games.

Order	Description
Examine the wall (1)	The game will provide a description of the object "wall", if it exists in the scene.
Go to the door (1)	The student's avatar in the game will move towards the place "door".
Use keys with locker (1)	The game will use the object "keys" on the object "locker"
Name items in the scene (2)	The game will tell the student which items have already been discovered so that he or she can interact with them.
Open options menu (2)	Pause the game and show the options menu.
Describe (the) scene (2)	The game will provide a description of the scene as a hint for the student.

Command processing is driven by a regular grammar that defines valid commands, combined with a list of synonyms for relevant verbs (actions) and nouns (interactive elements) that aggregates built-in synonyms for common words (e.g. "use", "grab", "talk") and synonyms specified by the game author for each game element. This regular grammar is automatically generated from the description of the game, taking the actions defined for the interactive elements available in each game scenario. During game play, the number of actions and interactive elements available in eAdventure games is susceptible to change at any time as they depend on the value of a number of variables that vary dynamically as specified by the game author (this is the mechanism that eAdventure provides to implement the game structure and flow). To deal with this issue the grammar is rebuilt each time an internal variable changes and also each time the scenario is reloaded.

Special rules that remain invariant are added to the dynamically generated ones. These special rules are used to define basic interactions with the game (e.g. open menus, exit game, skip dialogue lines etc.) (see Table 1).

4.2. Low vision

Fig. 3. Above: Adapted visualization of an eAdventure game for people with low vision. High contrast rendering mode is applied darkening the background and highlighting the interactive elements. Below: Standard visualization of the same game scene.

eAdventure does not use color schemes to convey information. Thus major barriers for low vision users are related to having interactive elements that blend into the background or elements and pieces of text that are too small.

To cater for these needs a low vision mode was developed and integrated in the game engine. When this mode is activated, the size of the text and small game elements is increased. Moreover, a special rendering mode is used to improve the contrast of the interactive elements over the background of the game scenarios, applying a strategy similar to Terraformers high-contrast mode [16]. The game engine automatically applies a light green filter to the interactive elements which increases their luminosity and a dark purple filter to decrease the brightness of other areas, making it easier to identify those interactive elements (Fig. 3). Font sizes and colors used for cursors, buttons and menus are also adapted automatically.

4.3. Hearing disability

Users with a hearing disability are probably those who encounter fewer barriers, as eAdventure games are mostly conversational and based on text. To reduce the cost needed to create the games, information is first conveyed with text and, if the budget allows it, audio is added in a secondary stage as a complement. Besides, audio cues are rarely used to convey information, and if used, they are combined with text and they will not require immediate attention as these games are low paced (e.g. there is no need to reply to enemy gunfire).

eAdventure games are not accessible by default for people with a hearing disability, but the platform provides features to support these special needs if that is the author's intention. However, the likelihood of an eAdventure game being accessible for deaf gamers "by accident" (without consideration during the design phase) is rather high.

4.4. Cognitive disability

Cognitive disability is the most complex profile, as the barriers can be present in almost anything related to the insights of the game. Thus the level of accessibility is solely determined by the design of the game, regardless of the characteristics of the implementation platform. However, if the author has the intention to make a game playable by users with a cognitive disability, she can use the eAdventure system of flags and variables to set up conditions in different parts of the game description. These conditions work as "locks" that block parts of the game. The author can define user interactions that trigger special effects that change the value of those flags and variables. These effects work as "keys" that open the locks. The result is a flexible and powerful system that supports the implementation of the storyboard and the flow of the game. It allows unveiling parts of the plot or unblocking elements as the user advances in the game. eAdventure also provides an adaptation engine to customize the game experience for each student by modifying the value of those flags and variables according to certain parameters.

Authors can use these features to support the needs of the students with a cognitive disability. It allows the game author to modify anything related to the game flow, content and mechanics, where these users usually encounter more barriers. For example, the author can use them to create alternative game plots, lessen the difficulty of the puzzles or adapt the game content (e.g. simplify the language used).

5. Case Study: "My First Day at Work"

To evaluate the effectiveness of eAdventure to support game authors in making an accessible game, we conducted a case study in collaboration with Technosite, a company that belongs to the ONCE group (National Organization for the Blind in Spain). A game was developed from scratch, and the process to make it accessible was tracked. The game targeted people with all kind of abilities, although special focus was placed on analyzing the effort required to adapt the game for these three profiles: blindness, limited mobility and low vision.

Fig. 4. Snapshot of the game "My First Day at Work", showing the avatar selection screen. Four characters with different disabilities are ready for their first day in the office.

The outcome is the game "My first day at work" (Fig. 4). In this game, the user plays the role of a person with a disability that starts working in a new company [64]. It is the first day and the player is told to complete several assignments by the supervisor. While fulfilling these tasks, the player will get to know other colleagues and explore the headquarters of the company, learning where the different spaces are and how to get around. After completing the game, the player will be familiar with the new environment, as well as with using basic devices for the job, like the fax, the e-mail, or the photocopy maker. The ultimate goal is to reduce the anxiety that many people with disabilities feel when they are introduced in a new, unfamiliar environment, and facilitate their acclimatization to the new job. The game takes from 20 minutes to one hour to complete, depending on the accessibility modes that are set up and the interface used (it takes longer to complete for blind players as all the information is conveyed through audio).

Next subsections discuss what was the effort needed to implement accessibility for each profile. First, an overview of the tasks that were carried out to adapt the game for each profile is provided. Second, the effort that these tasks involved is estimated. This information will be used later on to draw conclusions about to what extent the process can be automated.

Measuring effort –and ultimately cost– spent developing software is not an easy task, especially for games. There is no standard way to measure how much it costs to make a game, and there is little data publicly available to compare to. For that reason we set our own metrics to determine the additional effort required to make the game accessible. First, we developed the game for the average profile. We measured the 'size' of the elements that compose the game. Internally eAdventure games are defined through a) several XML documents that contain the definition of the objects, scenes and characters, the dialogues and the logic of the game, plus b) the art resources required for drawing each element (images, animations, sounds and/or videos). As an estimation of the size of the games, we measured the length (number of lines) of the XML files and the number of art resources. Then, the game was adapted for the aforementioned disability profiles. We measured again the size of the game and compared to the initial size. It is important to have into account that generally speaking it takes much less time, effort and cost to increase the XML files that describe the game than producing new art resources.

5.1. Blindness and Limited Mobility

Tasks needed to configure the adapted interfaces for blind users and users with limited mobility are very similar, and therefore required a similar effort.

The basic setup of the system was straightforward. Adapted interfaces for these two user profiles were activated using a simple panel for the accessibility features included in the eAdventure editor. As an example, **Fig. 5** shows how these features were activated for the blind user profile.

Two types of text input were needed to configure those modules:

- Input for the natural language processing module (keyboard interaction). This includes providing alternative synonyms for interactions, objects and characters in the game.
- Input for the audio description feature. This includes additional descriptions of the game scenes that are used to convey additional audio information for the blind user when a new scene is entered (e.g. "You are in a laboratory, with a door on your left and a computer on your right").

As Table 2 shows, the total length of the game text increased almost a 61%. Besides, a total of 510 synonyms were provided, which means 271% of the initial number of element names contained in the game.

A preliminary evaluation showed that some users found it difficult to learn to play using these interfaces. This flaw was addressed by designing and implementing two tutorials: one specifically devised for blind users, and another one for users with limited mobility.

It is difficult to estimate the effort needed to implement those tutorials. As a ballpark figure, we have measured the increase in the size of the XML documents that define the game after these tutorials were added, and how many extra art resources were required.

These data are provided in Table 3, showing an increase of about 10% of the XML documents and only 1.39% in art resources.

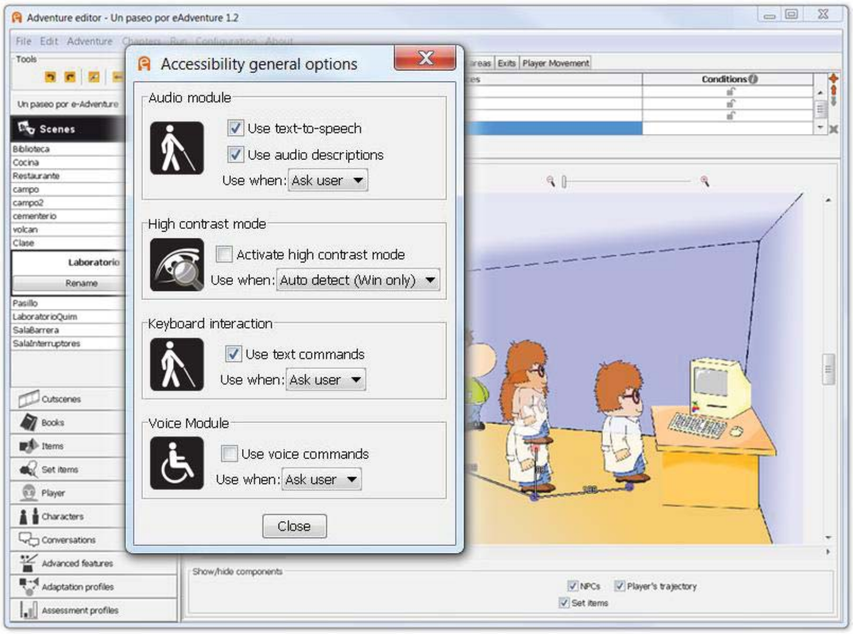

Fig. 5. Accessibility features activation panel. It shows the different accessibility features of the eAdventure editor to make automatic adaptations of the game interface. In this screenshot the options related to the blind user profile are selected. Note: these functionalities are only available in anon-public prototype

Table 2. Analysis of the effort derived from the configuration of the accessibility modules for blind users and users with limited mobility. Effort is estimated by calculating the increased length of the game texts in number of words (above) and additional synonyms to configure the natural language processing module (below).

Increased game text (No. of words) for audio descriptions				
Concept	B=Before	A=After	I=Increase (I=A-B)	% Increase (%=I/B·100)
Length of conversations and dialogues (Word count)	5712	5712	0	0%
Length of description of objects, characters and scenes (word count)	629	4496	3867	614.79%
Total	**6341**	**10208**	**3867**	**60.98%**

Synonyms for the natural language input processing module				
Concept	B=Before	A=After	I=Increase (I=A-B)	% Increase (%=I/B·100)
No. of synonyms for names of characters and objects	95	314	219	230.53%
No. of synonyms for names of scenes	80	328	248	310%

No. of synonyms for actions with custom names	13	56	43	330.77%
Total	**188**	**698**	**510**	**271.28%**

Table 3. Analysis of the effort derived from additional tweaks and manual adaptations for blind users and users with limited mobility. Effort is estimated by calculating the increase in the game size after implementing the tutorials, considering both the XML documents that describe the game and the number of art resources.

Size of the tutorials implemented for blind users and users with limited mobility				
Concept	B=Before	A=After	I=Increase (I=A-B)	% Increase (%=I/B·100)
Size of the XML documents that describe the game (No. of lines)	9220	10172	952	**10.32%**
Number of art resources	638	647	9	**1.39%**

The overall impact of all these tasks on the cost of the game was not very high. Most of the effort was devoted to writing 4,300 words of additional game text: descriptions, dialogues and synonyms. According to our estimations, game text is produced at an average rate of 500 words per hour, resulting in around 8.5 hours of additional work. Also the game XML files increased in 952 lines. Although it is difficult to translate this value to a number of labor hours, our estimate average production rate using the eAdventure tool is of 300 lines per hour (the XML files are not created manually), making it around 3 hours of work. Finally, some extra effort was dedicated to the production of art resources. This is one of the most expensive tasks in game development, taking around 0.5 hours to make a new resource on average. This results in 4.5 hours of additional work. This makes a total of 16 hours.

5.2. Low Vision

Configuration of the low vision mode was straightforward. The activation of the module was done using the configuration panel described in section 5.1 (see **Fig. 5**). However, the game contained some scenes and objects where text was embedded in images. The system was unable to adapt these images automatically and alternative versions of these art resources had to be provided. As Table 4 shows, this resulted in a 7.57% increase in the art resources produced for the game. As a rough estimation, adapting each art resource from the original took around 0.5 hours,, making around 26.5 hours in total, which is a considerable but affordable extra effort.

Table 4. Analysis of the effort derived from the configuration of the low vision accessibility mode. Effort is calculated by measuring the number of additional art resources that had to be produced.

Number of alternative art resources developed for the low vision mode				
Concept	B=Before	A=After	I=Increase (I=A-B)	% Increase (%=I/B·100)
Number of art resources	647	700	53	**7.57%**

5.3. Hearing and Cognitive Disabilities

In this case, it was not necessary to make any further adaptations to make the game accessible for users with a hearing disability, since from the very beginning all the information was conveyed using text only and audio feedback was added in a second stage. This is the normal process for creating a game using eAdventure. For that reason, this user profile was excluded from the evaluation of the game.

To deal with the needs of users with a cognitive disability a completely different approach was followed. The content and structure of the game was designed from the very beginning to be simple and easy to understand and follow by users with all sort of abilities. These requirements were considered throughout the whole design and implementation process, and resulted in multiple variations of the game design and the addition of game elements that are disperse around the game. Therefore it is not feasible to quantify the effort involved. However, it is reasonable to assume that it is much more complex to adapt the game for this user profile, compared to the others, as it is necessary to produce alternative versions of almost all parts of the game design, which may translate in having almost two different games.

6. Usability

A usability evaluation was conducted involving 12 volunteers with a disability (3 blind users, 4 with low vision, 3 with reduced mobility and 2 with mild cognitive disabilities). Average age of participants was 35.64 (±9.64), with a minimum of 21 and a maximum of 55. Most of the participants were females (11/14; 78.57%). Most of the users were able to complete the game, requiring from 25 to 40 minutes. Each user played alone in a controlled environment under the observation of the researchers. A slot of 60 minutes was allocated for each user regardless of their disability, which was a disadvantage for blind users who required longer to complete the game (they had to listen to long and numerous audio descriptions). As a consequence, 2 blind users were unable to complete it. Users with limited mobility had also problems to complete the game as a consequence of a technical error in the voice recognition system, which ran with an unexpectedly low recognition accuracy.

After playing, a short evaluation survey with 9 Likert 4-point items (e.g. Was it fun?, Was sufficient guidance provided?) was conducted. 7 of the 9 items showed strong correlation (Cronbach's alpha test: 0.905) and were added up to generate a scale ranging from 7 to 28 that estimates the overall player experience and usability of the game. Results from blind users and users with low vision were similar to users with no disability (means: 20.00±5.66, 20.67±6.51 and 21.20±3.42 respectively). In contrast, users with reduced mobility scored significantly lower (Median: 17.00, Mean: 19.33±6.81).

Although users evaluated the game mostly positively, they also identified several flaws that constrained usability. Blind users did not like the voice used for the text-to-speech engine, which was free software, and demanded a better quality Spanish voice. They also requested an improved tutorial and making the commands more intuitive. They also experienced some minor technical problems introducing text commands that were solved immediately after the test. Users with reduced mobility mostly had problems with the accuracy of the voice recognition software used, which was not fine tuned for the Spanish language. Finally, users with low vision pointed out that when they needed to use an external magnification tool some of the context of the game was lost (e.g. occasionally a text string was displayed outside the magnified part of the window).

7. Summary and Discussion

Data discussed in section 5 demonstrate that the effort required to configure the game "My First Day at Work" to be accessible was moderate, at least for physical disabilities. Roughly, two types of additional inputs were required: text, which is "cheap" to produce, and additional art resources, which are expensive but only a few were needed. Furthermore, the level of usability achieved with the architecture developed was satisfactory, although it could be improved. The good balance between effort required and usability achieved suggests that the introduction of accessibility in game authoring platforms is feasible and it can deliver significant reductions in the development cost of accessibility solutions that game authors can benefit from. Not all the user profiles required the same effort and, consequently, the same cost. Eventually, the derived cost of introducing accessibility seems to be tightly linked to the types of adaptations that are required. As a consequence, the level of automation that can be achieved depends on the type of disability. Table 5 provides an overview. Disabilities requiring mostly an adaptation of the interaction (input/output) or modality are prone to be dealt with automatically, as it is usually the case with the physical disabilities (those related to sight, hearing, or mobility) covered in “My First Day at Work”.

Table 5. Summary of adaptations performed for each profile. The table reflects what aspects of the game were affected and the level of automation achieved. Medium and low effort values are considered affordable.

Profile	Aspect	Example of adaptation(s) required	Effort Needed	Potential for Automation
Blind	Interaction / modality	New interface Adapted return of information	Medium-Low	High
Limited mobility	Interaction / modality	New interaction	Medium-Low	High
Low vision	Interface / rendering pipeline	High contrast rendering filters, magnification, alternative images and color schemes	Medium	High
Hearing disability	NONE	NONE	N/A	High
Cognitive disability	Game design and content	Lessened difficulty of puzzles, alternative version of texts	N/A	Low

However, there are cases where more exhaustive adaptations are required, affecting not only the game interface but also the story, the game mechanics, or how the virtual world is constructed. Complex disabilities, like the cognitive ones, usually require adapting a combination of those aspects. It is hard to envision a similar level of automatic support for these disabilities, as they require a deep understanding of the game design and a great dose of creativity. However, this type of adaptations was not analyzed in the case study presented, and therefore empirical data cannot be provided to support this claim.

8. Conclusions and Future Work

Educational games should be as accessible as possible to avoid potential digital divide when they are brought into the classroom. To achieve this it is necessary to reduce the overhead needed to make the games accessible, especially in education where budgets are usually limited. Cost reduction can be reached by integrating accessibility tools in the game development software.

In this paper we have addressed to what extent a game authoring tool can effectively support game developers in making a game accessible. The most important conclusion we have drawn from the study is that the level of automation that can be achieved depends on the type of disability and, especially, on the sort of adaptations that a particular user requires. Adaptations related to the modality, how the user interacts with the game or perceives the game feedback are prone to be automated (e.g. interfaces for blind users and users with reduced mobility). This does not mean that solutions are straightforward, but that current state-of-the-art in technologies like text-to-speech or voice recognition allows building interfaces that can be used by a high number of users. Once these interfaces have been built, they can be reused across different games with little extra work. This kind of solution can help many users.

However, there are cases when these processes cannot be automated, especially for cognitive disabilities. It is still uncertain how to support game authors in dealing with these disabilities, and how to add that support to game authoring software. A possibility is to develop accessibility auditing tools to educate, detect barriers and propose solutions to improve the process of introducing accessibility. Nonetheless, this is just a proposal that we expect to develop further in future research.

It should be noted that these automatic adaptations were designed specifically for educational games, where the tradeoff between cost and accessibility is critical, and accessibility should not be ignored. Entertainment games may also benefit from this type of approach, even though the game industry tends to favor specific developments for each game, due to the rapidly changing technology required to be competitive in that field.

Finally, the solutions proposed were tailored to one particular game authoring tool, eAdventure, which is focused on a very specific type of games. Similar approaches could be applied to other software, since the general spirit is applicable to any game development framework. However, it is still necessary to transfer these ideas to other tools to confirm that the results obtained are scalable.

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7.6. Usability Testing for Serious Games: Making Informed Design Decisions with User Data

7.6.1. Cita completa

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Usability testing is a key step in the successful design of new technologies and tools, ensuring that heterogeneous populations will be able to interact easily with innovative applications. While usability testing methods of productivity tools (e.g., text editors, spreadsheets, or management tools) are varied, widely available and valuable, analyzing the usability of games, especially educational "serious" games, presents unique usability challenges. Because games are fundamentally different than general productivity tools, 'traditional' usability instruments valid for productivity applications may fall short when used for serious games. In this work we present a methodology especially designed to facilitate usability testing for serious games, taking into account the specific needs of such applications and resulting in a systematically produced list of suggested improvements from large amounts of recorded game play data. This methodology was applied to a case study for a medical educational game, MasterMed, intended to improve patients' medication knowledge. We present the results from this methodology applied to MasterMed and a summary of the central lessons learned that are likely useful for researchers who aim to tune and improve their own serious games before releasing them for the general public.

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Research Article

Usability Testing for Serious Games: Making Informed Design Decisions with User Data

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Usability testing is a key step in the successful design of new technologies and tools, ensuring that heterogeneous populations will be able to interact easily with innovative applications. While usability testing methods of productivity tools (e.g., text editors, spreadsheets, or management tools) are varied, widely available, and valuable, analyzing the usability of games, especially educational "serious" games, presents unique usability challenges. Because games are fundamentally different than general productivity tools, "traditional" usability instruments valid for productivity applications may fall short when used for serious games. In this work we present a methodology especially designed to facilitate usability testing for serious games, taking into account the specific needs of such applications and resulting in a systematically produced list of suggested improvements from large amounts of recorded gameplay data. This methodology was applied to a case study for a medical educational game, MasterMed, intended to improve patients' medication knowledge. We present the results from this methodology applied to MasterMed and a summary of the central lessons learned that are likely useful for researchers who aim to tune and improve their own serious games before releasing them for the general public.

1. Introduction

As the complexity of new technologies increases, affecting wider portions of the population, usability testing is gaining even more relevance in the fields of human-computer interaction (HCI) and user interface (UI) design. Brilliant products run this risk of failing completely if end users cannot fully engage because of user interface failures. Consequently, product designers are increasingly focusing on usability testing during the prototype phase to identify design or implementation issues that might prevent users from successfully interacting with a final product.

Prototype usability testing is especially important when the system is to be used by a heterogeneous population or if this population includes individuals who are not accustomed to interacting with new technologies. In this sense, the field of serious games provides a good example where there should be special attention paid to usability issues.

Because educational serious games aim to engage players across meaningful learning activities, it is important to evaluate the dimensions of learning effectiveness, engagement, and the appropriateness of the design for a specific context and target audience [1]. Yet because serious games target broad audiences who may not play games regularly, usability issues alone can hinder the gameplay process negatively affecting the learning experience.

However, measuring the usability of such an interactive system is not always a straightforward process. Even though there are different heuristic instruments to measure usability with the help of experts [2]; these methods do not always identify all the pitfalls in a design [3]. Furthermore, usability is not an absolute concept per se but is instead relative in nature, dependent on both the task and the user. Consider the issue of complexity or usability across decades in age or across a spectrum of user educational backgrounds—what is usable for a young adult may not be usable for an octogenarian. It is situations like these where deep insight into how the users will interact with the system is required. A common approach is to allow users to interact with a prototype while developers and designers observe how the user tries to figure out how to use the system, taking notes of the stumbling points and design errors [4].

However, prototype evaluation for usability testing can be cumbersome and may fail to identify comprehensively all of the stumbling points in a design. When usability testing sessions are recorded with audio and/or video, it can be difficult to simultaneously process both recorded user feedback and onscreen activity in a systematic way that will assure that all pitfalls are identified. Thus usability testing using prototype evaluation can be a time-consuming and error-prone task that is dependent on subjective individual variability.

In addition, many of the principles used to evaluate the usability of general software may not be necessarily applicable to (serious) games [5]. Games are expected to challenge users, making them explore, try, fail, and reflect. This cycle, along with explicit mechanisms for immediate feedback and perception of progress, is a key ingredient in game design, necessary for fun and engagement [6]. So the very context that makes a game engaging and powerful as a learning tool may adversely affect the applicability of traditional usability guidelines for serious games.

For example, typical usability guidelines for productivity software indicate that it should be trivial for the user to acquire a high level of competency using the tool, and that hesitation or finding a user uncertain about how to perform a task is always considered as unfortunate events. A serious game connects the pathways of exploration and trial and error loops to help the player acquire new knowledge and skills in the process [7]. This makes it imperative to differentiate hesitations and errors due to a bad UI design from actual trial and errors derived from the exploratory nature of discovering gameplay elements, a nuance typically overlooked using traditional usability testing tools.

In this paper we present a methodology for usability testing for serious games, building on previous instruments and extending them to address the specific traits of educational serious games. The methodology contemplates a process in which the interactions are recorded and then processed by multiple reviewers to produce a set of annotations that can be used to identify required changes and separate UI issues, game design issues, and gameplay exploration as different types of events.

Most importantly, a main objective of this methodology is to provide a structured approach to the identification of design issues early in the process, rather than to provide an instrument to validate a product achieving a “usability score”.

As a case study, this methodology was developed and employed to evaluate the usability of a serious game developed at the Massachusetts General Hospital’s Laboratory of Computer Science. “MasterMed” is a game designed to help the patients understand more about their prescribed medications and the conditions for which they are intended to treat. The application of this methodology using an actual game has helped us to understand better the strengths and limitations of usability studies in general and of this methodology in particular. From this experience, we have been able to synthesize the lessons learned about the assessment methodology that can be useful for serious games creators to improve their own serious games before releasing them.

2. Usability Testing and Serious Games

Usability is defined in the ISO 9241-11 as “*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*” [8]. This broad definition focuses on having products that allow the users to achieve goals and provides a base for measuring usability for different software products. However, digital games are a very specific type of software with unique requirements while serious games have the additional objective of knowledge discovery through exploratory learning. This presents unique usability challenges that are specific to serious games.

In this Section we provide an overview of the main techniques for usability testing in general, and then we focus on the specific challenges posed by serious games.

2.1. Usability Testing Methods and Instruments. Usability represents an important yet often overlooked factor that impacts the use of every software product. While usability is often the intended goal when developing a software package, engineers tend to design following engineering criteria, often resulting in products that seem obvious in their functioning for the developers, but not for general users, with correspondingly negative results [9].

There are a variety of methods typically used to assess for usability. As described by Macleod and Rengger [4], these methods can be broadly catalogued as (i) *expert methods*, in which experienced evaluators identify potential pitfalls and usability issues, (ii) *theoretical methods*, in which theoretical models of tools and user behaviors are compared to predict usability issues, and (iii) *user methods*, in which software prototypes are given to end users to interact.

Among user methods, two main approaches exist: observational analysis, in which a user interacts with the system while the developers observe, and survey-based methods, in which the user fills in evaluation questionnaires after interacting with the system. Such questionnaires may also be used when applying expert methods, and they are typically based on heuristic rules that can help identify potential issues [10].

There are a number of survey-based metrics and evaluation methodologies for usability testing. A method most commonly cited is the System Usability Scale (SUS) because it is simple and relatively straightforward to apply [11]. SUS focuses on administering a very quick Likert-type questionnaire to users right after their interaction with the system, producing a “usability score” for the system. Another popular and well-supported tool, the Software Usability Measurement Inventory (SUMI), provides detailed evaluations [12] by measuring usability across five different dimensions (efficiency, affect, helpfulness, control, and learnability). In turn, the Questionnaire for User Interaction Satisfaction (QUIS) [13] deals in terms more closely related with the technology (such as system capabilities, screen factors, and learning factors) with attention to demographics for selecting appropriate audiences. Finally, the ISO/IEC 9126 standard is probably the most comprehensive instrument, as described in detail in Jung and colleagues' work [14].

However, many of these metrics suffer from the same weakness in that they can yield disparate results when reapplied to the same software package [15]. In addition, it is very common for such questionnaires and methods to focus on producing a usability score for the system, rather than the identification and remediation of the specific usability issues. This focus on identifying remediation actions as well as the prioritization of the issues and the actions surprisingly is often missing in studies and applications [16].

When the objective is to identify specific issues that may prevent end users from interacting successfully with the system, the most accurate approaches are observational user methods [4], as they provide direct examples of how the end users will use (or struggle to use) the applications. However, observational analysis requires the availability of fully functioning prototypes and can involve large amounts of observational data that requires processing and analysis. The experts may analyze the interaction directly during the session or, more commonly, rely on video recordings of the sessions to study the interaction. This has also led to considerations on the importance of having more than one expert review each interaction session. As discussed by Boring et al. [16], a single reviewer watching an interaction session has a small likelihood of identifying the majority of usability issues. The likelihood of discovering usability issues may be increased by having more than one expert review each session [17]; but this increased detection comes at the expense of time and human resources during the reviewing process.

In summary, usability testing is a mature field, with multiple approaches and instruments that have been used in a variety of contexts. All the approaches are valid and useful, although they provide different types of outcomes. In particular, observational user methods seem to be the most relevant when the objective is to identify design issues that may interfere with the user's experience, which is the focus of this work. However, these methods present issues in terms of costs and the subjectivity of the data collected.

2.2. Measuring Usability in Serious Games. In the last ten years, digital game-based learning has grown from a small niche into a respected branch of technology-enhanced learning [18]. In addition, the next generation of educational technologies considers educational games (or serious games) as an instrument to be integrated in different formal and informal learning scenarios [19].

Different authors have discussed the great potential of serious games as learning tools. Games attract and maintain young students' limited attention spans and provide meaningful learning experiences for both children and adults [20], while offering engaging activities for deeper learning experiences [21].

However, as games gain acceptance as a valid educational resources, game design, UI development, and rigorous usability testing are increasingly necessary. And while there are diverse research initiatives looking at how to evaluate the learning effectiveness of these games (e.g., [1, 22, 23]), the usability of serious games has received less attention in the literature. Designing games for "regular" gamers is reasonably straightforward, because games have their own language, UI conventions and control schemes. However, serious games are increasingly accessed by broad audiences that include nongamers, resulting occasionally in bad experiences because the target audience "does not get games" [24].

Designing for broad audiences and ensuring that a thorough usability analysis is performed can alleviate these bad experiences. In this context, Eladhari and Ollila conducted a recent survey on prototype evaluation techniques for games [25], acknowledging that the use of *off-the-shelf* HCI instruments would be possible, but that the instruments should be adapted to the specific characteristics of games as reported in [26]. In this context, there are some existing research efforts in adapting Heuristic Evaluations (with experts looking for specific issues) to the specific elements of commercial videogames [27, 28]. However, usability metrics and instruments for observational methods are not always appropriate or reliable for games. Most usability metrics were designed for general productivity tools, and thus they focus on aspects such as productivity, efficacy, and number of errors. But games (both serious or purely entertainment) are completely different, focusing more on the process than on the results, on enjoyment than on productivity, and on providing variety than on providing consistency [5].

Games engage users by presenting actual challenges, which demand exploratory thinking, experimentation, and observing outcomes. Ideally, this engagement cycle intends to keep the users just one step beyond their level of skill for compelling gameplay whereas a game that can be easily mastered and played through without making mistakes results in a boring game [6]. Therefore, usability metrics that reflect perfect performance and no "mistakes" (appropriate for productivity applications) would not be appropriate for (fun) games [29].

A similar effect can be observed with metrics that evaluate frustration. Games should be designed to be "pleasantly frustrating experiences", challenging users beyond their skill, forcing users to fail, and therefore providing more satisfaction with victory [6]. In fact, the games that provide this pleasantly frustrating feeling are the games that are the most addicting and compelling. On the other hand, there are games that frustrate players because of poor UI design. In these cases, while the user is still unable to accomplish the game's objectives, failure is the result of bad UI or flawed game concepts. Usability metrics for serious games should distinguish in-game frustration from at-game frustration [30], as well as contemplating that "obstacles for accomplishment" may be desirable, while "obstacles for fun" are not [5].

Unfortunately, as game designers can acknowledge, there is no specific recipe for fun, and as teachers and educators can acknowledge, eliciting active learning is an elusive target. The usability and effectiveness of productivity tools can be measured in terms of production, throughput, efficacy, and efficiency. But other aspects such as learning impact, engagement, or fun are much more subjective and difficult to measure [31].

This subjectivity and elusiveness impacts formal usability testing protocols when applied to games. As White and colleagues found [32], when different experts evaluated the same game experiences (with the same test subjects), the results were greatly disparate, a problem that they attributed to the subjective perception of what made things "work" in a game.

In summary, evaluating the usability of games presents unique challenges and requires metrics and methodologies that aim to contemplate their variability and subjectivity of interacting with games, as well as their uniqueness as exploratory experiences that should be pleasantly frustrating.

3. General Methodology

As discussed in the previous section, gathering data to evaluate the usability of a serious game is an open-ended task with different possible approaches and several potential pitfalls. Therefore, there is a need for straightforward and reliable methods that help developers identify usability issues for their serious games before releasing them. In our specific case, we focus on facilitating an iterative analysis process based on observational methods, in which users play with early prototypes and researchers gather data with the objective of identifying and resolving design and UI issues that affect the usability of the games.

3.1. Requirements.

From the discussion above it is possible to identify some initial requirements to perform usability testing of serious games.

(1) Test Users. First, it is necessary to have a set of test users to evaluate the prototype. These test users should ideally reflect the serous game's target audience in terms of age, gender, education, and any other demographic characteristics that might be unique or pertinent to the educational objective of the serious game. In terms of number of test users, according to Virzi [33], five users should be enough to detect 80% of the usability problems, with additional testers discovering a few additional problems. In turn, Nielsen and Landauer [34] suggested that, for a "medium" sized project, up to 16 test users would be worth some extra cost, but any additional test users would yield no new information. They also suggested that the maximum benefit/cost ratio would be achieved with four testers. We suggest selecting at least as many users that would span the range of your target audience, but not so many users that hinder the team performing the usability data analysis.

(2) Prototype Session Evaluators. Another important requirement is the consideration of the numbers of evaluators or raters to analyze the play session of each test user. Having multiple evaluators significantly increases the cost, making it tempting to use a single evaluator. However, while some analyses are performed with a single evaluator observing and reviewing a test user's play data, Kessner and colleagues suggested that it is necessary to have more than one evaluator to increase the reliability of the analysis, because different evaluators identified different issues [3]. This effect is even stronger when evaluating a game, because their high complexity results in evaluators interpreting different causes (and therefore possible solutions) for the problems [32]. Therefore, we suggest having more than one evaluator to analyze each play session and a process of conciliation to aggregate the results.

(3) Instrument for Serious Game Usability Evaluation. For an evaluator who is analyzing a play session and trying to identify issues and stumbling points, a structured method for annotating events with appropriate categories is a necessity [17]. Because serious games differ from traditional software packages in many ways, we suggest using an instrument that is dedicated to the evaluation of serious game usability. Section 3.2 below is dedicated to the development of a Serious Game Usability Evaluator (SeGUE).

(4) Data Recording Setup. Nuanced user interactions can often be subtle, nonverbal, fast paced, and unpredictable. A real-time annotation process can be burdensome, or perhaps even physically impossible if the user is interacting with the system rapidly. In addition, any simultaneous annotation process could be distracting to the user's game interactions and detract from the evaluative process. For these reasons, we recommend screen casting of the test play sessions along with audio and video recordings of the user with minimal, if any coaching, from the evaluation staff. These recordings can be viewed and annotated later at an appropriate pace.

(5) "Ready-to-Play" Prototype. "Ready-to-Play" Prototype should be as close to the final product as possible for the test users to evaluate. The prototype should allow the test users to experience the interface as well as all intended functionalities so that the interactions could mimic the real play session, therefore, maximizing the benefits of conducting a usability test. When it is not feasible or cost effective to provide a full prototype, using an early incomplete prototype may fail to reflect the usability of the final product once it has been polished. White and colleagues [32] conducted their usability studies using a "vertical slice quality" approach, in which a specific portion of the game (a level) was developed to a level of quality and polish equivalent to the final version.

(6) Goal-Oriented Play-Session Script. Lastly, prior to the initiation of the study, a play-session script should be determined. The script for the evaluation session should be relatively brief and have clear objectives. The designers should prepare a script indicating which tasks the tester

is expected to perform. In the case of a serious game, this script should be driven by specific learning goals, as well as cover all the relevant gameplay elements within the design. There may be a need for more than one play session to be exposed to each user so that all the key game objectives could be included.

3.2. Development of the Serious Game Usability Evaluator (SeGUE). Evaluators who analyze a prototype play session will need a structured method to annotate events as they try to identify issues and stumbling points. This predefined set of event types is necessary to facilitate the annotation process as well as to provide structure for the posterior data analysis. This evaluation method should reflect the fact that the objective is to evaluate a serious game, rather than a productivity tool. As described in Section 2.2, serious games are distinct from other types of software in many ways. Importantly, serious games are useful educational resources because they engage the players on a path of knowledge discovery. This implies that the evaluation should focus on identifying not only those features representing a usability issue, but also the ones that really engage the user.

Since the objectives of evaluating a serious game not only focus on the prototype itself but also the process of interacting with the game and the user's experience, our research team developed a tool, the Serious Game Usability Evaluator (SeGUE), for the evaluation of serious game usability. The SeGUE was derived and refined using two randomly selected serious game evaluation sessions, in which a team comprising game programmers, educational game designers, and interaction experts watched and discussed videos of users interacting with an educational serious game. Two dimensions (system related and user related) of categories were created for annotation purposes. Within each dimension, several categories and terms were defined to annotate events.

Within the system-related dimension, there are six different event categories. Two event categories are related to the game design, including gameflow and functionality. Events of these categories are expected to require deep changes in the game, perhaps even the core gameplay design. Three event categories are related to the game interface and implementation, including content, layout/UI, and technical errors, where solutions are expected to be rather superficial and have less impact on the game. A nonapplicable category is also considered for events not directly related to the system, but still deemed relevant for improving the user experience.

In the user-related dimension, there are ten event categories across a spectrum of emotions: negative (frustrated, confused, annoyed, unable to continue), positive (learning, reflecting, satisfied/excited, pleasantly frustrated), or neutral (nonapplicable and suggestion/comment). For researchers' convenience an additional category named "other" was included in both dimensions for those events that were hard to categorize. Such events may be an indication that a new category is required due to specific traits of a specific game. More details about the categories and their meanings are presented in Tables 1 and 2.

3.3. Evaluation Process. We present here a step-by-step methodology to assess for usability events in serious games. Additionally we will show as a case study how we employed this methodology to assess for usability while accounting for the MasterMed game's specific learning objectives. According to the requirements described above, the methodology is organized in discrete stages, from the performance of the tests to the final preparation of a list of required changes. The stages of the methodology are as follows.

(1) Design of the Play Session. The evaluation session should be brief and have clear objectives. The designers should prepare a detailed script indicating which tasks the tester is expected to perform. This script should be driven by specific learning goals, as well as include all the relevant gameplay and UI elements within the design. There may be a need for more than one scripted play session to cover all the key objectives.

(2) Selection of the Testers. As noted above, invited testers' characteristics should closely represent the intended users and mimic the context for which the serious game is designed.

(3) Performance and Recording of the Play Sessions. The testers are given brief instructions about the context of the game and the learning objectives and prompted to play the game on their own, without any further directions or instructions. The testers are instructed to speak out loud while they play, voicing out their thoughts. During the play session, the evaluator does not provide any instructions unless the user is fatally stuck or unable to continue. Ideally, the session is recorded on video, simultaneously capturing both the screen and the user's verbal and nonverbal reactions.

(4) Application of the Instrument and Annotation of the Results. In this stage, the evaluators review the play sessions identifying and annotating all significant events. An event is a significant moment in the game where the user found an issue or reacted visibly to the game. Events are most commonly negative events, reflecting a usability problem, although remarkably positive user reactions should also be tagged, as they indicate game design aspects that are engaging the user and should be enforced. Each event is tagged according to the two dimensions proposed in the SeGUE annotation instrument (Section 3.2). Ideally each play session should be annotated by at least two evaluators separately.

(5) Reconciliation of the Results. Since multiple reviewers should annotate the videos independently, the annotations and classifications likely will end up being different. Therefore, it is necessary for all of the reviewers to confer for reconciliation of the results. There are several possibilities that result from initial discrepant event assessments: (1) an observed event may be equally recognized by multiple reviewers with identical tagging; (2) a single event might be interpreted and tagged differently by at least one reviewer;

Table 1: Event categories for the system dimension.

System-related event	
Functionality	An event is related to prototype's functionality when it is the result of the user activating a control item and it is related to one specific action.
Layout/UI	An event is related to layout/UI when the user makes a wrong assumption about what a control does, or when the user does not know how to do something (negative events). It is also a *layout/UI* positive event when a user appreciates the design (figures, attempts, colors, etc.) or having specific information displayed.
Gameflow	An event that is caused not by a single specific interaction, but as a consequence of the game sequences interactions and outputs and the specific gameplay design of the game.
Content	A content event is related to text blurbs and other forms of textual information provided by the game.
Technical error	A technical *error* event is related to a nonintentional glitch in the system that must be corrected.
Nonapplicable	When the event is not related to the system and/or not prompted by a system behavior.
Other	An event that is related to the system, but does not match any of the above (this suggests that a new category is needed).

Table 2: Event categories for the user dimension.

User-related event	
Learning	The user figures out how to perform an action that was unclear before (learn to play), or when the user is actively engaging in consuming content (learn content).
Reflecting	The user pauses or wonders what to do next. Unlike when the user is *confused* and does not know what to do, reflecting events indicate pause to create action plans within the game space.
Satisfied/excited	The user displays a remarkably positive reaction.
Pleasantly frustrated	The user expresses frustration in a positive manner. A pleasantly frustrating moment urges the user to try to overcome the obstacle again.
Frustrated	The user voices or displays negative feelings at not being able to complete the game or not knowing how to do something. A frustrating moment urges the player to stop playing.
Confused	The user does not know how to perform an action, misinterprets instructions, and/or does not know what he/she is supposed to do.
Annoyed	The user performs properly a task in the game (knows how to do it), but feels negatively about having to do it.
Unable to continue (fatal)	This is usually the consequence of one or more of the above, or of a fatal technical error. An event is related to when the user becomes definitely stuck and/or cannot continue without the help of the researcher. Such events are highlighted because the origin of these events must always be resolved.
Nonapplicable	An event is not related to the user (e.g., it is a remark by the researcher, or a glitch appeared but the user did not notice it).
Suggestion/comment	The user verbalizes a comment or a suggestion that is not related to a specific interaction or event.
Other	An event is related to the user, but does not match any of the above (this suggests that a new category is needed).

or (3) an event could be recognized and tagged by one observer and overlooked by another. In the latter two cases, it is important to have all the reviewers to verify and agree on the significance of the event and have subjective agreement on the proper tag. Most importantly, the objective of this task is not to increase the interrater reliability, but to study collaboratively the event in order to better understand its interpretation, causes, and potential remediation actions.

(6) Preparation of a Task List of Changes. Finally, the eventual product from this evaluation process should be a list of potential improvements for the game, with an indication of their importance in terms of how often the problem appeared and how severely it affected the user or interfered with the game's educational mission. For each observed negative event, a remediation action is proposed. Changes proposed should avoid interfering with the design and game-play elements that originate positive events to maintain engagement. Users' comments and suggestions may also be taken into account. Quite possibly, some of the encountered issues will occur across multiple users, and some events might occur multiple times for the same user during the same play session

(e.g., a user may fail repeatedly to activate the same control). For each action point there will be a frequency value (how many events were recorded that suggest this action point) and a spread value (how many users were affected by this issue).

Finally after reconciliation, the evaluation team should have an exhaustive list of potential changes. For each modification, the frequency, the spread, and a list of descriptions of when the event happened for each user all contribute to the estimating of importance and urgency for each action, as it may not be feasible to implement every single remediation action.

It must be noted that although a predefined set of tagging categories facilitate the annotation and reconciliation process, the work performed in stages 4 and 5 can be labor intensive and time consuming depending on the nature and quantity of the test user's verbal and non-verbal interactions with the prototype.

Finally, depending on the scope and budget of the project, it may be appropriate to iterate this process. This is especially important if the changes in the design were major, as these changes may have introduced further usability issues that had not been previously detected.

4. Case Study: Evaluating MasterMed

This SeGUE methodology, including the specific annotation categories, has been put to the test with a specific serious game (MasterMed) (see Figure 1), currently being developed at Massachusetts General Hospital's Laboratory or Computer Science. The goal of MasterMed is to educate patients about the medications they are taking by asking patients to match each medication with the condition it is intended to treat. The game will be made available to patients via an online patient portal, iHealthSpace (https://www.ihealthspace.org/portal/login/index.html), for patients who regularly take more than three medications. The target audience for this game is therefore a broad and somewhat older population that will be able to use computers, but not necessarily technically savvy. This makes it very important to conduct extensive usability studies with users similar to the target audience, to ensure that patients will be able to interact adequately with the game.

Performing an indepth evaluation of the MasterMed game helped us refine and improve the evaluation methodology, gaining insight into the importance of multiple reviewers, the effect of different user types in the evaluation, or how many users and reviewers are required. In addition, the experience helped improve the definitions of the categories in the SeGUE instrument.

In this section we describe this case study, including the study setup, the decisions made during the process, and the results gathered. From these results, we have extracted the key lessons learned on serious game usability testing, and those lessons are described in Section 5.

4.1. Case Study Setup

4.1.1. Design of the Play Session. The session followed a script, in which each participant was presented three increasingly difficult scenarios with a selection of medications and problems to be matched. The scenarios covered simple cases, where all the medicines were to be matched, and complex cases in which some medicines did not correspond with any of the displayed problems. In addition, we focused on common medication for chronic problems and included in the list potentially problematic medications and problems, including those with difficult or uncommon names. As a user progressed through the script, new UI elements were introduced sequentially across sessions. The total playing time was estimated to be around 30 minutes.

4.1.2. Selection of the Testers. Human subject approval was obtained from the Institutional Review Board of Partners Human Research Committee, Massachusetts General Hospital's parent institution. The usability testing used a convenience sampling method to recruit ten patient-like participants from the Laboratory of Computer Science, Massachusetts General Hospital. An invitation email message contained a brief description of the study, eligibility criteria, and contact information was sent out to all potential participants. Eligible participants were at least 18 years old and not working as medical providers (physicians or nurses). Based on a database query, our expected patient-gamer population should be balanced in terms of gender with roughly 54% of participants are female. Patient age ranges from 26 to 103 with a mean of 69.3 years (SD = 12.5) for men and a mean of 70.14 years (SD = 12.75) for women. We recruited five men and five women with their age ranged from mid-30 s to 60 s to evaluate the game.

4.1.3. Performance and Recording of the Play Sessions. Each participant was asked to interact with the game using a think-aloud technique during the session. The screen and participant's voice and face were recorded using screen/webcam capture software. The duration of the play sessions ranged between 40 and 90 minutes.

4.1.4. Application of the Instrument and Annotation of the Results. After conducting the sessions, a team of evaluators was gathered to annotate the videos identifying all potentially significant events. There were four researchers available, two from the medical team and two from the technical team. Five videos were randomly assigned to each researcher to review; thus two different researchers processed each video independently. In order to avoid any biasing factors due to the backgrounds of each researcher, the assignment was made so that each researcher was matched to each of the other three researchers at least once. The annotations used the matrix described in Section 3.2. Two more fields were added to include a user quote when available and comments describing the event in more detail.

4.1.5. Reconciliation of the Results. The reconciliation was performed in a meeting with all four researchers, where (i) each unique event was identified and agreed upon, (ii) each matched event classified differently was reconciled, and (iii) each matched event with the same tags was reviewed

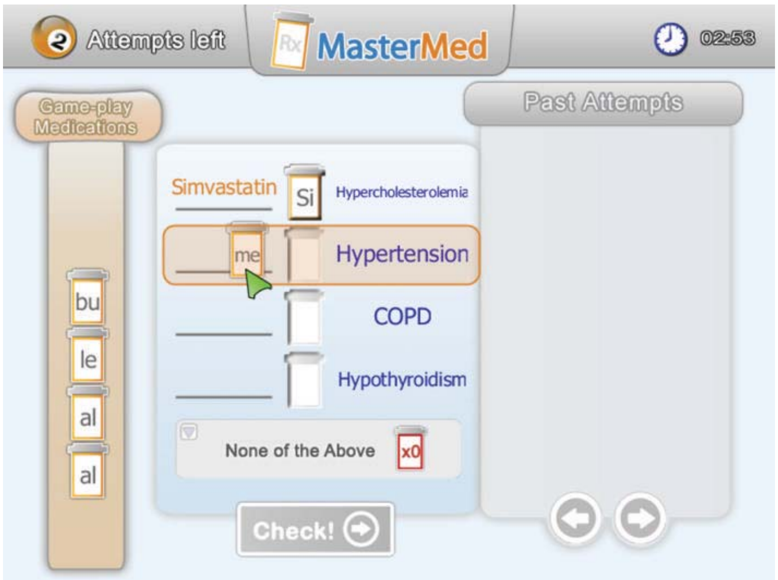

Figure 1: A screenshot of the MasterMed game, version 0.4.5: the user is dragging a medication to a condition.

for completeness. This process was crucial in determining the nature of overlooked events and facilitated the discussion on the possible causes for those events that had been tagged differently by the reviewers.

4.1.6. Preparation of a Task List of Changes. For each observed negative event, a remediation action was proposed and prioritized.

4.2. Case Study Results. The first artifact of the case study was a set of 10 video files resulting from the screen/webcam capture software. Since the evaluation method was experimental, two randomly selected videos were used for a first collaborative annotation process. This step helped refine and improve the tags described in Section 3.2. Therefore, the final evaluation was performed only on the eight remaining play sessions.

The average play session was around 30 minutes in length, although most users took between 40 and 60 minutes (and only one user as much as 90 minutes). A total of 290 events were logged. We summarize the events identified for each user (see Figure 2). A *unique* event is defined when the event was only tagged by one of the two researchers reviewing the video (and overlooked by the other). A *matched* event is defined when the event was tagged by both researchers and classified equally with the same tags and interpretation. Finally, a *reconciled* event is defined when the event was identified by two researchers, but tagged differently and then agreed upon during the reconciliation process.

In Figure 3, we summarize the number of appearances of each tag and the relative frequencies for each event type. The number of negative events (138) was much higher than positive events (46). Also the number of interface and implementation events (179) is greater than events related to design (91).

Finally, in Table 3 we provide an excerpt of the action points that were derived from the analysis of the results. For each action, we also indicate the frequency (number of events that would be solved by this action) and the spread (number of users that encountered an event that would be solved by this action). Both numbers were used to determine the priority of each action.

4.3. Case Study Discussion. An interesting aspect for discussion is the variability of event statistics across users. Figure 2 is sorted according to the number of unique events, as this category requires special attention. Indeed, while a reconciled event indicates an event that was perceived different by each researcher, a unique event indicates that one of the researchers overlooked the event. In a scenario with only one reviewer per play session, such events may have gone unnoticed. The annotations for some users presented very high numbers of unique events. It is possible that this is related to the total number of events, affecting the subjective thresholds of the reviewers when the frequency of events is high. However, the results do not suggest that a correlation between the total number of events and the proportion of unique, matched, and reconciled events. For example, results from users with small total number of events vary, as user no. 2 presents 77.78% unique events while user no. 1 has only 30.77% unique events.

Regarding the tag statistics, the number of negative events in the user dimension is clearly predominant. This result may be considered normal, as evaluators are actively

Table 3: Excerpt of the prioritized action points list. It shows the type (D: design/I: interface), the frequency (number of occurrences), the spread (number of users affected), and the priority they were given according to these two numbers.

Priority	Action	Type	Freq.	Spread
1	Rearrange the tutorials (shortening and skipping)	D	28	8
2	Remove "none of the above" feature	D	23	8
3	Unify "close dialog" interactions	I	37	5
4	UI tweaking (color schemes, minor layout changes, etc.)	I	22	6
5	Review wording	I	13	6
6	Improve mouse clicking accuracy	I	11	4
7	Improve handout contents (remove unnecessary sections)	I	11	4

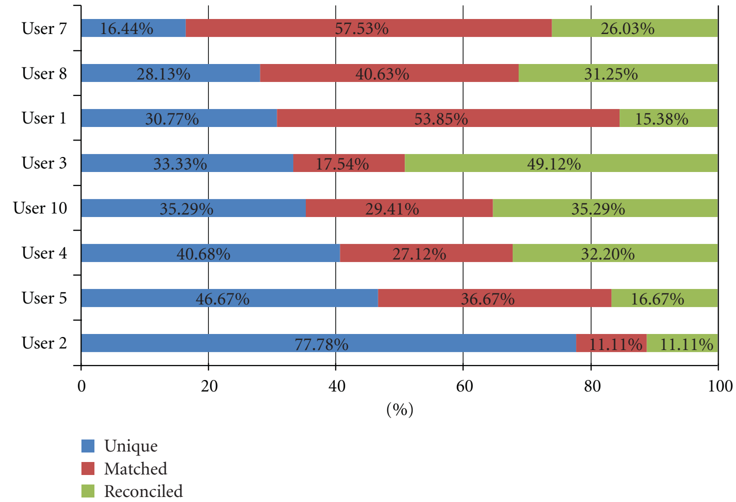

Figure 2: Event statistics. Each bar shows the percentage of unique, matched and reconciled events for each individual user. The total number of events for each user is shown in parenthesis.

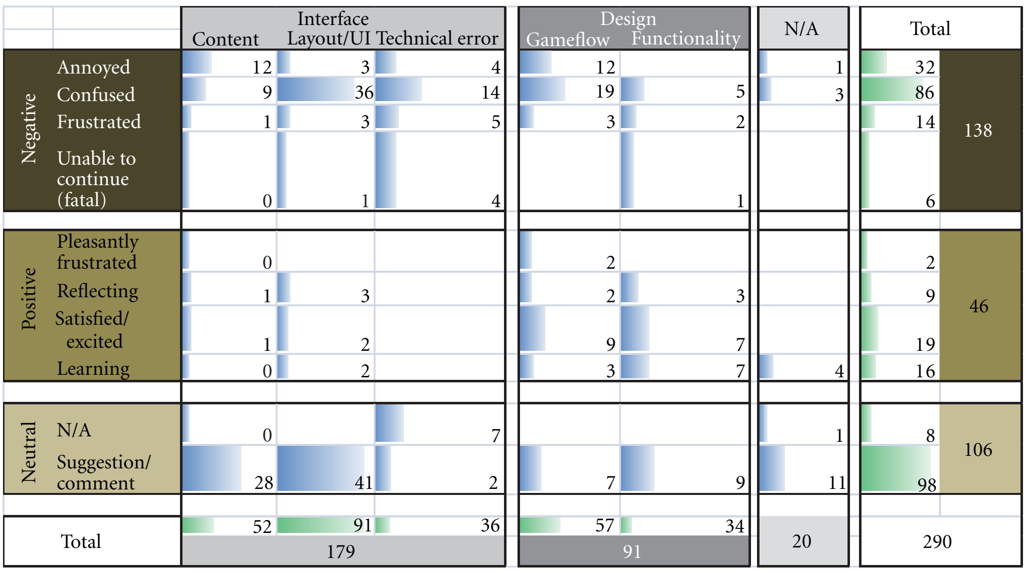

Figure 3: Tag statistics: the events are categorized on two dimensions: the source of the event (interface, design) and the reaction of the user.

looking for issues and pitfalls, while regular play working as intended may not be considered as an event. However, the identification of specific positive events was still helpful to identify specific game moments or interactions that really engaged the users in a visible way.

In the game element dimension, the number of events related to the design of the game was significantly less than the number of events related to the interface and implementation (91 versus 179). This data suggests that users were more satisfied with the flow and mechanics of the MasterMed game than with its look and feel. Nonetheless, this difference seems reasonable, as it is easier for users to identify pitfalls in superficial elements like the UI (e.g., font size is too small) then in the design (e.g., the pacing is not appropriate). The correlation between user and system dimensions is also interesting, as positive events are usually related to aspects of the game design. Since the gameplay design is the key element for engagement, this result may be considered an indication that the design was, in fact, successful.

The process to determine the remediation actions and a heuristic assessment of their importance deserves also some discussion. The prioritization of the list is not fully automatable. While the frequency was an important aspect to consider (an event that happened many times), so was the spread (an event that affected many users). These variables allowed researchers to limit the impact of having multiple occurrences of the same event for a single user. A specific example: the action "remove none of the above feature" was regarded as more important than "unify close dialog interactions" because it affected all users, even though the total number of occurrences was significantly lower (23 versus 37).

Other factors such as the cost of implementing a change or its potential return were not considered, but large projects with limited budget or time constraints may need to consider these aspects when prioritizing the remediation actions.

5. Lessons Learned

The result of the case study not only helped to identify improvement points, but also served as a test to improve and refine the SeGUE instrument for annotation. Some design decisions, taken on the base of the existing literature, were put to the test in a real study, which allowed us to draw important conclusions. And these conclusions are helpful for researchers using this methodology (or other variations) to evaluate and improve their own serious games. The main lessons learned are summarized below.

5.1. Multiple Evaluators. As discussed in Section 3.1, different studies have taken different stances when it comes to how many researchers should review and annotate each play session. The key aspect is to make sure that all usability issues are accounted for (or as many as possible).

The interrater reliability displayed by the results for our case study is, in fact, very low (Figure 2). Both matched and reconciled events were identified by both reviewers, but unique events were only registered by one of the reviewers. For most users, the number of unique events is between 33% and 50%, giving a rough estimate of how many events may have been lost if only one reviewer had been focusing on one play session (user no. 2 has an unusually high number of unique events).

This result is consistent with the concerns expressed by White and colleagues [32] and confirms the importance of having multiple evaluators for each play session in order to maximize the identification of potential issues. While it might be very tempting for small-sized teams to use only one annotator per gameplay session to reduce costs, our experience shows that even after joint training the number of recorded unique events is high. Thus, multiple evaluators should be considered as a priority when planning for usability testing.

5.2. Importance of Think-Aloud Methods. Most observational methods do not explicitly require users to verbalize their thoughts as they navigate the software, as it is considered that the careful analysis of the recordings will suffice to identify usability issues, even with only one expert reviewing each recording.

However, the results from the case study indicate the importance of requesting (and reinforcing) users to think aloud while they play. For our case study MasterMed evaluation, there was a direct correlation between the number of unique events tagged and the amount of comments verbalized by users. While all users were instructed to verbalize their thoughts, not all users responded equally. On one extreme, user no. 7 was loquacious, providing a continuous stream of thoughts and comments. On the other extreme, user no. 2 was stoic, apparently uncomfortable expressing hesitations out loud, rarely speaking during the experiment, despite of being reminded by the researcher about the importance of commenting. This had a direct impact in the number of unique events (16.44% unique events registered for user no. 7 and 77.78% unique events for user no. 2), as it made it difficult for the researchers to distinguish between hesitations caused by a usability issue from actual pauses to think about the next move in the game.

5.3. Length of the Play Sessions. The length of the play sessions was estimated to be around 30 minutes, although the range was 40–90 minutes. During the play session, familiarity with the tool and its expected behaviors may improve, and this may mean that most usability issues would be detected in the first minutes of a play session. To get a better insight about this issue, we produced the event timestamp frequency histogram provided below in Figure 4. Most of the events were tagged during the first 13 minutes of the session (44.06%) after which the rate decreases, with only 24.95% of the events tagged in the following 13 minutes. Beyond this point, the rate slowed even further, even though new, more complex gameplay scenarios were being tested.

Users are also encouraged to verbalize their impressions and explain their reasoning when deciding the next move or interaction; but as the play session becomes longer, the users also grow tired. This suggests that play sessions

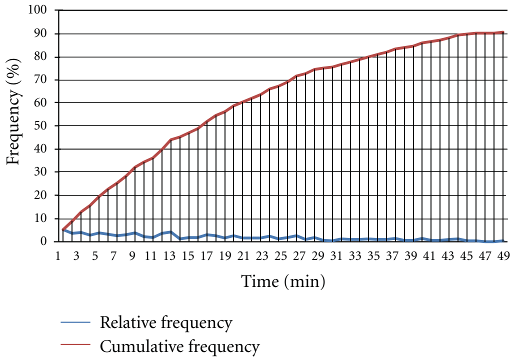

Figure 4: Frequency histogram of tagged events during MasterMed evaluation. Cumulative frequency graph shows that 40% of the events were tagged within the first 12 minutes.

should be kept short and focused. It should also be noted that researchers observing recorded play sessions thoroughly needed to stop, rewind, and rereview video footage frequently to tag the issues encountered, thereby requiring lengthy evaluation sessions. When more than 30 minutes are required to explore all the concepts, different sessions with breaks may be desirable.

5.4. Evaluator Profile. Even though the proposed methodology called for multiple experts evaluating each play session, we have found differences between the annotations depending on the researcher's profile. The foremost difference was between technical experts (developers) and field experts (clinicians).

Technical issues were one of the main sources of events that had to be reconciled (cases in which both researchers tagged the same event, but assigned different categories). Developers would spot subtle technical issues and tag them accordingly, while clinicians often attributed those events to usability problems related to the UI. This does not necessarily mean that an effort should be made to assign field experts and technicians to review each play session (although it may be desirable). However, it does reflect the importance of having experts from all sides participating in the reconciliation stage. In particular, the goal of the reconciliation stage is not necessarily to agree on the specific category of the event, but on its origin, impact on the user experience and significance; so that appropriate remediation actions can be pursued based on the data gathered.

5.5. Limitations. The methodology has a very specific objective: to facilitate the identification of design pitfalls in order to improve the usability of a serious game. As such, it does not deal with other very important dimensions of user assessment in serious games. In particular, it cannot be used to guarantee that the game will be effective in engaging the target audience or to assess the learning effectiveness of the final product. While the methodology takes care of identifying those elements that are especially engaging, this is done in order to help the designers preserve the elements with good value when other design or UI issues are addressed. Before the final version of the game is released for the general public, further assessment of engagement and learning effectiveness should be conducted.

Another limitation that this methodology shares with typical observational methods (and in particular with think-aloud methods) is that the results are subjective and dependant on both the specific users and the subjective interpretations from the evaluators. The subjectivity of the process was highlighted in the case study in the number of events overlooked by at least one reviewer (number of *unique* events) and the discrepancies when annotating the perceived root cause of each event. While this subjectivity could be reduced by increasing the number of users and evaluators, this increases the cost of the evaluation process. This problem is further aggravated when the process is applied iteratively.

Small and medium sized development projects will need to carefully balance the number of users, evaluators, and iterations depending on their budget, although we consider that having more than one evaluator for each session is essential. Similarly, multiple iterations may be required if the changes performed affect the design or UI significantly, potentially generating new usability issues. In turn, bigger projects with enough budget may want to complement the observational methods by tracking physiological signals (e.g., eye tracking, electrocardiogram, brain activity) to gather additional insight into engagement. However, such advanced measurements fall beyond the scope of this work, which targets smaller game development projects with limited budgets.

6. Conclusions

The design of serious games for education is a complex task in which designers need to create products that engage the audience and provide an engaging learning experience, weaving gameplay features with educational materials. In addition, as with any software product targeting a broad audience, the usability of the resulting games is important. In this work we have discussed the unique challenges that appear when we try to evaluate the usability of a serious game before its distribution to a wide, nongamer audience. The key challenge is that typical usability testing methods focus on measurements that are not necessarily appropriate for games, focusing on aspects such as high productivity, efficacy, and efficiency as well as low variability, number of errors, and pauses. However, games contemplate reflection, exploration, variety and trial, and error activities.

While generic heuristic evaluative methods can be adapted to contemplate the specificities of games, observational instruments that generate metrics and scores are not directly applicable to serious games. In addition, observational data is by definition subjective, making it difficult to translate a handful of recorded play sessions into a prioritized list of required changes.

For these reasons, we have proposed a step-by-step methodology to evaluate the usability of serious games that focuses on obtaining a list of action points, rather than a single score that can be used to validate a specific game. Observational methods can be useful in determining design pitfalls but, as we have described in the paper, the process is subjective and sometimes cumbersome. The methodology provides a structured workflow to analyze observational data, process it with an instrument designed specifically for serious games, and derive a list of action points with indicators of the priority for each change, thus reducing the subjectivity of the evaluative process.

The Serious Games Usability Evaluator (SeGUE) instrument contemplates tagging events in the recorded play sessions according to two dimensions: the system and the user. Each observed event has an identifiable cause from a certain interaction or UI element and effect on the user (confusion, frustration, excitement, etc.). The categories for each dimension contemplate aspects specifically related to serious games, distinguishing, for example, between in-game frustration (a positive effect within the description of games as "pleasantly frustrating experiences") and at-game frustration (a negative event when the game interface, rather than the game design, becomes a barrier for achieving objectives).

The inclusion of positive events is relevant when studying the usability of serious games. These games need to engage users by both presenting challenges and variability and achieving a learning objective. The events in which the users are engaging intensively with the game (displaying excitement or pleasant frustration) are important parts of the game-flow, and the action points to improve usability should be designed such that they do not dilute the engagement.

The application of the SeGUE methodology in the MasterMed case study allowed us to draw some conclusions and summarize important lessons learned during the process, as summarized in Section 5. Among them, the experience provided answers to typically open questions regarding observational methods such as (a) the appropriate number of test subjects, (b) number of experts to review each play session, and (c) the importance of the think-aloud technique.

We expect the methodology, the SeGUE tagging instrument, and the summary of lessons learned to be useful for researchers who aim to improve the usability of their own serious games before releasing them. Small- and medium-sized projects can use this methodology to test the usability of their games, record data that is typically subjective and difficult to process, and then follow a structured methodology to process the data. The number of evaluation cycles, the specific designs, and the aspects of the games that need to be evaluated may vary across development projects. Therefore, these steps and the SeGUE instrument might be adapted and/or refined to incorporate any particular elements required by specific serious game developments.

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7.7. Evaluation of Semi-automatically Generated Accessible Interfaces for Educational Games

7.7.1. Cita completa

Torrente J, Freire M, Moreno-Ger P, Fernández-Manjón B. **Evaluation of Semi-automatically Generated Accessible Interfaces for Educational Games**. Computers & Education [JCR-SCI 2,775 2012; 15/100 *Categoría Computer Science, Interdisciplinary Applications*] (En proceso de revisión, enviado Julio 2014).

7.7.2. Resumen original de la publicación

The increasing body of evidence supporting the use of videogames in educational settings (usually referred to as serious games) is pushing their deployment across different areas of the educational system. However, this increased adoption also raises serious ethical issues: videogames are one the least accessible forms of multimedia, and if education is to embrace serious games, there is an imperative need for universal accessibility in serious games to prevent a digital divide. However, producing accessible games is expensive and effort consuming, and serious games development already fare with limited budgets. In this work we explore the potential impact of the (semi-) automatic adaptation of game interfaces as a way to facilitate accessible game development (and thus trim the cost down). We propose a game interface model optimized for point-and-click games that we have used to perform different semi-automatic adaptations in a game, which has also been tested with users with specific disability profiles. Our tests discovered that automatic adaptations produced usable games that retained part of their attractive, although different usability issues had a negative impact on the user experience. We also discuss the origins of such limitations and possible remediation actions, as well as propose a refined interface model.

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Thomas Westin is one of the most renown experts in the field of educational accessible game design and development. He's advocated for the need of improving game accessibility for more than 10 years now, helping to found the Game Accessibility interest group, organization he's been deeply involved since 2004.

Opposed Reviewers:

Evaluation of Semi-automatically Generated Accessible Interfaces for Educational Games

Abstract

The increasing body of evidence supporting the use of videogames in educational settings (usually referred to as serious games) is pushing their deployment across different areas of the educational system. However, this increased adoption also raises serious ethical issues: videogames are one the least accessible forms of multimedia, and if education is to embrace serious games, there is an imperative need for universal accessibility in serious games to prevent a digital divide. However, producing accessible games is expensive and effort consuming, and serious games development already fare with limited budgets. In this work we explore the potential impact of the (semi-) automatic adaptation of game interfaces as a way to facilitate accessible game development (and thus trim the cost down). We propose a game interface model optimized for point-and-click games that we have used to perform different semi-automatic adaptations in a game, which has also been tested with users with specific disability profiles. Our tests discovered that automatic adaptations produced usable games that retained part of their attractive, although different usability issues had a negative impact on the user experience. We also discuss the origins of such limitations and possible remediation actions, as well as propose a refined interface model.

Keywords

Accessibility, games, educational, interface adaptation

1 Introduction

Education is a Universal Human Right (United-Nations, 1948). As new technologies are brought into the classrooms, equality principles and eventually laws require that they be made accessible to all students to prevent the infringement of this right (see for example section 508 (IT Accessibility & Workforce Division (ITAW), n.d.)). This should also be the case of educational games, commonly referred to under the term *serious games*, which are rapidly gaining acceptance and represent a promising educational tool for the near future (Johnson et al., 2013; Johnson, Adams, & Cummins, 2012), as evidence proving positive impact on students' achievements (Papastergiou, 2009; Sadler, Romine, Stuart, & Merle-Johnson, 2013) and motivation continues to grow (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Hwang & Wu, 2012).

However, the current levels of accessibility in videogames (both educational and recreational) are still relatively low compared to those of Web-based technologies commonly used to support learning (Bierre et al., 2005; Westin, Bierre, Gramenos, & Hinn, 2011; Yuan, Folmer, & Harris, 2011), and far below acceptable standards. One of the most relevant causes is the non-trivial cost of implementing accessibility into an existing game, an effort-consuming process which may affect multiple aspects of the game. Typically this would require interventions affecting art resources, game design, difficulty adjustments, puzzles, language used, gameplay mechanics, and the different underlying game technologies (Grammenos, Savidis, & Stephanidis, 2009; Ossmann, Miesenberger, & Archambault, 2008). For this reason, game accessibility solutions are usually game-specific and therefore hard to scale and reuse across games. And that is partly why it is rare to find educational games that take accessibility into consideration.

With the goal of increasing the accessibility of serious games we advocate for providing developers with software tools that take care of as much of the process of making a game accessible as possible. We denominate the approach as "semi-automatic" because the developer will always need to deal with some tasks, but the goal is to reduce these manual adaptations at a minimum.

In this paper we discuss a first approach focused only in improving the accessibility of the game interface. Although making a game accessible is much more than providing alternative user interfaces (Grammenos et al., 2009), we consider this work a necessary first step before more ambitious approaches that deal with other aspects of the games can be considered.

The article is structured as follows: in section 2 we describe the general approach, setup the specific scope of this work, and provide some general context about point-and-click games necessary to understand our work. In section 3 we describe the general interface model proposed. Section 4 contains a case study where we evaluate the approach, while section 5 discusses a potential set of improvements that may yield improved results. In section 6 we describe some related work and finally, in section 7, we summarize our conclusions and outline the next natural steps in this research area.

2 Approach, Scope and Context

In this section we briefly introduce our approach (section 2.1.). We also discuss the actions we have taken to narrow down the scope of this work (section 2.2.). Finally, we provide an overview of *point-and-click* games from the point of view of its interface and the accessibility barriers and opportunities they offer, which is essential to understand the game interface model described in section 3.

2.1 Approach

Our approach to reduce the overhead of accessible game development is to (semi-) automatically adapt the user interface, taking into account the special needs of each user profile, requiring a minimum amount of input from the game author. However, it is still necessary to make simple editions such as providing alternative synonymous for command recognition, making final tweaks and revising the adaptations made by the system. After revising and complementing the automatic adaptations, different versions of the same game are available for delivery to the end-users, each one configured with a different interface (see Figure 1).

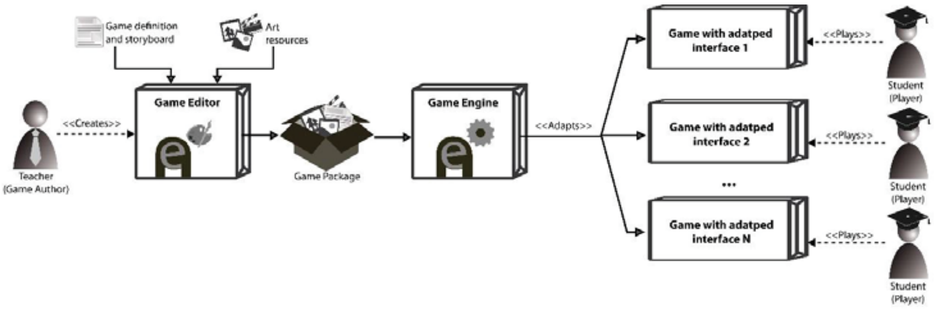

Figure 1: General approach. Base games are written once and the different accessible variants are generated semi-automatically. The process must require minimal human intervention for cost-effectiveness and maintainability reasons.

The application of this approach to the adaptation of serious games to different accessibility profiles is a significant challenge for different reasons: (1) The capabilities of persons with disabilities vary a lot for each individual, depending on the type and degree of disability, (2) games have some of the most complex interfaces in modern software, and (3) it is significantly more difficult to make a game accessible than a desktop or web application (Archambault, Ossmann, Gaudy, & Miesenberger, 2007).

2.2 Scope

We have taken two actions to narrow down the scope of this work. First, we have focused on classic "*point-and-click*" adventure games as the target game genre. Videogames are an heterogeneous media and it is not possible to propose a solution that covers all of them at once. We focus on this genre because it has been identified in the literature as having the higher potential for serious and educational applications due to its strong narrative underpinnings (Dickey, 2006; Garris, Ahlers, & Driskell, 2002). In addition, these games are excellent representatives of point-and-click interfaces (another term for graphical user interfaces) in general and the accessibility barriers they pose, making it easier to transfer the results obtained to other highly interactive applications and contents.

Second, in our proposal we consider only physical disabilities, focusing on three profiles: blindness, low vision and reduced mobility. Physical disabilities are the most interesting for the purpose of this work since most of the barriers they find in videogames are related to the interface. Cognitive disabilities (another relevant area of research in accessible games (Pereira et al., 2012; Standen, Camm, Battersby, Brown, & Harrison, 2011; Authors 2012b)) fall out of scope for this paper since coping with these types of disability typically requires interventions related to changing the game design and contents in order to cater for different degrees of problem-solving ability..

2.3 Context: Game Interface Model in *Point-and-click* Adventure Games

Classical *point-and-click* adventure games had their golden age in the 90's, with titles like *Monkey Island*© or *Myst*©. In these games the user moves the mouse cursor around the game scene to find elements to interact with. When hovering over an interactive element, visual feedback is provided. For instance, to indicate an active element, the cursor may change shape, the element's borders may become highlighted, and a label with an element description may be temporarily revealed. Users can decide, based on this feedback, to further interact with the element (e.g. clicking on a character may launch a conversation, and clicking on a door may trigger a menu with options such as open, close, or examine for clues) (Figure 2)

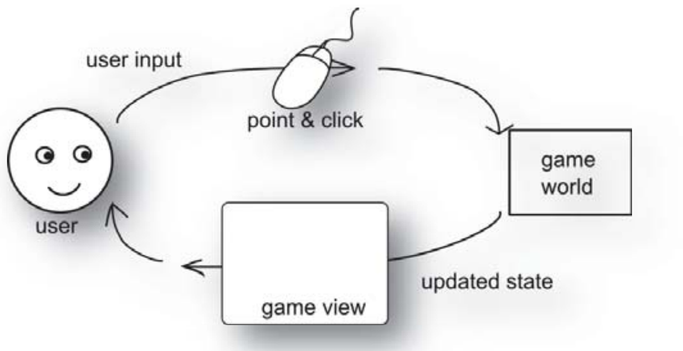

Figure 2: Feedback loop interacting with a point-and-click adventure game.

From an accessibility perspective this type of interface presents advantages and drawbacks. The main accessibility problems presented by these games are the reliance on sight to explore the game world, and the need for both sight and fine upper-limb motor control in order to use the mouse for pointing and clicking with precision. Both of these also are common accessibility problems in other game types (Archambault et al., 2007).

Another positive aspect is that point-and-click adventure games do not present many other typical accessibility barriers, such as fast pacing, absence of subtitles (these games are close-captioned very often), or the use of time pressure to provide challenge (Bierre et al., 2004). Additionally, narrative games (both linear or with multiple branches) are well suited to textual interfaces. Indeed, text-only adventure games predated the graphical, point-and-click variety. Adventure games are therefore uniquely suited to supporting accessibility, offering a clear separation between game actions and interface which allows the use of multiple interface variants (Grammenos, Savidis, & Stephanidis, 2007).

3 Proposed Adapted Game Interface Model for *Point-and-click* Adventure Games

Since it is possible to detach interface and in-game tasks in *point-and-click* games, we propose a revised interaction model where the same game world can be affected by different alternative input methods, and its internal state can be represented in different alternative forms (**Error! Reference source not found.**)

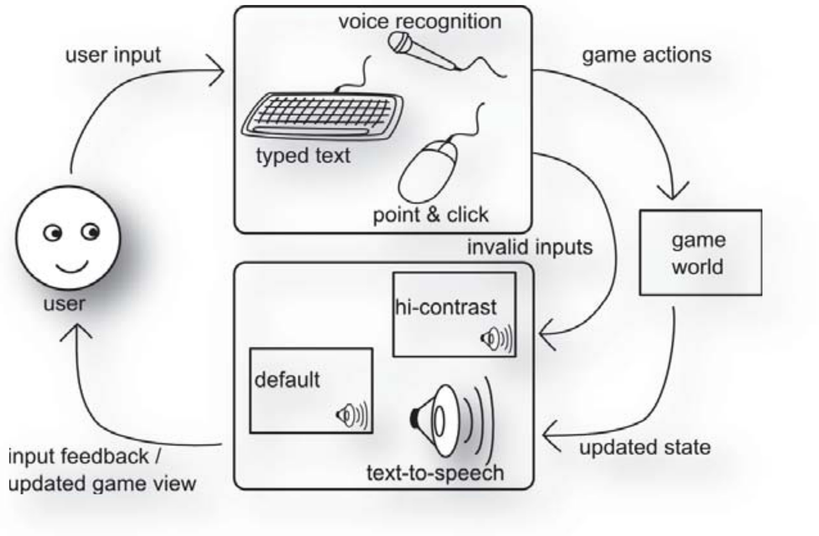

Figure 3: Advanced feedback loop in a point-and-click adventure game. Accessibility alternatives are displayed in the center boxes. Input handling and feedback is handled outside the game engine (i.e. piece of software that runs the game); only valid game actions actually alter game state.

The next sections describe in more detail how this interface model works for the user profiles selected. Also a reference implementation of this model based on the eAdventure platform can be found in (Authors, 2009). The implementation of the game interface was possible because the eAdventure authoring platform provides an explicit representation of the game model, which can therefore be processed and adapted.

3.1 Interface model for Blind Users and Users with Reduced mobility

Both blind users and users with reduced mobility experience problems for providing input using the mouse, either due to missing feedback (blind users cannot perceive what they are pointing to) or due to lack of fine motor control, respectively. In addition, blind users have problems to perceive feedback from the game if it is transmitted through graphical output (Yuan et al., 2011).

In both cases, players formulate short commands in natural language: (e.g. “grab the notebook”, or “talk to the character”). An interpreter reads the commands, executes them if they pass a syntactic and semantic validation, and provides suitable feedback using the appropriate channel (auditory for blind users through a built-in text-to-speech engine, and text for users with reduced mobility). As depicted in **Error! Reference source not found.**, unrecognized commands are never sent to the game world, which expects only valid game actions. For the game itself, the specific interface used to specify these commands is totally transparent; only the commands themselves are important.

Command processing is driven by a grammar that defines valid commands, combined with a list of synonyms for relevant verbs (actions) and nouns (interactive elements) that includes built-in synonyms for common words (e.g. "use", "grab", "talk") and synonyms specified by the game author for each game element. The grammar is automatically generated from each game description, based on the game actions defined for each of the interactive elements available in each game scenario. An additional set of game-independent vocabulary provides access to always-available interactions such as opening menus, skipping dialogue lines, or exiting the game altogether.

Table 1: Example of natural language commands available during game-play. Examples tagged with (1) would be dynamically defined for each scene. Examples tagged with (2) are common to all scenes and games. In all cases, feedback is provided using either text or speech, as appropriate.

Textual command	Effect
Examine the wall (1)	Describes of the object "wall", if it exists in the scene.
Go to the door (1)	The student's character in the game attempts to move towards a place called "door".
Use keys with locker (1)	The game attempts to use the "keys" object on the "locker" object
Name items in the scene (2)	Lists the scene elements that have already been discovered and are therefore available for examination or interaction
Open options menu (2)	Pauses the game and show the options menu.
Describe (the) scene (2)	Provides a description of the scene as a hint for the student.

The grammar in Table 1 can be automatically generated for each game without human intervention. This includes the provision of synonyms for those verbs that are common to all games (e.g. *grab/take*, *examine/inspect*, etc.), resulting in a grammar that includes the standard verbs their synonyms and the standard names for all in-game objects and characters.

However, human intervention is required to facilitate further context-based synonyms for in-game elements (e.g. *door/gate*). While it would be feasible to use dictionaries to further automate these definitions, it would not be desirable since the appropriateness of synonyms may depend on the specific context (e.g. there may be a door and a gate on the same scene) and narrative (e.g. a character that represents a talking cat called Alfred could be referred to as *the cat* or *Alfred*). In addition, the in-game scene descriptions may need to be adapted to each profile, since the required level of detail and actual use of language may be different when targeting users with reduced mobility or blindness. However these adaptations are simple to make once the developer is provided with a support tool that loads the results of the automatic modification and allows the developer to fine tune as needed.

3.2 Interface for Users with Low Vision

Major barriers for low vision users are related to having interactive elements that blend into the background or elements and fragments of text that are too small (Bergel, Chadwick-dias, Ledoux, & Tullis, 2005). Additionally, color-blindness can result in nominally different colors blending into each other, and is especially problematic when color is used to encode important attributes or to convey relevant information.

A number of strategies to address these barriers are proposed. First, text size and small game elements are significantly enlarged. Second, a special rendering mode is used to increase the contrast of interactive elements over game-scenario backgrounds. Luminosity of interactive elements is increased using a light green filter. A dark purple filter is applied to all other areas, decreasing their brightness, resulting in a high-contrast scheme (Figure 4).

These effects, as well as additional adjustments in font sizes and colors used for cursors, buttons and menus can all be performed automatically, and so they are in our reference implementation. In some cases, human intervention may be required to identify unexpected outcomes of the automatic adaptations (e.g. artifacts generated by the automated border generation). But still this intervention is very cost effective compared to the manual generation of those adapted assets.

Figure 4: Left: Standard visualization of a game scene from eAdventure game 'Eating Out'. Right: Adapted visualization of the scene for people with low vision. High contrast rendering mode is applied darkening the background and highlighting the interactive elements.

4 Case Study

As a preliminary evaluation of the interface model proposed, we conducted a case study, which is discussed in this section. The main objective of the case study was to observe how these simple semi-automatically generated interfaces could be used in a real scenario with real users, and how far it is possible to reach with limited human intervention in the generation of accessible educational games.

4.1 Method, Participants and Settings

14 volunteers with diverse characteristics were recruited. Five of these users had no disability and played the standard version of the game, three had reduced mobility (but good vision), three were blind, and the final three had low vision and used the high contrast mode. The number of users recruited, although limited, is consistent with available recommendations for usability evaluation through user observational methods (Macleod & Rengger, 1993).

Average age of participants was 35.64 (±9.64), with a minimum of 21 and a maximum of 55. Most of the participants were females (11/14; 78.57%). 9 of the participants held a college degree or a PhD, 4 had only completed high school and only 1 had no studies at all. They were asked to rate their own computer literacy from 1 to 5, resulting on 3.07 on average (± .616) and a median of 3.

Participants were individually briefed on the experiment and asked to sign a standard consent form, in which they were informed that only anonymous results would be published for research purposes, and that they were free to abandon the experiment at any time without penalty. The participants were requested to fill a short questionnaire including demographic and general computer literacy questions. Next, users where provided with an adapted version of the same game to play for roughly 40 minutes allowing them to play more or stop earlier if desired. Users with no physical disability played the original game with no adaptations. The same facilitator that provided the briefing stayed with the participant during the whole session, providing advice when requested and occasionally asking participants to reason out loud when they appeared to be stuck.

All sessions were recorded in high-definition video, capturing the screen and the voice of the participants and the facilitator (who was free from taking notes during sessions). At the end of each session, regardless of whether the game had been finished or not, participants were asked to fill a survey on their experience. Post-game comments to the facilitator were also captured on the video soundtrack. An empty, quiet classroom was used for recording, and long sessions were often split to allow the participant and the facilitator a few minutes of rest.

Video recordings were analyzed using a user observational method similar to the one described in Authors, 2012a).

4.2 Materials

4.2.1 The Game "My First Day at Work"

The eAdventure educational game that participants were asked to play, "My First Day at Work", places the protagonist as a newly-hired office worker, arriving for his or her first day on the job. Participants could choose among a cast of 4 characters, each of them with different accessibility requirements; and were requested to choose the character that matched the interface they were using. Game-play differed slightly according to player character; for example, the blind character was expected to perform additional setup steps to customize her in-game workplace. These adaptations were not fully automatically generated, as they involved minor modifications in the game design. "My First Day at Work" was developed in collaboration with Technosite, an offshoot of Spain's largest disability-oriented NGO, ONCE (http://www.once.es).

The game is structured into two chapters. The first chapter has no back-story, and is intended as a short tutorial covering the interaction techniques the user will need. It is intended to allow participants to adapt themselves to the settings used to configure the interface, and consists of a single small puzzle involving a table, a key hidden inside a book placed on this table, and a keypad where the key must be entered in order to proceed to the actual game. Upon entering the main chapter, players were greeted with an explanation of the setting for the main adventure, and guided through the avatar selection process.

While a speed run through the game can be performed in less than 15 minutes, typical gameplay ranges from 30 to 60 minutes (see Figure 7), depending on the interface used. Participants were limited to around 40 minutes of gameplay, and completing the game was not considered mandatory, so some stopped playing before completing it.

In the game, upon arriving at the company's front desk, the player character is instructed to find the Director of Human Resources at her office, and given a series of tasks. There are no separate levels, and several of the tasks can be performed out-of-order. The game ends when the character visits the Human Resources Director after completing all tasks. Figure 5 depicts an overview of the game-structure, used when reporting user times in Figure 7 and Figure 8.

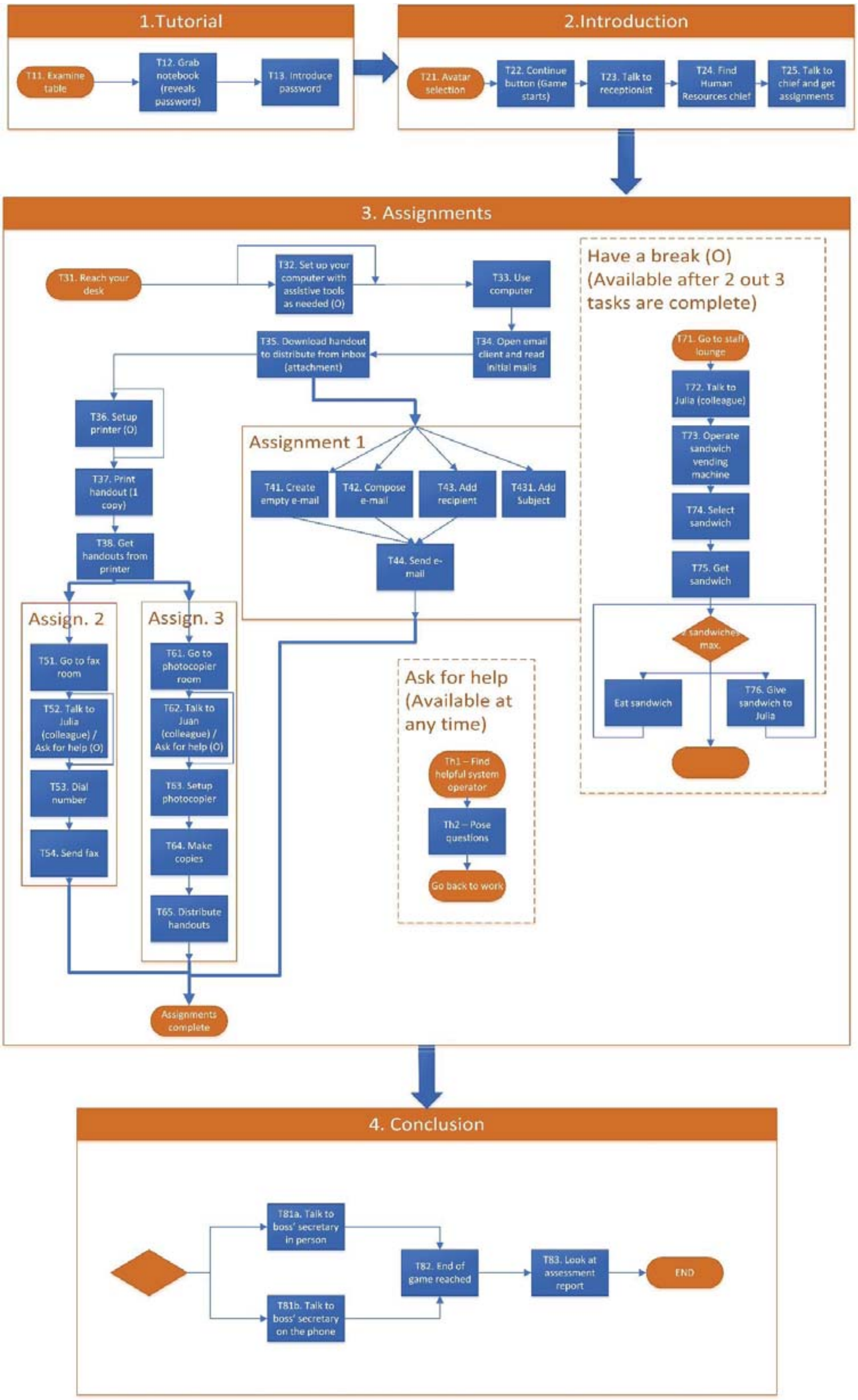
1.Tutorial
T11. Examine table
T12. Grab notebook (reveals password)
T13. Introduce password
2.Introduction
T21. Avatar selection
T22. Continue button (Game starts)
T23. Talk to receptionist
T24. Find Human Resources chief
T25. Talk to chief and get assignments
3. Assignments
T31. Reach your desk
T32. Set up your computer with assistive tools as needed (O)
T33. Use computer
T34. Open email client and read initial mails
T35. Download handout to distribute from inbox (attachment)
T36. Setup printer (O)
T37. Print handout (1 copy)
T38. Get handouts from printer
Assignment 1
T41. Create empty e-mail
T42. Compose e-mail
T43. Add recipient
T431. Add Subject
T44. Send e-mail
Assign. 2
T51. Go to fax room
T52. Talk to Julia (colleague) / Ask for help (O)
T53. Dial number
T54. Send fax
Assign. 3
T61. Go to photocopier room
T62. Talk to Juan (colleague) / Ask for help (O)
T63. Setup photocopier
T64. Make copies
T65. Distribute handouts
Assignments complete
Ask for help (Available at any time)
Th1 – Find helpful system operator
Th2 – Pose questions
Go back to work
Have a break (O) (Available after 2 out 3 tasks are complete)
T71. Go to staff lounge
T72. Talk to Julia (colleague)
T73. Operate sandwich vending machine
T74. Select sandwich
T75. Get sandwich
Eat sandwich
T76. Give sandwich to Julia
4. Conclusion
T81a. Talk to boss' secretary in person
T81b. Talk to boss' secretary on the phone
T82. End of game reached
T83. Look at assessment report
END

Figure 5: Map of the game. The third chapter encompasses the main tasks.

The game contains a total of 25 scenes with approximately 40 scene items, 4 playable characters, 7 non-playable characters (NPCs) with 20 interactive conversations, and 11 inventory items.

4.2.2 End-User Questionnaire

A four item Likert questionnaire was handed out to the users after each test session. The questionnaire had nine common items for all users, plus four additional items for users using one of the adapted interfaces (see Tables 2 and 3). These items were formulated to evaluate either what was the general feeling of the users about their gameplay experience or the usability of specific aspects of the game interface.

Table 2: Wording for the general section of the end user questionnaire; (*) indicates items which were reversed for result analysis.

Item Id	Wording
G.INT	*I was able to interact with the game without experiencing any problems.* 1="Not at all", 4="Absolutely".
G.TXT	*Text descriptions and dialogues helped me to understand the game mechanics*. 1="Did not help at all" 4="Helped a lot".
G.LOST*	*I felt lost very often and I did not know how to continue*. 1 = "Totally disagree", 4="Totally agree".
G.HELP	*Support and help contents provided by the game are appropriate*. 1 = "Totally disagree", 4="Totally agree".
G.CTRL	*Controls and game commands are adequate*. 1 = "Totally disagree", 4="Totally agree".
G.COM	*I felt comfortable using the game*. 1 = "Very uncomfortable", 4="Very comfortable".
G.FRUS	*I felt frustrated using the game*. 1 = "I felt very frustrated", 4="I did not feel frustrated at all".
G.FUN	*The game was fun*. 1 = "Totally disagree", 4="Totally agree".
G.MEC	*The game mechanics were easy to understand for me*. 1 = "Very difficult", 4="Very easy".

Table 3: Wording for the disability-specific section of the end user questionnaire.

Profile	Item Id	Wording
Speech Interface (Reduced	S.COM	*I always knew what commands introduce.* 1 = "Totally disagree", 4="Totally agree".

	S.REC1	*Voice recognition was efficient.* 1 = "Totally disagree", 4="Totally agree".
	S.FEED	*I was able to notice when the game had recognized a command.* 1 = "Totally disagree", 4="Totally agree".
	S.REC2	*The game has recognized my commands.* 1 = "Totally disagree", 4="Totally agree".
Keyboard interface (Blind)	K.COM	*I knew what commands or phrases type in.* 1 = "Totally disagree", 4="Totally agree".
	K.REC2	*The game has recognized my commands.* 1 = "Totally disagree", 4="Totally agree".
	K.FEED	*I was able to notice when the game had recognized a command.* 1 = "Totally disagree", 4="Totally agree".
	K.FEED2	*I knew when the game was ready to accept new commands.* 1 = "Totally disagree", 4="Totally agree".
High Contrast Interface	H.ELM1	*I could easily recognize objects and characters on the screen.* 1 = "Very difficult", 4="Very easy".
	H.TXT	*I could read the texts clearly.* 1 = "Very difficult", 4="Very easy".
	H.DLG	*I could always tell what character was talking.* 1 = "Very difficult", 4="Very easy".
	H.ELM2	*I could distinguish interactive elements from non-interactive elements.* 1 = "Very difficult", 4="Very easy".

Two different scales were built upon the common section of the questionnaire (Table 2):

- G: *Rate for the Usability of the game*. Aggregation of all nine elements: G.INT-G.MEC. (G.LOST was reversed first, resulting in item G._LOST=5-G.LOST).
- G.UX: *Rate for the User Experience of the game*. Aggregation of four items related to user feelings about the gameplay experience: G._LOST, G.COM, G.FRUS and G.FUN.

A Cronbach's alpha test was conducted to assess the reliability of both scales, resulting in .696 for G.UX and .847 for G. Two items with low item-total correlation factors (<.5) were removed from both scales (G._LOST and G.TEXT), achieving and increased Cronbach's alpha of .867 for G.UX (3 items) and .905 for G (7 items).

4.3 Results

This section provides the results obtained organized in three subsections: a quasi-quantitative analysis of the results of the end-user questionnaires; a qualitative analysis of end user comments, and finally and heuristic evaluation produced by usability experts that reviewed the recording sessions.

4.3.1 End user questionnaires

Average scores for the scales G (usability) and G.UX (gameplay experience) were measured and compared across user profiles, using the average score of users with no-disability group for comparison. As Figure 6 and Table 4 show, rates provided by Blind and Low vision users were similar to users with no disability. Only users with reduced mobility provided lower scores.

In general, both usability and user experience were positively evaluated by the users.

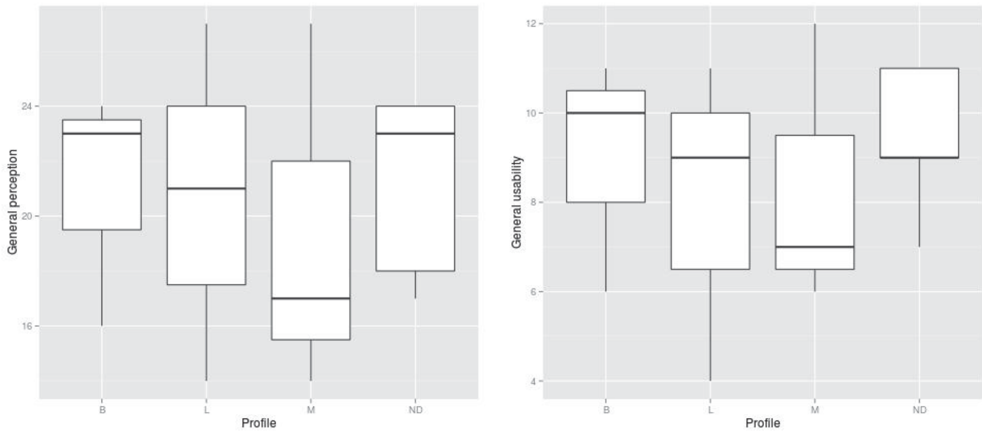

Figure 6: Aggregate general perception by profile type (left) and aggregate usability perception by profile type (right). Participants within the blind profile rated the game as highly in the G category as those in the non-disabled profile, and almost as highly in the G.UX category, while limited-mobility players rated it significantly lower in than other profiles in both categories.

Table 4. Medians of User experience and general usability for each user profile.

	General Usability (G) **[Range 7-28; 7 items]**				Evaluation of user experience (G.UX) **[Range 3-12; 3 items]**			
Profile	**Blind**	**Low Vision**	**Reduced mobility**	**No Disability**	**Blind**	**Low Vision**	**Reduced mobility**	**No Disability**
Median	23	21	17	23	10	9	7	9

Individual analysis of all items in scale G reaches a similar conclusion. Table 5 provides the median for each item, highlighting any data above (+) or below (-) the group of non-disabled users. There are almost no differences observed compared to the control group but in the reduced mobility group, which consistently scored lower.

Table 5. Median for every item on the common section of the questionnaire. Medians above and below the control group are highlighted. This table clearly shows that the speech interface underscored compared to the other three.

Profile	G.INT	G.TXT	G.LOST	G.HELP	G.CTRL	G.COM	G.FRUS	G.FUN	G.MEC

Blind	3.00	(+)**4.00**	(-)**2.00**	3.00	3.00	3.00	3.00	3.00	3.00
Low vision	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Reduced Mobility	(-)**2.00**	3.00	(-)**2.00**	3.00	3.00	(-)**2.00**	(-)**2.00**	3.00	(-)**2.00**
No Disability	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Data collected on items that were specific to each disability profile are reported on the next tables. Recognition of speech commands achieved the lowest scores, which may be the reason why users with reduced mobility provided lower scores.

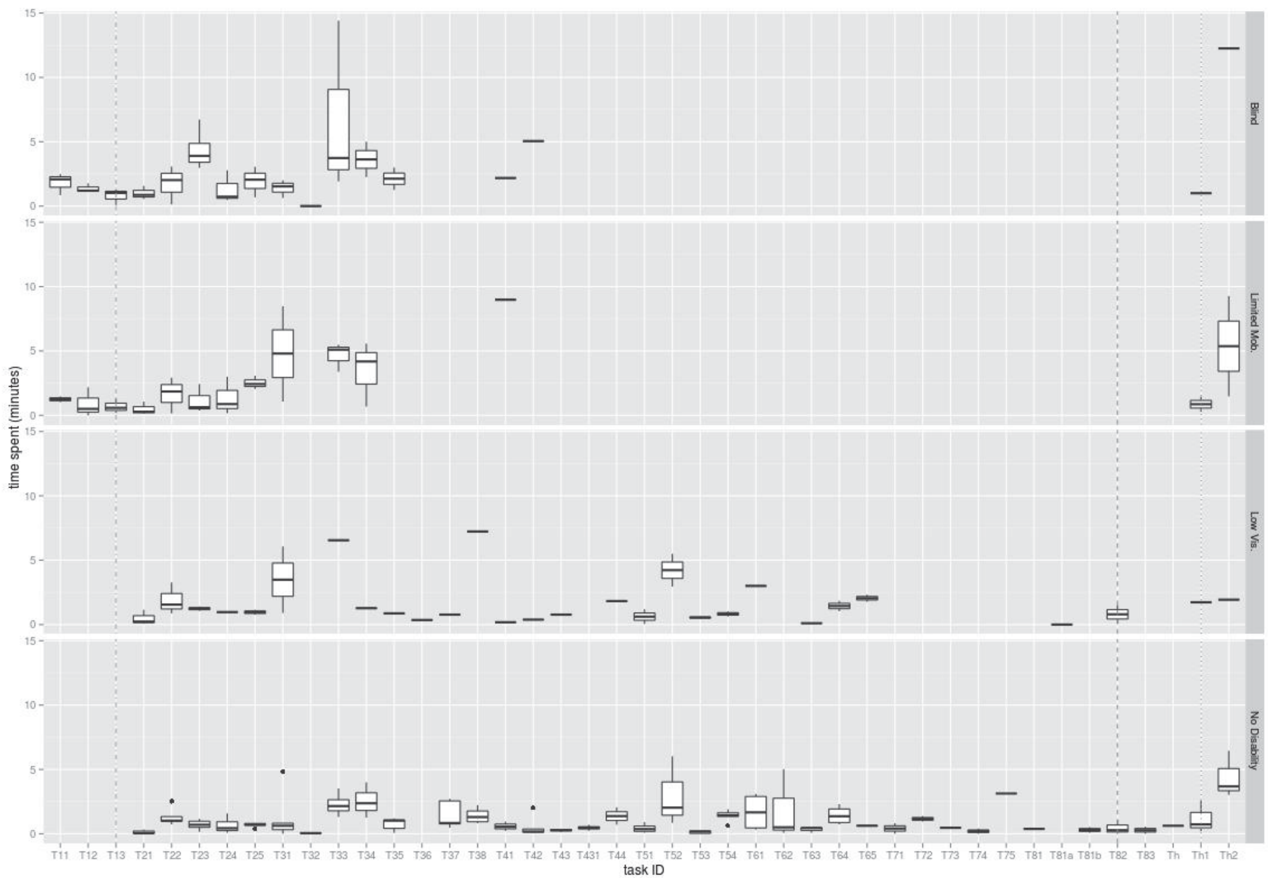

Figure 7: Time spent in tasks by user profile (labels at far right). The first vertical dashed line at T13 marks the end of the tutorial, which was only available for users in the Blind and Reduced mobility profiles. The line at T82 marks the end of the game itself, reached by only 5 of the 14 users, all of them from the No Disability and Low Vision profiles. The vertical dotted line at Th1 marks the start of the help task (available at any time after T24 is finished). Large delays in this task were due to users exploring available help questions, and often having problems finding the exit from the task itself. T33 was particularly difficult for certain profiles, as was T23 (the first conversation). Compared with T25 (second conversation), a strong learning effect can be observed.

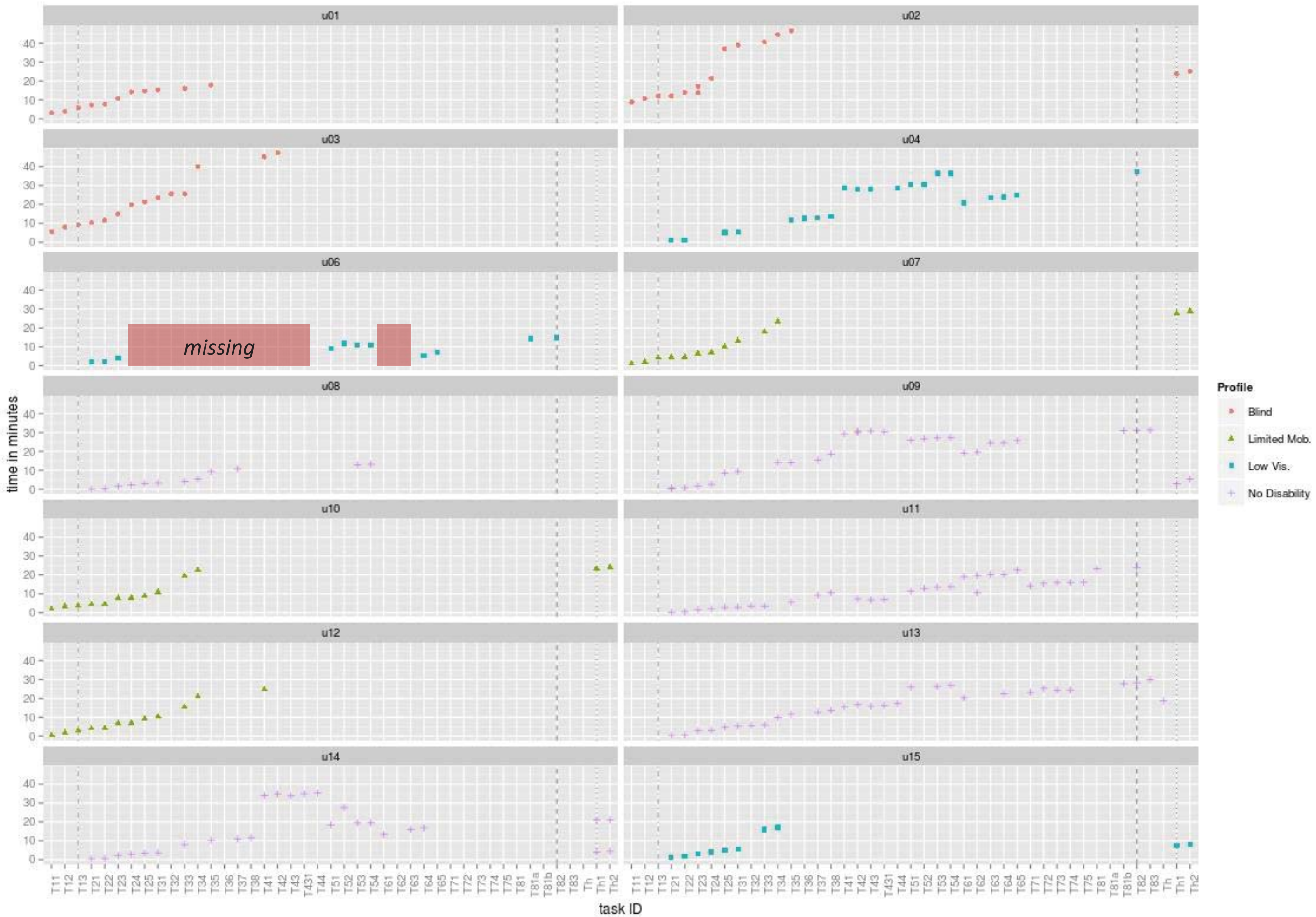

Figure 8: Task end times for each user (vertical lines explained in Fig. 6). Each point is redundantly encoded, using both color and shape, according to the corrresponding user's profile. A set of data-points for u06 is missing (due to a corrupted video file). Several tasks could be performed in multiple orders; for instance, in U13, tasks T51-T54 were perfomed after T74 and before T81b; additionally, some tasks could be skipped without penalty. Only 5 participants managed to finish the game, all of them from the Low Visibility and No Disability profiles. Due to problems with voice-recognition and text-input interfaces, users from the Blind and Reduced mobility profiles reached similar results; however, feedback by both groups is very different.

4.3.2 Annotations

Participant sessions were recorded in video. The videos only captured user interaction (the screen of the particpant's computer) and spoken comments and interactions between the participant and the facilitator. The following events were coded and time-stamped:

- **User interaction with the game**:
  - *good, not useful* (for instance, chosing to go back to a completely visited area),
  - *exploratory* (systematically explore all available objects or actions in a scene, without a clear goal), and
  - *not recognized* (for instance, when spelling errors or unexpected syntax was used in textual or spoken interfaces).
- **User interaction with facilitator**:
  - *user requests help*,
  - *facilitator provides help*, and
  - *general conversation*

Full transcripts were generated.

- **Game events**:
  - *session start/end*,
  - *user changes scene*,
  - *user finishes task*.

All video tagging and coding was performed by a single author, avoiding inter-coder aggreement issues, while raising the possibility of coder errors, omissions or interpretation issues (Boring & Gertman, 2005; Law & Hvannberg, 2004). Figures 6 and 7 contain visualizations generated from the coded transcripts of the user videos, totaling around 12 hours of gameplay time and over 3000 events. Both visualizations were generated using R's ggplot2 package[1].

4.3.3 Discussion of gameplay issues

Of the low-vision and no-disability profiles, only one user of each failed to complete the game in time. None of the blind or limited-mobility groups came close. This is a major setback, although it does not necessarily mean it is caused by the adapted interfaces. Moreover, much can be learned from analyzing the videos looking for the root causes.

The traces for users from the Reduced Mobility (RM) profiles are remarkably similar. All users became stuck in approximately the same moment, and decided not to progress any further. The greatest cut-off is T34, where players were first comfronted with a long in-game e-mail that layed out the tasks that they were expected to accomplish during the rest of the game. Having invested upwards of 20 minutes to reach this point, and given the difficulties interacting with the voice-recognition input, they decided not to continue playing. Blind users (B) found no accuracy problems (being limited only by their actual keyboard accuracy), but still had problems formulating correct commands, and also abandoned shortly after T43. The large difference in their feedback of the game experience (see Figure 6) is due to the perceived cause for slow progress, rather than the progress itself. For the blind, the interface behaved mostly according to expectations, while for reduced mobility users, who had a clear idea of exactly what they wanted to do but had problems achieving those goals due to poor voice

[1] http://cran.r-project.org/web/packages/ggplot2/index.html

recognition and error feedback, the interface was to blame for not allowing them to achieve their goals. Nonetheless, poor voice recognition accuracy was not a problem related to the interaction model proposed, but of the open-source voice recognition software used, which was also untrained.

Blind and low-vision players could use the "actions" command to see a list of available actions. However, many available actions were only hinted at. For example, the command "actions" could comment on the existence of 3 objects in the scene; but it was up to the user to first say "objects" to know what they were, and then actually examine each object in turn to probe it for additional actions that could be performed. Certain complex commands would show up in "actions" only after exploring the relevant objects.

Error reporting was far from detailed. In particular, it was very common for players to forget to dismiss conversations or messages before sending in new commands –approximately 63 commands were ignored for this reason, as the only valid action when a message or conversation was active was to say "advance" (or click a mouse button or arrow-key on the keyboard). When commands failed, no details were provided as to the reason of the failure. At this point, players often requested clarification from facilitators in figuring out what had failed. Indeed, players with Blind and Reduced Mobility profiles requested significantly more assistance from facilitators (helped 25 times on average during their sessions) than players with the LV or No Disability profiles (helped on average in 3.7 occasions). As expected, slow progress throughout the game tasks also resulted in more casual conversation with facilitators, with over 3.2 times the amount of general-conversation events in Blind/Reduced Mobility profiles as compared to Low Vision/No Disability. This also prevented users in Blind and Reduced Mobility groups from completing the game, since the amount of time available was limited (60 minutes).

4.3.4 Examples of inteface problems found in transcripts

Several users tried to rely on dialogues with in-game characters to "help them out", since in the real world asking people is a very effective way of gaining information. However, the game's conversations were limited in scope, and sometimes, as in the following transcript, contained breaches of protocol:

- U01 (Blind profile, issuing text command): *talk to receptionist* (who had just told her to visit the Managing Director's office to present herself)
- Receptionist (game character): *I have nothing more to say*
- U01 (to facilitator): "*This is totally unrealistic! Nobody expects a blind person to find her way around an unknown office without offering guidance!*"

This problem, although it may have had a significant impact in the whole experience, was related to the adaptation of the game design and not to the interface, which is the subject of the study.

Users that had not been able to play with accessible videogames often had encouraging comments regarding the game.

- U01 (Blind profile, to facilitator): "*hey, this is fun. Can I take a copy to play at home?*"

Lack of context (the interface did not remember previous incomplete commands) and contextual help (the interface could not suggest possible continuations, or diagnose the cause of errors) was a significant hurdle for participants in the Blind and Reduced mobility groups.

- U07 (Reduced Mobility profile, issuing spoken commands): talk (fails)
- Facilitator: you have to specify with whom
- U (command): managing director (fails)
- F: now you have to specify the verb
- U (command): talk to the managing director (fails; extra 'the')
- U (command): talk to managing director (ok – conversation starts)

In some cases, intrinsic task difficulty (such as assuming familiarity with certain concepts) was a greater problem than expected.

- Facilitator: do you know how to use an e-mail reader? (U15, Low Vision profile, has spent a few seconds looking blankly at the screen)
- U15: yes, sort-of… actually, I haven't used e-mail for a long time
- F: do you know what Powerpoint is?
- U: actually, no.

4.3.5 Remarks to intevewers during debriefing

Participants were asked to comment on positive and negative aspects and things that they would improve in the game; facilitators elicited the following responses:

Participants commented positively on

- Exploratory nature; liked not knowing what was in store (U1 Blind)
- Novelty; never played something like this before (U2 Blind)
- Accesibility; very few accessible games (U3 Blind)
- Unexpected outcomes during the game; for instance, a certain co-worker seems to be willing to date (U4 Low Vision)
- Design and simplicity (U6 Low Vision)
- Avatars for people with disabilities; general accessibility (U15 Low Vision)
- Small touches of humor (U8 No Disability)
- The need to focus in order to interact correctly with other characters (U11 No Disability)
- Good dialogue scripts, which should make it fun also for players with disabilities (U13 No Disability)
- It is not only educational, it is an actual game – that is, it is fun to play (U14 No Disability)

Suggestions and negative comments were

- Some way to prevent players getting stuck without knowing what to do next (U3 Blind)
- Faster game pace; currently progress is too slow (U4 Low Vision, U12 Reduced Mobility, U1 Blind)

- Game should be available in full-screen mode (U6 Low Vision, U15 Low Vision). Additionally, game should be zoom-accessible (people that use high-contrast also rely on zooming to figure out text); currently, playing while zoomed in makes certain interface elements invisible (general for Low Vision users).
- Fix the system operator “help guy”; he is hard to escape once you go to visit him (U15 Low Vision)
- Voice-recognition commands lack a good online help. I frequently did not know what to say to be understood correctly (U10, Reduced Mobility)
- Alternatively, voice-recognition commands could benefit from the use of a simple menu displaying available choices (U7 Reduced Mobility, U10 Reduced Mobility, U12 Reduced Mobility)
- Having to press an arrow-key instead of enter text, or indeed having to press anything at all, is prone to errors – U3 Blind
- Character avatars could be more dynamic, and sound is under-used (U8 No Disability)
- Provide hints to prevent frequent mistakes, such as forgetting to dimiss dialogue text in order to continue playing; highilght active scene elements (U13 No Disability, U14 No Disability)

5 Proposed Amendments to the Model

The most important part for the scope of this paper is to analyze game interface issues and how these can help us improve the interface model proposed. It is interesting to point out that a considerable number of the issues identified in the case study are related, partially or totally, to the game design and not to the game interface, which is the subject of study. For example, problems related to the “help guy” character are a consequence of a poorly designed conversation that did not take into account previous topics discussed with the character. While this was a problem all users suffered, it was especially frustrating for blind and reduced mobility users. Other game-design issues can be explained by the experience users had playing videogames. For example, while some users struggle to understand how the game worked, others rapidly understood the mechanics and found the pace too slow.

Also implementation-related issues arose in user interviews (e.g. problems with the voice recognition software), which require technical interventions (e.g. including a more mature voice recognition package).

Most interaction problems for users within the blind (Blind) or reduced-mobility (RM) profiles were due to players not knowing what actions to perform to achieve a given goal, or having problems when attempting to communicate these actions to the game engine. Many of interaction problems could be solved implementing hierarchical menu-driven action selections, as found in the suggestions of all limited-mobility users. The same approach would be of use for blind users – especially during the first minutes of interaction, when players are faced with the dual challenge of learning the gameplay and the interface simultaneously.

Therefore, in our amended model, we propose a new menu-driven interaction mode for profiles Blind and Reduced Mobility. This mode would be the default for new users, until they felt comfortable enough to write or dictate commands directly, and would allow menu navigation similar to that of standard voice-driven automated call centers (including numerical selection of options by order of presentation), augmented with typical text-to-speech controls to skip items, control output speed, and repeat the last utterance. User familiarity with these systems, currently highly widespread in company call centers, is seen as an added benefit. As an example, a possible menu would be the following (triggered by pressing a key or saying "menu"):

- Actions, 10 available
  - Use, telephone or fax machine (select to choose which)
  - Take telephone
  - Talk to Jane
  - Examine, 4 targets (select for list)
- Persons: Jane (collapsed due to having a single option available)
  - Examine
  - Talk to
- Objects, 3 in scene
  - Potted plant (can examine)
  - Telephone (can use, take, or examine)
  - Fax machine (can use, examine)
- Tasks
  - Your current task is to send a fax; say "change" to change
  - There are 3 hints available for this task
  - You have completed 5 tasks, say "completed" for list (list follows)
  - There are 10 tasks remaining, say "remaining" for list (list follows)
- Game
  - Stop using menu by default; you can activate it again saying "menu"
  - Help for voice commands
  - Save or restore game
  - Quit

Before being sent to the game, commands would be shown or spoken briefly to the user. This would help users learn the correct commands that would allow them to bypass the menu system entirely. Additionally, menus would be displayed on the screen for reduced mobility players in a similar way to in-game conversations or decisions, providing a more consistent interaction throughout the game. For reduced mobility users, additional visual feedback can be provided at low development cost by highlighting scene objects as they are mentioned, mimicking the discovery process of "hovering the mouse over the scene" frequently identified in the group of users with no disabilities when encountering a new game-scene.

Notice that a new type of commands is being proposed: the "Tasks" submenu was not available in the previous version of the interface. We feel that its addition would allow players to track their progress and request context-dependent help. This would attempt to address the increased amount of facilitator support requested by certain user profiles observed during our experiment, as in many cases, facilitators limited themselves to restating the player character's context.

Significant improvements can be made in error handling and reporting. In our amended model, we propose additional error-related output, indicating the exact point of the command that caused the problem and, if available, possible continuations. For example, we envision the following interaction (which could only arise in free command mode; menu actions would always be correct in a syntactic sense):

- Alice (player): *talk to Bob*
- Interface: *Bob cannot be talked to; you can talk to Peter or John*

Or

- Alice (player): *talk*
- Interface: *you can talk to Peter or John*

The addition of a menu system and of improved error handling and reporting will require only small changes to the game platform, and most importantly, no changes at all to the games themselves. The addition of a tasks submenu and hints for the tasks would require additional game-hooks and authoring tool support, but we feel that it would offer increased support to players who may become lost during game-play.

6 Related work

We believe this work is innovative and the first of its kind to the best of our knowledge, since automatic adaptation of game interfaces for accessibility purposes has not been proposed elsewhere. However, there are several works that have deeply influenced us which deserve discussion.

We have taken ideas from a body of works that deal with automatic generation of interfaces, which has a long history in other fields (Boutekkouk, Tolba, & Okab, 2011; Falb et al., 2009). Also state-of-the-art accessible game interaction has been considered and integrated, being the literature reviews provided by Westin (Westin et al., 2011) and Yuan (Yuan et al., 2011) especially helpful. The high contrast adaptations performed are also influenced by Westin's Terraformers (Westin, 2004). We have also integrated ideas from other authors that have identified accessibility barriers users with physical disabilities face, and proposed guidelines to overcome them (Game Accessibility Guidelines, 2012; MediaLT, 2006; Ossmann, Archambault, & Miesenberger, 2008). Finally, a very inspiring work is the Unified Design of Universally Accessible Games (Grammenos et al., 2007, 2009), a methodology proposed by Grammenos et. al for developing universally accessible games that enforces designing game tasks that are not bound to any specific interaction, and which has also been adopted by other authors (Garcia & de Almeida Neris, 2014).

7 Conclusions and Future Work

We have described a case study that tested user perceptions, perceived usability, and performance on an automatically adapted game for three physical disability profiles: blind, low vision, and reduced mobility, along with a group of users with no apparent physical disabilities for comparison. From the point of view of performance, two out of three low vision participants managed to finish the game within time, while none of the participants in the reduced mobility or blind profiles advanced into the second half of the game. These profiles had in common the use of a text (or speech-recognition) interfaces for command input.

Most to the problems found are not a consequence in the interface model proposed, but to technical errors or flaws in the game design. In this sense, this experience confirms that users with physical disabilities need not only to have an adapted interface, but also an adapted game design including the alternative branches of the plot and enhanced character support. The semi-automatic adaptation of game design and content, which was not the purpose of this work, will be explored in the future.

As for the interface model proposed, examination of session video recordings and user interviews has allowed us to identify the problems with our automatic adaptations, leading to several important changes to the adaptation model we proposed.

It is striking that the general perceptions and usability is markedly different between participants from the reduced mobility and blind profiles, given that they were using the same game interface. In particular, blind participants rate the system and its usability much higher than the reduced mobility participants. We attribute some of these differences to the novelty of accessible video games from the point of view of our blind participants, coupled with the unacceptably high failure rate of speech recognition encountered by users of the reduced mobility interface. However, we understand that the main culprit is the underlying textual command system and its lack of visual feedback for otherwise users with unimpaired sight.

As a final remark, we would like to highlight the fantastic acceptance of the game, which shows people with disabilities are avid to have more content like this available and justifies further research in the field.

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7.8. Eyes-free Interfaces for Educational Games

7.8.1. Cita completa

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7.8.2. Resumen original de la publicación

Any new technology introduced in the classroom has a potential risk of increasing the divide for students with disabilities. This impact becomes greater as the new complexity of new technologies increases. In this sense, one of the most complex technologies currently being considered are educational videogames. And while the potential benefits of videogames are great also pose significant challenges from an accessibility perspective. In this paper we investigate interfaces that may facilitate access to educational games for blind students. The long-term goal is to integrate these interfaces into educational game engines or authoring tools, facilitating the adaptation of educational games to avoid a future problem of digital divide. Three eyes-free interfaces have been developed: 1) a navigation system that allows the user to browse and interact with elements using arrow and action keys; 2) a sonar that helps blind users find interactive elements in the game universe with the mouse; and 3) an interface that interprets commands typed in natural language.

Eyes-free Interfaces for Educational Games

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Abstract—**Any new technology introduced in the classroom has a potential risk of increasing the divide for students with disabilities. This impact becomes greater as the new complexity of new technologies increases. In this sense, one of the most complex technologies currently being considered are educational videogames. And while the potential benefits of videogames are great also pose significant challenges from an accessibility perspective. In this paper we investigate interfaces that may facilitate access to educational games for blind students. The long-term goal is to integrate these interfaces into educational game engines or authoring tools, facilitating the adaptation of educational games to avoid a future problem of digital divide. Three eyes-free interfaces have been developed: 1) a navigation system that allows the user to browse and interact with elements using arrow and action keys; 2) a sonar that helps blind users find interactive elements in the game universe with the mouse; and 3) an interface that interprets commands typed in natural language.**

Keywords-Accessibility, audio 3D, eAdventure, point-and-click interaction, eyes-free games, e-learning, distance learning, game authoring tools, game-based learning, online learning, videogames.

I. INTRODUCTION

Educational computer and videogames (from now on, simply referred to as "games") are gaining acceptance in academic forums as more and more empirical research and evidence about their educational potential are becoming available [1], [2], and also from educational institutions which are increasingly adopting game-based learning paradigms [3].

However, educational games pose a significant source of digital divide for students with disabilities, as the accessibility of this type of content is not well covered yet [4]. Accessibility of educational games should be improved in order to avoid a potential problem for teachers willing to use games, who may need to plan alternative activities and contents for students with a disability, with the consequent stigmatization for the students.

One of the main arguments used to justify the lack of accessibility of games in general is that it has a considerable extra cost associated. Most of this cost comes from the need to develop expensive interfaces for users that represent rather little percentages of the target audience, given the segmentation of adaptations needed by users with disabilities. For example, to make a game accessible for blind users, it is necessary to include an interface that allows interacting with a keyboard or Braille device and provides feedback with audio, while users with a motor disability may need a speech-powered interface.

To improve the accessibility of educational games we propose shipping configurable accessible interfaces along with educational game authoring tools [5]. This would help to make games more accessible without requiring additional efforts from game developers or educators.

Nonetheless, for this approach to be feasible, first it is necessary to investigate, from a human-computer interaction perspective, what type of accessible interfaces could be applied in different contexts and for different games. While research has been done in the last years exploring the design of game interfaces for users with disabilities, solutions still lack scalability as they are developed for specific games.

Accessible game interfaces should allow user-friendly and pleasant interaction but preserving elements that are central to entertainment and learning (e.g. immersion, challenge or engagement) for all users regardless of their abilities or previous experience. For example, if an accessible interface alters substantially the level of challenge of the game, enjoyment would be diminished, as there is a clear relation between an appropriate level of challenge and players' engagement [6]. The results would be a game with less educational potential, as engagement is a key element in games supporting active learning [7].

The purpose of this study is to investigate accessible interfaces that can deliver the best game experience to blind users with different abilities and gaming habits. To narrow the scope of the project we have focused on point-and-click adventure games, a genre that is especially suitable for education due to the emphasis on reflection and problem-solving instead of action and pacing [8], [9].

This paper is structured as follows: section 2 summarizes the state-of-the-art in designing games that are accessible for blind users. Section 3 analyses the

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point-and-click genre we are focusing on. Section 4 introduces the eAdventure gaming platform, which has been used as a base to implement the interfaces proposed, which are described in section 5. Section 6 provides a discussion about the interfaces developed and finally section 7 provides conclusions and future lines of work.

II. Related Work

Blind users are the community most affected by accessibility barriers in educational games, and therefore are one of the target groups that have attracted more focus from academic research [4]. They are also backed up from communities of practice that lead cutting-edge initiatives regarding accessibility in games, like AudioGames.net [10], or the International Game Developers Association (IGDA) special interest group on accessibility [11]. They have also done a very intense job in identifying accessibility issues in video games, as Bierre et al describes in [12] for example.

Many research contributions about game design and interaction for users with lack of vision explore the use of new senses to improve the game experience, especially haptic feedback. One of the first examples is the use of the PHANToM™ device to increase accessibility [13]. More recently this kind of technique has been applied, through different devices, to games like a 2D pong [14] or a Sudoku [15]. This kind of feedback has proven to be successful not only in computers but also in mobile devices [16].

Other publications investigate the use of auditory feedback to substitute the visual interface [17], [18]. For example, Atkinson et al. [19] introduce the idea of associating "earcons" to game elements. Directional audio [14], [20] and 3D sound systems have been used to orient users and help them locate static or moving elements in the game universe [21], [22]. For example, the project "The Sound of Football" combined mobile devices with a sonar-like interface to help users play football without using sight [23].

In turn, some other contributions have focused on making specific commercial games accessible after their release, such as Quake [19], "Dance Dance Revolution" [24], Rockband [25] or Guitar Hero [26]. Most of these approaches succeeded in delivering accessible and fun experiences to the target users. However, most results were very specific for a single tool or game, and it is not always clear how to scale and reuse the solutions proposed.

Other approaches have addressed design methodologies or implementation frameworks that are applicable to a broader number of games. For example, Grammenos et al. [27] introduce a unified design method that guide developers in producing more accessible games. It uses the concept of abstract tasks to make the games device and technology independent, and therefore can be more easily adapted to the needs of different users. Roden and Parberry [28] propose a game engine for creating interactive audio only games.

III. Point-and-Click Adventure Games

In this section we describe the point-and-click adventure game genre, which we have focused on in this study. The importance of these games for education is discussed, and interaction is described as a means to understand the challenge of introducing accessibility in these games.

A. The Genre

Point-and-click adventure games lived their golden age in the 90's, when titles like the "Monkey Island™", "Indiana Jones™", "Myst™" or "Day of the Tentacle™" sagas were easily found among the highest positions of the best selling games rankings. The genre lost attractive in the 2000's, at least among mainstream titles, but it still has a place in the independent (or *indie*) market and keeps an important community of users. Besides, the point-and-click adventure genre is receiving an increasing attention from academia because of its potential for serious and educational applications, due of its strong narrative underpinnings [9], [29], an aspect that is well aligned with learning [30].

From a Human-Computer Interaction perspective, it is an excellent representative of point-and-click interfaces and the barriers they pose, which are present in many modern games and applications. In classical adventure games, to find interactive elements in the game universe the user moves the mouse cursor around. When it hovers over an interactive element, some visual feedback is provided, meaning that the user can click it and then the game universe reacts (e.g. a character starts talking) or a contextual menu with available actions is displayed.

Therefore, the main problem that makes these games inaccessible for blind students is the need of use sight to explore the game world, which is also a characteristic present in other games. Nonetheless, point-and-click adventure games have some advantages as they lack many typical accessibility barriers, like a very fast pace or the use of time pressure to provide challenge [11].

B. Exploration in Point-and-Click Adventure Games Provide Challenge

An appropriate balance of challenge throughout all the game play is a key success factor in all games [6], [31]. In point-and-click adventure games a non-trivial mechanism to explore the game universe contributes to provide adequate challenge and make the game enjoyable. Any adaptation of the interaction aiming to improve accessibility must conserve this exploration process or the pleasure of the game experience may suffer.

Challenge helps the player to reach a flow experience where engagement, feeling of personal fulfillment and enjoyment are maximum according to Csikszentmihalyi's theory [32]. The difficulty of the game is usually designed to challenge the player's abilities but without surpassing them to the extent of becoming frustrating or unbeatable. Since players' skills are expected to grow as they play, so does the challenge provided. There are different strategies to provide challenge (e.g. time pressure), and most of the games use a different combination of these.

In point-and-click adventure games, challenge is provided by setting out non-trivial puzzles the player must solve by applying reasoning and problem-solving skills. The player needs to observe the game world, apply reflection, compare to past experiences and build on previous meanings [33] to reach the solution of the puzzles. Without these components enjoyment is seriously damaged.

Observation involves exploring the game universe to discover which valid interactions are hidden in a scene, which elements can be interacted with, how to interact with them and what are the expected consequences of these interactions. This process requires time, with players often wandering around and exploring at their own pace, trying out different things. It is not immediate and it is scaffolded as the game starts with just a little part of the game universe available and new parts are unlocked as players advance in the game. The game must subtly guide the player in this exploration and discovery process, but it must not be evident (it is important that the players use their own problem-solving skills to beat the game).

C. *The Importance of the Story*

Point-and-click adventure games use an attractive story to engage players, as opposed to other kind of games that rely on elements like striking visual effects and images [9]. From an accessibility perspective, game interfaces must allow every user to experience the story in a comfortable way to have a pleasant experience.

A strong narrative component is usually present in point-and-click adventure games. An appealing plot is unveiled while the player progresses in the game, solving different puzzles and riddles that are integrated within the game plot. This is how many of the most successful adventure games manage to keep players immersed and engaged. In terms of accessibility this is interesting as story can be considered as a neutral element (it is not bound to devices or technology) that may appeal to different players with different abilities, including blind and sighted players.

IV. THE EADVENTURE PLATFORM

The eAdventure platform is a game authoring tool that allows for the development of 2D educational games, with special focus in point-and-click adventure [34], [35]. It was designed to facilitate the development of educational games by people with little technical background (e.g. educators). It is compound by a What-You-See-Is-What-You-Get (WYSIWYG) game editor used to create the games (see Figure 1), and a game engine that can be distributed following the Learning Object Model to deliver the games to the students [36].

The game universe in eAdventure is defined by a number of 2D game scenarios that are interconnected using "exits"; that is, regions of the scene that can be clicked and that transport the player to a different scene (see Figure 1). Exits, along with objects and characters are the basic interactive elements supported by eAdventure. In addition, objects and characters support several types of interactions (e.g. grab, talk to, use, etc.).

The platform has already been used as a testbed for educational accessible game research [5], and the long-term goal is to integrate multiple forms of accessible interfaces in the eAdventure game editor and engine so they could be easily configured by game creators (i.e. educators) to adapt the games.

Both the author and the player would profit from having alternative interfaces available. The author (e.g. educator) could include several interfaces in a game, and decide which users would use each one depending on the design, special needs of the users, previous experience, etc. The author could also leave this decision to the user, who could choose the interface that she/he prefers, or even to the game, who could set up an easy interface in first place and suggest other interfaces as the user progresses in the game gaining expertise and skills.

However, in order to inform this process, it is necessary to understand the restrictions and affordances of different accessible interaction mechanisms. In this work we have implemented three alternative accessible interfaces for blind users. All of them have been built on top of the eAdventure platform, with the objective of identifying which elements of each interface provide value or limitations.

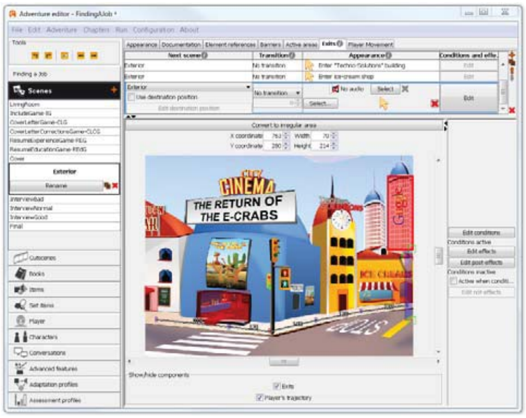

Figure 1. Screenshot of the eAdventure game editor, version 1.4. The red rectangle marks an exit defined on a game scene.

V. THREE EYES-FREE INTERFACES FOR POINT-AND-CLICK GAMES

Each eyes-free interface prototype developed provides a different experience to explore the game universe. To be more specific, we define exploration as the process from which the player obtains information about what are the available interactions on the scene (what can be done in it) and the more likely consequences these will have in the game world.

All the interfaces use the same system for providing auditory feedback. Each time the game universe changes an audio message is reproduced using the eSpeak free text-to-speech software. This includes, for example, entering a new game scene or triggering any interaction with objects or characters as defined in the game. The system is flexible, allowing the game author to define alternative messages for each specific interaction depending on users' performance and progress.

The flexibility of the audio feedback system helps to provide fine-tuned guidance to explore each game scene, keeps the user engaged in the story and contributes to create drama and tension. It is also used to provide a message describing the scene when the user moves from one scenario to another. The message changes depending on the number of times each scene has been visited.

Next subsections describe each interface: a cyclical navigation system that resembles how a blind user navigates through a web page using the keyboard; a sonar, which uses 3D audio to identify the location of interactive elements on the scene; and a natural language interface that interprets text commands written in plain language.

A. *Interface 1: Cyclical navigation system*

With this interface, interaction is similar to browsing the web using a screen reader. Available interactions in the scene are structured in a two-level focus cycle that can be navigated with the left and right arrow keys (see Figure 2).

The first level is compounded by the interactive elements on the scene (characters, objects, exits, etc.). The second level contains actions related to each element (e.g. talk to, grab, leave, etc). To access the second level, the user hits the action key (intro). To return to the first level, the user hits the go-back key (escape).

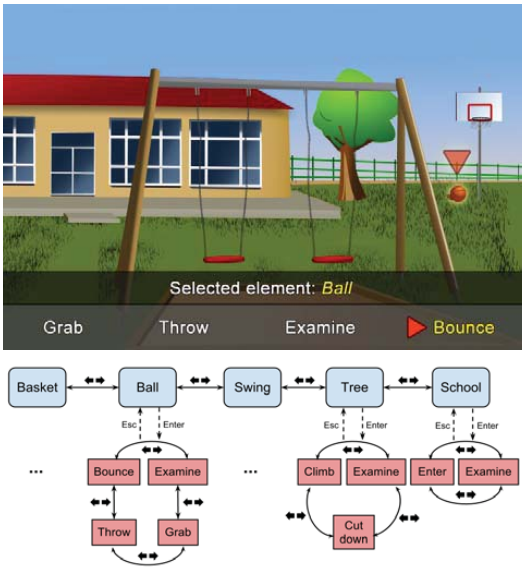

Figure 2. Example of navigation through elements of a game universe with interface 1 (cyclical navigation system).

This interface was designed to be as intuitive and natural for blind users as possible and should be perceived as the most usable since all actions are accessible within a minimum number of key strokes. However it is not expected to be very fun since the actions are presented to the player directly, turning game exploration into a trivial process.

B. *Interface 2: Sonar*

The purpose of this interface is to guide the player in finding interactive elements with the mouse, instead of using the keyboard. On the scene a 3D positional audio system is configured. In this system, each interactive element emits a different sound that can be configured. Information about the position of the element related to the mouse cursor is provided by altering the intensity and pitch of the sound. Depending on the distance of the element to the mouse cursor, the sound is perceived with a different intensity. Pitch is used to provide information about the vertical position of the mouse pointer (high pitch denotes that it is near an element, while low pitch denotes that it is far from it).

When the user hovers the mouse over an element, a confirmation sound is played using the audio feedback system. The user can also activate or deactivate the sonar with the space bar to limit acoustic fatigue. When the mouse accidentally exits the game window boundaries, a special sound is played. The mouse is relocated to the center of the screen each time the scene changes.

C. *Interface 3: Natural language commands interface*

With this interface interaction is articulated through short text commands formed in natural language that the user introduces in a little text box. After the command is introduced, the system tries to interpret it and match it to one of the available interactions in the scene, using a regular grammar that defines the structure of supported commands and a thesaurus of synonymous based in a previous work [5]. The user receives audio feedback about the results of this matching and if it has succeeded, the interaction is triggered.

The kind of feedback returned by the system after each command is introduced can be configured by the author of the game. By default, the system will return a random message (e.g. "Ummm ... I'm not sure what you mean" or "I think rather not to do so") depending on the rules of the grammar that caused the matching to fail. However, it is possible to use the flexible audio feedback system to provide hints if more guidance is required.

In contrast to interface 1, in this case the interactions available are not directly revealed to the user, but instead the player has to find them out by test-and-error of different commands.

This interface also supports a list of special commands:

- **Actions**: remembers the user all interactions that he/she had previously discovered in the scene.
- **Describe scene**: provides audio feedback about settings of the scene, combining an optional message introduced by the game author and a summary of the elements presented (e.g. there are two exits, an object near character A, etc.).
- **Help**: Provides hints and interaction instructions.

VI. Discussion

The three interfaces have different characteristics and may be adequate for different users and applications. In this regard, it is interesting to discuss how usability and entertainment varies across these interfaces.

Probably the most usable is Interface 1 (navigation system), according to a classic definition of the term, because it allows triggering interactions with minimum effort. Therefore, this interface may be suitable for blind students with little gaming background, or for games with an intense simulation component. It could also be useful for inexperienced sighted students that want to lessen the difficulty level of the game. Nevertheless, students with more gaming habits would rapidly find this interface boring.

The most entertaining interface is probably number 2 (sonar). It is the most provoking of the three and has a great potential to engage students as it enhances the challenge of exploring the game universe. So it would probably be useful for students with frequent gaming habits. However, this interface can provoke fatigue in students if it is used in very long games or the sounds are not carefully chosen.

Interface 3 provides an interesting balance between usability and engagement/entertainment. Regarding usability, if users know the right command that needs to be introduced to trigger an interaction they just need to type in a single sentence. But, which makes the system interesting is that students must apply deduction to find the correct command, and therefore the process is not immediate.

The impact on the game authoring experience differs among interfaces. Interface1 and Interface 3 do not take into account the location of interactive elements on the screen, forcing the author of the game to feed the audio system with descriptions that are automatically spoken using text-to-speech to provide contextualization for the blind user. Interface 2 does not pose this extra burden, but requires the author to specify different multiple sounds for each scene. From a cost perspective entering text is easier than producing additional audio resources. These considerations must be taken into account, given that the goal is to limit the cost needed to make educational games accessible as much as possible.

The following table provides a summary of the characteristics of each interface.

TABLE 1. COMPARISON OF THREE INTERFACES

Interface	Usability	Engagement	Additional Cost
Navigation (1)	↑	↓	=
Sonar (2)	↓	↑	↑
Commands (3)	=	=	=

VII. CONCLUSIONS AND FUTURE WORK

Educational games are gaining momentum very quickly, and they will probably increase their presence in schools and universities in the midterm [3]. However, it is necessary to make an additional effort to ensure the accessibility of games to guarantee they do not create more problems than they solve.

For that purpose we have proposed three interfaces that could be used to improve access to educational games for blind students. The idea is to allow a seamless integration of accessible interfaces in educational games to ensure accessibility is covered.

We have recently conducted a preliminary evaluation with 10 blind users to check the usability of the interfaces generated. The analysis of data collected is among our first lines of future work.

Next steps in this research are to refine these interfaces, use them to develop games and test them with experts in educational game authoring, in order to identify the best practices when designing accessible game interfaces. In addition, it may be possible to combine successful features of different interfaces to produce new interfaces.

Once these interfaces reach a certain level of maturity, it would be necessary to define a system that allows the authors of the game (and/or the users themselves) to setup the interface that is best for them.

Once these actions are accomplished the interfaces will be ready for production stage, and they will be integrated in the public release of the eAdventure platform to allow other game authors and players reuse the work done. Ideally, the integration of accessibility features in the game editors (rather than *ad hoc* modifications for each game) should consequently reduce the cost of introducing accessibility in educational games.

Long term goals of this approach is to make accessible educational games, similar to the ones created in collaboration with CATEDU (Centro Aragonés de Tecnologías para la Educación), without a significant increase in the production costs. These educational games are currently available at http://www.catedu.es/webcatedu/index.php/descargas/e-adventures.

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7.9. Evaluation of Three Accessible Interfaces for Educational Point-and-Click Computer Games

7.9.1. Cita completa

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7.9.2. Resumen original de la publicación

Despite the increasing importance of digital games, game accessibility has not yet received enough attention. As a consequence it is unclear how to design games that are engaging and usable also for people with disabilities. This work analyses perceived usability, entertainment and overall experience provided by three interfaces for blind people with different gaming habits: (1) a keyboard navigation system, (2) a sonar and (3) a conversational interface. Data collected from a preliminary experience suggests that the three interfaces could be used for games, although (3) seems a better choice for occasional gamers and novice users and (2) for regular and frequent gamers or users seeking new challenges.

Evaluation of Three Accessible Interfaces for Educational Point-and-Click Computer Games

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Abstract
Despite the increasing importance of digital games, game accessibility has not yet received enough attention. As a consequence it is unclear how to design games that are engaging and usable also for people with disabilities. This work analyses perceived usability, entertainment and overall experience provided by three interfaces for blind people with different gaming habits: (1) a keyboard navigation system, (2) a sonar and (3) a conversational interface. Data collected from a preliminary experience suggests that the three interfaces could be used for games, although (3) seems a better choice for occasional gamers and novice users and (2) for regular and frequent gamers or users seeking new challenges.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, graphical user interfaces (GUI), natural language, screen design*;

K.3.1 [**Computers and Education**]: Computer uses in education – *distance learning, computer-managed instruction*;

K.8.0 [**Personal Computing**]: General – *games*.

D.1.7 [**Programming Techniques**]: Visual programming;

General Terms
Design, Economics, Human Factors.

Keywords
Accessibility, audio 3D, eAdventure, point-and-click interaction, eyes-free games, e-learning, distance learning, game authoring tools, game-based learning, online learning, videogames.

1. Introduction
Playing digital games has become one of the most popular leisure activities for people of all ages, genders and backgrounds. Moreover digital games are increasingly being adopted in education as a way to engage students and improve academic performance (Johnson, Adams, & Cummins, 2012). But at the same time digital games remain almost inaccessible for people with disabilities, as the number of games that are accessible in the

market is still very limited (Westin, Bierre, Gramenos, & Hinn, 2011). Given their importance in modern society, this means a significant potential source of digital divide (Abrahams, 2010; Yuan, Folmer, & Harris, 2011).

Research to improve the accessibility of the games has been conducted in the last years. Nonetheless, the state-of-the-art in game accessibility is years behind other fields. Broad guidelines have been built from successful case studies by influential organizations like the International Game Developers Association (Bierre et al., 2004) and also by enthusiastic advocates (Game Accessibility Guidelines, 2012; Yuan et al., 2011). But these recommendations are far from being as stable, as used and as widely accepted as other guidelines like the WAI, which even have the status of standard (W3C, 2006). This is partially because games are very complex pieces of software that deliver a unique user experience (J. L. G. Sánchez, Vela, Simarro, & Padilla-Zea, 2012) and thus approaches that have helped to improve accessibility of other Information Systems are not fully applicable. Accessible game interfaces should be usable, allowing user-friendly and pleasant interaction but preserving elements that are central to entertainment, like immersion, challenge and engagement regardless of the player's abilities or previous experience. For example, if an accessible interface alters substantially the level of challenge of the game, enjoyment would be diminished, as there is a clear relation between an appropriate level of challenge and players' engagement (Chen, 2007).

Game play experience is influenced by a number of personal and contextual factors that makes the 'one-size-fits-all' approach unlikely to suit all players. Studies like (Yee, 2006) reveal how players differ from one another, showing that the motivations that drive players to play a game and their mental goals are variable. In education, there are additional personal parameters to consider, like the different backgrounds, gaming habits and preferences of the students, which result in having a very diverse population. Dealing with player diversity, which is something that many good games do naturally, is very important to avoid exclusion and maximize the positive effects of Game-Based Learning (GBL). For example, literature has shown that gender affects student performance and perspectives on GBL (Hwang, Hong, Cheng, Peng, & Wu, 2013).

Game accessibility research usually ignores the effects of personal characteristics on the game play experience. This paper aims to contribute to bridge this gap. As previously discussed, diversity is determined by a wide number of factors. In this study we focus on gaming habits as a single player diversity parameter. We investigate accessible interfaces that can deliver an optimum game experience to blind people with different gaming habits. To narrow the scope of the project we have focused on *point-and-click* adventure games, a genre that is suitable not only for entertaining but also for education and other serious applications (Amory, Naicker, Vincent, & Adams, 1999; Dickey, 2006). Usability and entertainment provided by three non-visual interfaces for blind users are analyzed: (1) a keyboard navigation system that makes playing similar to web browsing, (2) a sonar that allows play by using the mouse; and (3) a conversational interface that interprets short commands in natural language.

This paper is structured as follows: section 2 summarizes the state-of-the-art in designing games that are accessible for blind users. Section 3 analyses the point-and-click adventure genre we are focusing on. Section 4 introduces the eAdventure gaming platform, which has been used as a base to implement the interfaces proposed, which are described in section 5. Section 6 describes the preliminary evaluation conducted and section 7 elaborates conclusions and future lines of work.

2. Related Work: Non-Visual Games

Blind people are among the communities of people with a disability that find more barriers in mainstream titles. However, they also constitute one of the target groups that have attracted more research (Westin et al., 2011). They are also supported by influential communities of advocators and gamers like AudioGames.net (Audio-Games, 2013), or the International Game Developers Association (IGDA) special interest group on accessibility (Bierre et al., 2004), which are actively engaged in the development of guidelines and recommendations that are considered the state-of-the-art in game accessibility. These communities have also contributed in pointing out barriers present in mainstream video games (Bierre et al., 2005).

Reviewing the literature on non-visual games, a common approach is to substitute all visual stimuli by auditory feedback, finding many variants and examples (Friberg & Gärdenfors, 2004; Röber & Masuch, 2005). Atkinson et al. used "earcons", structured sounds that are designed to alert the user to an object or event (Atkinson, Gucukoglu, Machin, & Lawrence, 2006). Directional audio (Grammenos, Savidis, Georgalis, & Stephanidis, 2006; Savidis, Stamou, & Stephanidis, 2007) and 3D sound systems have been used to orient users and help them locate static or moving elements in the game universe (J. Sánchez & Espinoza, 2011; J. Sánchez, Sáenz, & Ripoll, 2009). The project "The Sound of Football" also combined mobile devices with a sonar-like interface to help users playing football without using sight (Pepsico, 2011).

In an effort to create more appealing experiences for blind gamers, other developments have explored stimulation of multiple senses, especially the use of touch combined with supplementary audio. One of the first examples is the use of the PHANToM™ device that was able to convey 3D haptic feedback (Sjöström & Rassmus-Gröhn, 1999). More recently this kind of technique has been applied, through different devices, to games like a 2D pong (Savidis et al., 2007) or a Sudoku (Gutschmidt, Schiewe, Zinke, & Jürgensen, 2010). This kind of feedback proved successful not only in computers but also in mobile devices (Kim & Ricaurte, 2011).

Game accessibility has also been addressed conceptually by proposing general design methodologies or frameworks that may be applicable to a broad number of games. For example, Grammenos et al introduced a unified design method that guides developers in producing more accessible games (Grammenos, Savidis, & Stephanidis, 2007). It uses the concept of abstract tasks to make the games independent from the device and technology used, and therefore they can be more easily adapted to the needs of different users. In some cases, these initiatives are supported by demonstration prototypes (Grammenos et al., 2006; Grammenos, Savidis, & Stephanidis, 2005). However, they often lack of reference implementations or support tools that facilitate their application for developing new games. As a consequence most of these approaches are difficult to scale. In this regard, focus is usually placed on specific titles, like Quake (Atkinson et al., 2006), "Dance Dance Revolution" (Miller, Parecki, & Douglas, 2007), Rockband (Allman, Dhillon, Landau, & Kurniawan, 2009) or Guitar Hero (Yuan & Folmer, 2008), with few game development packages catering for accessibility more generally. One example is the work of Roden and Parberry who propose a game engine for creating interactive audio-only games (Roden & Parberry, 2005).

3. *Point-and-click* Adventure Games

In this section we describe the *point-and-click* adventure game genre, which we have focused on in this study. The importance of these games for serious applications is discussed, and interaction is described as a means to understand the challenge of introducing accessibility in these games.

3.1 The Genre

Point-and-click adventure games were very popular in the 90's, when titles like the *Monkey Island™*, *Indiana Jones™*, *Myst™* or *Day of the Tentacle™* sagas were easily found at the very top of the best selling games rankings. The genre lost traction in the 2000's, at least among mainstream titles, but it still has a place in the indie market (e.g. *Machinarium* or *Tomorrow*) and attracts an active user community. Besides, the *point-and-click* adventure genre gathered interest from the academia because of its potential for serious and educational applications, which is partly attributed to its strong narrative underpinnings (Amory, 2001; Dickey, 2006), an aspect that is well aligned with learning (Garris, Ahlers, & Driskell, 2002).

From a Human-Computer Interaction perspective, these games are excellent representatives of *point-and-click* interfaces and the barriers they pose, which are present in many modern games and applications. In classical adventure games the user moves the mouse cursor around to find elements in the game universe to interact with. When hovering over an interactive element visual feedback is provided, hinting to the user that clicking on it will trigger a reaction of the game universe (e.g. a character starts talking or a menu with additional actions being displayed). The problem that makes these games inaccessible for blind players is the need of using the sight to explore the game world, which is also a common problem in other game types (Archambault, Ossmann, Gaudy, & Miesenberger, 2007). But in general *point-and-click* adventure games are more accessible than other genres as they lack many typical barriers, like a very fast pace, absence of configuration features or the use of time pressure to provide challenge (Bierre et al., 2004).

3.2 Exploration in Point-and-Click Adventure Games is Key to Achieve Fun

Providing well balanced challenges for the player throughout the whole game play is a key success factor of any good game (Chen, 2007; Gee, 2003). Challenge helps the player to reach a flow experience where engagement, feeling of personal fulfillment and enjoyment are maximum according to Csikszentmihalyi's theory of flow (Csikszentmihalyi, 1991). The difficulty of the game is usually designed to challenge the player's abilities without surpassing them to the extent of becoming unbeatable to prevent frustration. Since players' skills are expected to grow as they play, the challenge posed by the game needs to increase as well, to avoid ending up with a boring experience. There are different strategies to provide challenge (e.g. time pressure, problem-solving or lateral thinking puzzles), and most of the games use a different combination of these.

In *point-and-click* adventure games, observation and exploration are key aspects to reach engagement. The player is challenged with puzzles that require designing a problem-solving strategy. For that purpose the player applies information provided by the game and also previous meanings and patterns learned from previous puzzles in the game (Egenfeldt-Nielsen, 2003). To gather information the player carefully explores and scrutinizes the game world searching for hidden clues and resources for solving the problem. Although the game subtly and non-intrusively guides the player to facilitate discovery of information, this process must be neither immediate nor trivial or obvious. Should the exploration system be unbalanced, it may have a deep impact on the overall game experience. Any adaptation of the interaction aiming to improve accessibility must preserve the exploration process to avoid breaking the game experience.

3.3 The Importance of the Story

Point-and-click adventure games use an attractive story to engage players, as opposed to other kind of games that use other elements to stimulate the player like striking visual effects and images (Dickey, 2006). From an accessibility perspective, game interfaces must allow every user to experience how the story unfolds in a comfortable way to have a pleasant experience.

Strong narrative underpinnings are usually present in *point-and-click* adventure games. An appealing plot is unveiled while the player progresses in the game, solving different puzzles and riddles that are integrated within the game plot. This strategy keeps the player immersed and engaged. The story is a technology-independent element that appeals to different players with different abilities, including blind and sighted players. Any action taken to improve accessibility must preserve the narrative experience of the game.

4. The eAdventure Platform

The eAdventure platform is a game authoring tool that allows for the development of 2D educational games, with special focus in *point-and-click* adventures (Moreno-Ger, Burgos, Sierra, & Fernández-Manjón, 2008; Torrente, Del Blanco, Marchiori, Moreno-Ger, & Fernández-Manjón, 2010). It was designed to facilitate the development of educational games by people with little technical background (e.g. educators). It is composed by a What-You-See-Is-What-You-Get (WYSIWYG) game editor used to create the games (see Figure 1), and a game engine that can be distributed following the Learning Object Model to deliver the games to the students (Torrente, Moreno-Ger, Martínez-Ortiz, & Fernández-Manjón, 2009).

The three interfaces evaluated in this work were implemented with the eAdventure platform, which has already been used as a testbed for educational accessible game research (Torrente, Del Blanco, Moreno-Ger, Martínez-Ortiz, & Fernández-Manjón, 2009). The long-term goal is to integrate these accessible interface prototypes in eAdventure so they could be easily configured by game creators. Both author and player would benefit from having alternative interfaces available. The author (e.g. educator) could include several interfaces in a game, and decide which users would use each one depending on the design, special needs of the users, previous experience, etc. The author could also leave this decision to the user, who could choose the interface that she/he prefers. Or it could be the game itself that sets up an easy interface initially and suggests other interfaces as the user progresses and gains expertise and skills (Torrente, Del Blanco, et al., 2009).

The game universe in eAdventure is defined by a number of 2D game scenarios that are interconnected using "exits"; that is, regions of the scene that can be clicked and that transport the player to a different scene (see Figure 1). Exits, along with objects and characters are the basic interactive elements supported by eAdventure. In addition, objects and characters support several types of action verbs (e.g. grab, talk to, use, etc.). Those are the resources the game can supply for puzzle solving.

5. Three Non-Visual Interfaces For Point-And-Click Games

Each non-visual interface prototype developed provides a different experience for game world exploration. For the purpose of this paper, exploration is defined as the process from which the player obtains information

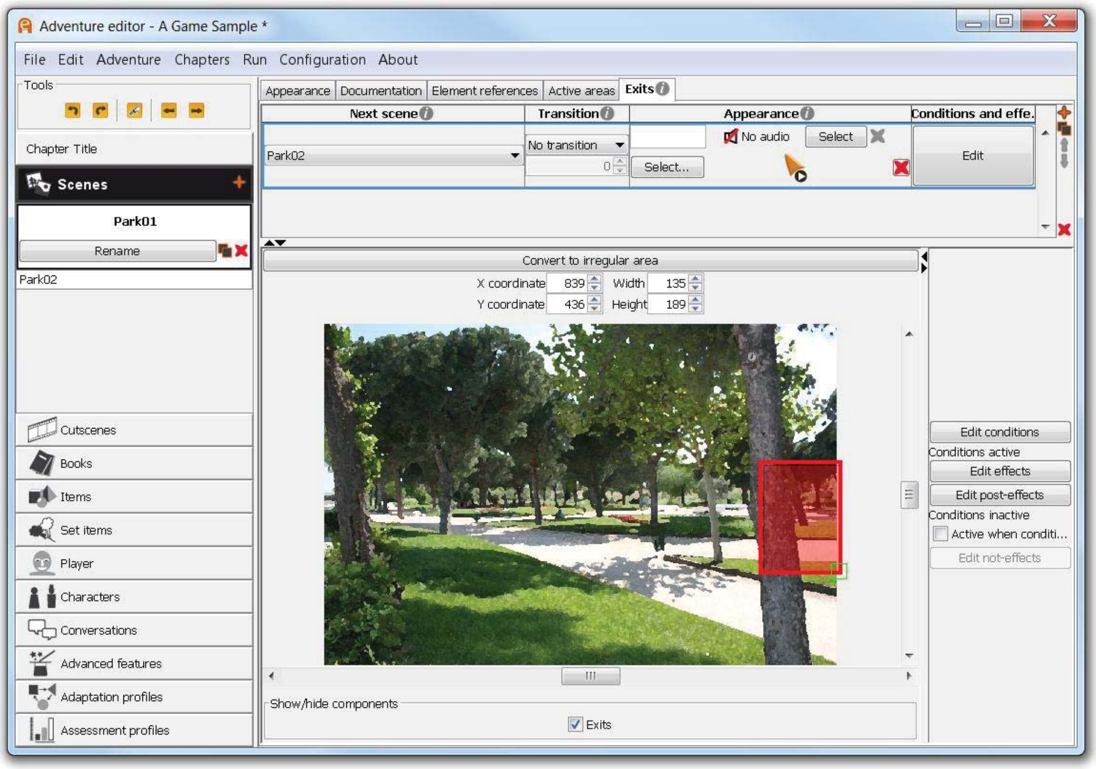

Figure 1. Screenshot of the eAdventure game editor, version 1.5. The red rectangle marks an exit defined on a game scene.

about what are the available interactions on the scene and speculate about the consequences these will have in the game world.

All the interfaces use the same system for providing auditory feedback. Each time the game universe changes an audio message is reproduced using the *eSpeak* free text-to-speech software. This includes changes in the game scenario or any interaction with objects or characters defined in the game. The system is flexible, allowing the game author to define alternative messages and audio clues for each specific interaction depending on the users' performance and progress.

The flexibility of the audio feedback system helps to provide fine-tuned guidance to explore each game scene, keeps the user immersed in the story and contributes to create drama and tension. In these games audio was used to provide a message describing the scene a user is in after every change. The descriptions of these scenes change in each subsequent visit to avoid repeating information provided.

5.1 Cyclical navigation system

With this interface interaction is similar to browsing the web using a screen reader. Available interactions in the scene are structured in a two-level focus cycle that allows moving the cursor between the elements with the arrow keys (see Figure 2). The first level is composed by the interactive elements on the scene (characters, objects, exits, etc.). The second level contains available actions for each element. To access the second level, the user hits the action key (enter). To return to the first level, the user hits the go-back key (escape).

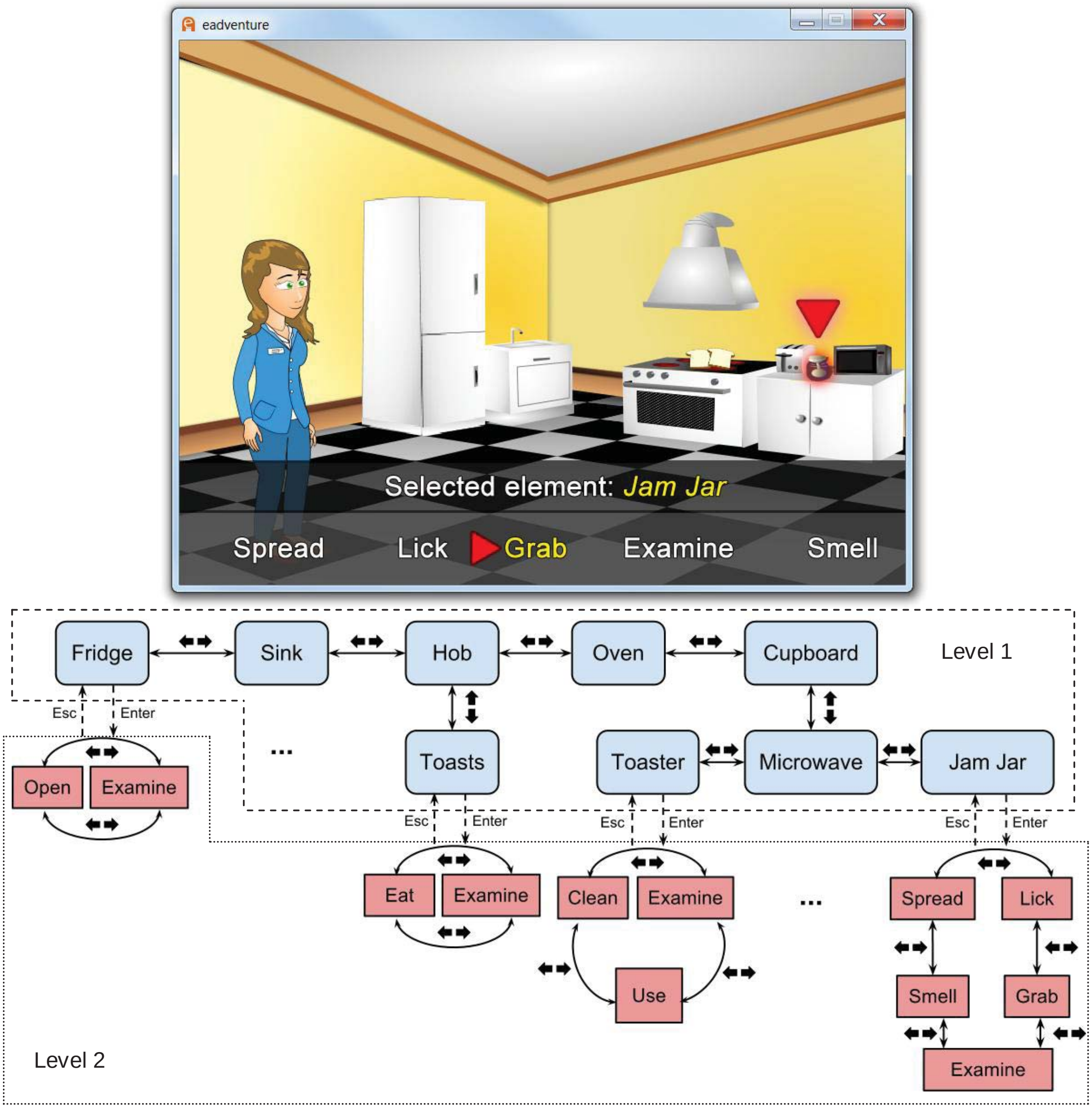

Figure 2. Example of navigation through the elements of a game universe with interface 1 (cyclical navigation system).

This interface was designed to be intuitive, natural and usable for blind users since all actions are accessible within a minimum number of key strokes.

5.2 Sonar

This interface guides the player in finding interactive elements using the mouse instead of the keyboard. A 3D positional audio system is configured for the scene (Vallejo-Pinto, Torrente, Ortega-Moral, & Fernández-Manjón, 2011). This system is inspired by the working of a sonar, which helps submarines detect near objects by listening to the echo of pulses of sound as reflected by these objects. Similarly, in our system each interactive element emits a different sound that can be modified if necessary. The position of the element relative to the mouse cursor is encoded by altering the intensity and pitch of the sound. Depending on the distance of the element to the mouse cursor, the sound is perceived with a different intensity. Pitch is used to provide information about the vertical position of the mouse pointer. High pitch denotes that it is near an element, while low pitch denotes that it is far from it.

When the user hovers the mouse over an element, a confirmation is again provided by means of a sound. The user can also activate or deactivate the sonar with the space bar to limit acoustic fatigue. If the game is played in non-full screen mode, a special sound is emitted when the mouse cursor accidentally exits the game window boundaries. The mouse is relocated to the center of the screen each time the scene changes.

5.3 Natural language commands interface

With this interface interaction is articulated through short text commands expressed in natural language that the user needs to type. After the command is introduced, the system tries to interpret it and match it to one of the available interactions in the scene, using a regular grammar that defines the structure of the supported commands and a list of synonyms. This system is further described in a previous work (Torrente, Del Blanco, et al., 2009). The user receives audio feedback about the results of this matching and if it succeeds the interaction is triggered.

The feedback after each successfully or failed command is introduced can be modified by the game author. By default, the system will return a random message (e.g. "Ummm ... I'm not sure what you mean" or "I think rather not to do so") depending on which rules of the grammar caused the mismatching. However, it is possible to use the audio feedback system to provide hints if further guidance is required.

In contrast to the cyclical navigation interface (described in section 5.1 and shown in Figure 2), in this case the interactions available are not obvious to the user. Instead, the player has to find them out by try-and-error of different commands.

This interface also supports a list of special commands:

- **“actions”**: reminds the user all interactions that he/she had previously discovered in the scene.
- **“describe scene”**: provides audio feedback with settings of the scene, combining an optional message introduced by the game author and a summary of the elements presented (e.g. there are two exits, an object near character A, etc.).
- **“help”**: provides hints and interaction instructions.

6. End-user Evaluation

6.1 Participants, Method and Settings

Three games were set up with a different interface each. The games were play-tested by four mid age blind users (3 men and one woman from 28 to 36 years old).

Users #1 and #4 were used to play or have played adapted games intensively in the past. For the sake of simplicity, we refer to these users as *frequent gamers*. One user reported playing mobile games on his iPhone very often, and adapted games or audiogames on his computer (e.g. Papa Sangre, games from AudioGames.net, etc.). The other user said that he had quite a lot of experience with adapted games in the past. He used to play online role playing games although, as he claimed, he did not have the time to play anymore.

In contrast, users #2 and #3 had little experience playing games. In this section we refer to these users as *occasional gamers*. One declared himself a casual gamer having little gaming habits actually. He had played a few adapted PC and mobile games in the past but he does not usually play games at the moment. The other user reported having almost no taste for games, and she had played only a few in her life.

Two aspects were being analyzed:

a) Usability, defined as the ability of players to explore the game scenes, find interactive elements and trigger desired interactions without finding barriers;

b) Entertainment value provided, defined as the ability of the interface to make the game interesting and appealing to the user.

Two researchers were present during each test: one welcomed and helped users to get started while the other monitored users' activity. The sessions were video recorded for the analysis of the completion times and the number of interactive elements used and scenes visited. We used these numbers as a heuristic to estimate how successful each interface was in guiding users to explore the game universe.

Users completed the evaluation in individual game-play sessions of 60 minutes. They were exposed to each game for about 10-15 minutes on average, and they were asked to provide feedback and rate the usability and entertainment provided by each interface using a 7 point Likert scale. Finally they were asked to identify what interface is the best for point-and-click conversational adventure games, according to their opinion.

6.2 The Games

The games used in the evaluation share a uniform design, having similar number of scenes, objects, game mechanics and stories. Each game universe had 3 to 4 scenes and 7-10 interactive elements. Figure 3 shows the composition of each game world.

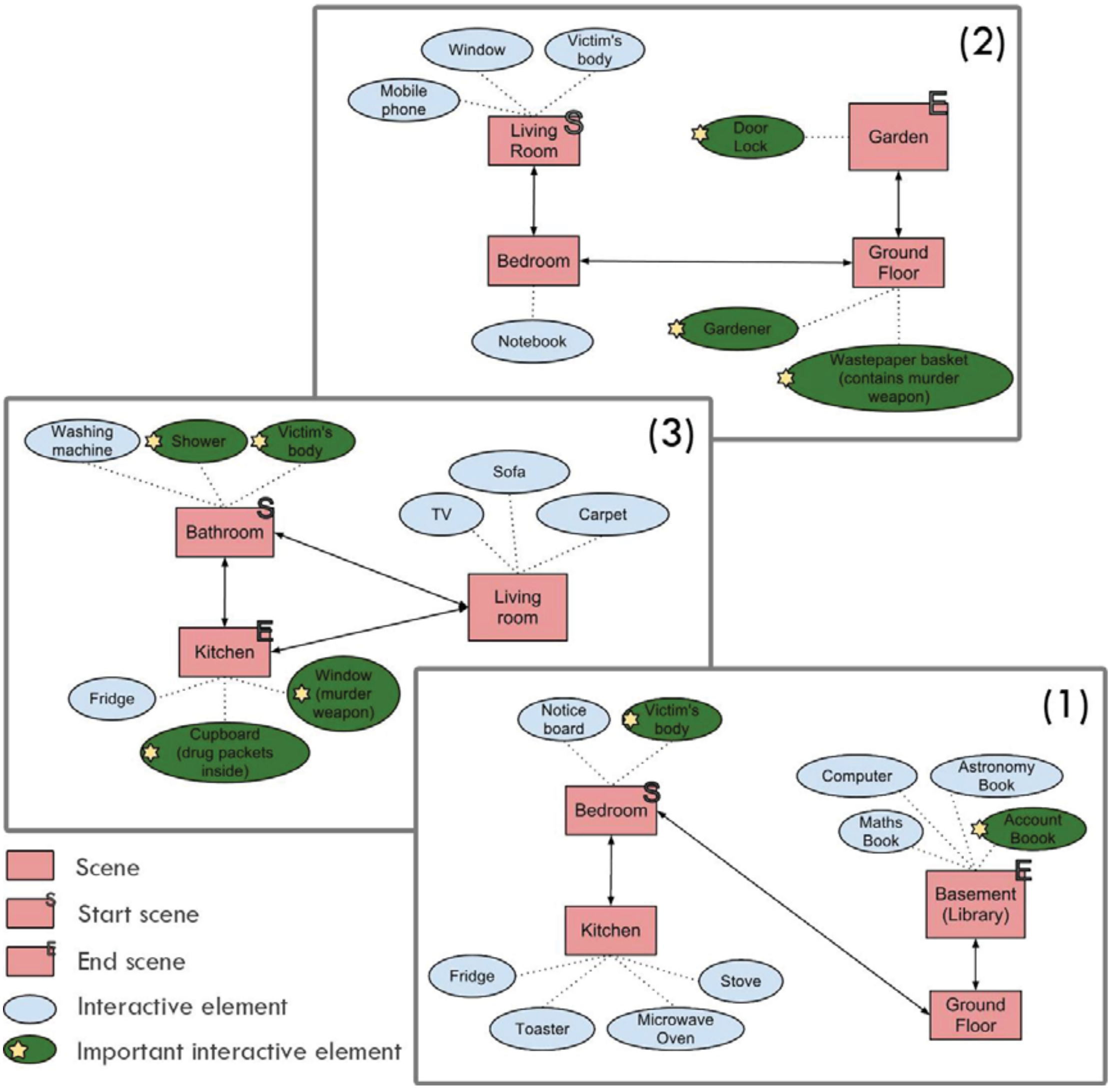

Figure 3. Game Universe of each interface (1) Navigation system, (2) Sonar, (3) Natural language commands.

In each game the player is set out to solve a crime. The game mechanics are simple: the user has to inspect the crime scene and surrounding areas, finding and collecting evidences. The game finishes when all the evidence items are collected and the mystery is solved.

For each interactive element there is one action available. For example "examine body", "inspect stove" or "read book". After interacting with some of the elements in the scene a new clue is revealed. Some of them are deliberately designed to confuse the player, making the crime more difficult to solve as a mechanism to keep user's interest.

Each game starts with a short explanation of the crime scene and basic instructions about the interaction. For example, game 1 begins with this brief note: *"Paula Suárez, 55 years-old, found dead in her bedroom. No signs of forced entry."* (see Figure 4). In short, to complete this game the player has to navigate from the bedroom to the basement (see Figure 3), find her company's account book and read it. Then the plot is unveiled - Paula discovered that a colleague was stealing from the company and the thief decided to murder her to silence the affair.

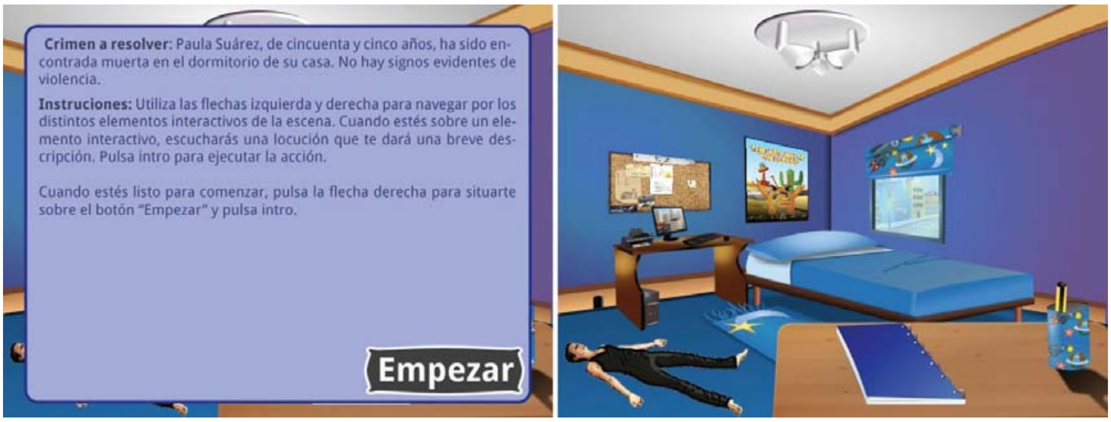

Figure 4. Screenshots of introduction and first screen in game 1.

6.3 Results

6.3.1 Metrics

Most of the users were able to complete the mini-games. Four users played games 1 (keyboard navigation interface) and 2 (sonar). Due to logistic problems, game 3 (conversational interface) was only played by two users.

All users who played game 1 (4) completed it and found the answer to the riddle that was set out. They needed 3:21 minutes on average (2:54 min, 3:48 max). All of them visited the four scenarios of the game at least once. They interacted with 6 elements out of 10 (60%) at least once on average.

3 out of the 4 users who played game 2 were able to complete it. These three users needed 6:54 minutes on average (6:17 min, 7:21 max). All of them visited the four scenarios of the game at least once. They interacted with 4 elements out of 7 (57.14%) at least once on average.

Game 3 was played by 2 users, who also completed it in 4:19 and 4:34 minutest respectively. They visited 2 scenarios out of 3 at least once and interacted with 6 or 7 elements out of 9 at least once.

6.3.2 Perceived usability.

At the end of each play session users were asked to rate the usability of the game interface. A 7 point Likert scale was used (1=very hard to use, 7=very easy to use). Table 1 provides all ratings collected for the four users. All users (4) agreed that interface 1 (keyboard cyclical navigation system) was the most usable (6.75 on average). There was not much difference for interfaces 2 (sonar - 4.75) and 3 (conversational - 5.25).

Table 1. Usability ratings provided by each user (1=very hard to use, 7=very easy to use)

	User #1	User #2	User #3	User #4	**Average**
Interface 1	7	6	7	7	**6,75**
Interface 2	3	5	5	6	**4,75**
Interface 3	5,5			5	**5,25**

6.3.3 Perceived entertainment value

Users were also asked to rate the entertainment value of game interface using a 7 point Likert scale (1=not fun at all, 7=very fun). Since all games were similar in content, mechanics, story and duration, we assume differences in scores achieved can be attributed to the use of a different interface. Table 2 shows all data collected for each user. 3 out of 4 users rated interface 2 (sonar) as the most fun (6 on average). Interface 3 is the next with higher ratings (5.5 on average). Finally 2/4 users rated interface 1 (keyboard navigation) as the less fun (4.75 on average).

Table 2. Entertainment ratings provided by each user (1=not fun at all, 7=very fun)

	User #1	User #2	User #3	User #4	**Average**
Interface 1	4	6	3	6	**4,75**
Interface 2	6	5	6	7	**6**
Interface 3	5			6	**5,5**

6.3.4 Final user recommendation

Finally users were asked to identify the best interface for point-and-click conversational games like those evaluated, according to their opinion. It is remarkable that some users argued that the three interfaces could be applied in games, depending on the target audience, the context, and the game design. However, frequent gamers (users #1 and #4) leaned towards interface 2 (sonar). They were both very convinced about their recommendation and provided some reasoning to back up their choice. For example, user #4 voiced that the sonar interface (game 2) is the best because it makes it more attractive. He considered that it is better than the conversational interface, which makes the game have a bit of the taste of old-style conversational games around the 80's. He dislikes the arrow interface a little bit because it is "too cyclical and predictable".

In contrast, occasional gamers (users #2 and #3) preferred interfaces 1 (keyboard navigation) and 3 (conversational) respectively. For example, user #3 expressed that, for her, interface 3 (natural language commands) was probably the best, because it is more interactive and fun than interface 1 (web-like navigation) but it is easier to use than interface 2 (sonar).

6.3.5 Technical errors and usability flaws identified

Researchers identified several technical problems and design flaws thanks to the play sessions. In game 1 (keyboard navigation) users complained about two issues, especially the frequent gamers. First, the feedback system (based on a text-to-speech layer) could be gauged to allow faster navigation. Sometimes descriptive sounds overlapped if the user browsed from one element to the next one very quickly, or if there was only one interactive element in the scene, making it hard to understand new information being given. As a consequence, frequent gamers could not navigate through the elements as fast as they would like to. Second, users found the interface too cyclical and predictable. They would have appreciated a more complex way to structure the information (having more levels of aggregation added to the navigation graph).

In game 2 (sonar), the text-to-speech system occasionally failed to reproduce the name and brief description of an interactive element when the mouse hovered over the same element two consecutive times. This was caused by a technical bug in the text-to-speech layer that was only noticeable in interface 2 (sonar), as it was impossible to visit the same element twice in interface 1 (keyboard navigation). Interface 3 (conversational) used a different strategy to give feedback to the user.

The sonar also presented other interaction problems. Sound emitted by all the interactive elements was very similar. Users were able to distinguish the source of the sounds in most scenes with 2 or 3 interactive spots. In the dining room, which has 4 interactive spots, users had more problems. In this regard, one of the users proposed using variations in the timbre and intermittency of each source of sound to facilitate distinguishing each source more easily.

Some users had problems with mouse clicks over interactive elements. Sometimes the mouse shifted involuntarily as a consequence of lifting a finger to press the left button. The system did not provide any feedback, leading the user to click in a spot that did not trigger the interaction expected. This usability issue could be addressed by playing a simple audio effect when this happens.

As a minor issue, some users were unpleased to have to activate the sonar manually after each scene transition. While this behavior was designed to prevent acoustic fatigue, it became an annoying inconvenient for a couple of users.

Some users complained about the difficulty of remembering all the commands for interface 3 (conversational). Researchers observed many situations where the user knew what to do to go on in the game, but she/he was unsuccessful because the system did not recognize the command formulated. As a consequence, users had to memorize some of the commands. Researchers identified that it was necessary to add flexibility to the syntactic processor that analyzes each sentence the user inputs. Also the number of synonyms included in the thesaurus had to be increased.

Figure 5. User interacting with interface 3 (sonar).

6.3.6 Discussion.

The methodological flaws and small scope of this quasi-experiment limits the strength of the findings we can infer. But the eloquence of the evidence collected at least allows us to draw some promising conclusions and make recommendations that should be backed up with further research in the future.

Data suggest that interface 1 (keyboard navigation system) is the most effective in guiding users through the exploration of the game world. Game 1 has the smallest average completion time, and all the users were able to complete the game quickly. Also researchers observed that users could iterate through all the elements very quickly. Users also agreed in rating interface 1 as the most usable (6.75/7 on average). This confirm the initial hypothesis, since it is similar to the interface of a website adapted with a screen reader, which is a kind of interaction blind users are familiar with. However it suggests this interface is not very engaging, given that as the actions are obvious to the player it turns exploration into a trivial process.

But it is also clear that interface 1 was the less fun for the users. It is a very usable interface as it is very simple. However, in games simplicity can turn into a disadvantage if it causes the game fail in providing the player with appropriate challenge, which is necessary to maximize engagement (Chen, 2007). This was the case of users with more gaming habits, who found the first interface boring because their skills surpassed by far the challenge the game sets out.

The most entertaining interface seems to be number 2 (sonar), which achieved the best user rankings (6 on average). Frequent gamers especially appreciated the interface for introducing fresh ideas, like using the mouse as input device, which is unfamiliar to them. Occasional gamers also found the interface enticing. However, it is also the more complex interface. Game 2 required more time from the users to complete it, compared to games 1 and 3. Researchers also observed that users needed full concentration to explore the game universe. This reflects that the sonar interface poses a cognitive load to the user that is significantly higher than the other interfaces. As users were exposed to this type of interface for a short time, it is not clear if symptoms of fatigue could appear in a longer session, which could yield to different conclusions.

It is remarkable that the three interfaces achieved good results in overall. As a consequence, we may say that the three could be used for this type of games. The best choice depends on the context and target audience.

7. Conclusions and Future Work

Game accessibility is still a young discipline in the field of human-computer interaction and universal design. In recent years movements advocating towards policies that allow people with disabilities to play digital games have risen. As a result general guidelines to make accessible games are now available (Bierre et al., 2004; Game Accessibility Guidelines, 2012; Grammenos et al., 2007). But research in the field is still incomplete, needing further investigation on how to create games that are usable and engaging for people with disabilities, or how to adapt existing games for such purpose. This research should also cater for diversity. Game play is a unique and personal experience that can be influenced by multiple factors. Therefore personal characteristics and background should be taken into account when designing an accessible game interface in order to deliver user experiences that are meaningful for each player. Dealing with diverse backgrounds is especially relevant when digital games are used in education, as students with very different gaming experience, prior experiences and skills coexist in the same group.

This paper presents a small quasi-experiment that explores three different interfaces for educational computer games. The interfaces were developed for blind people as specific target audience. The goal was to compare the perceived usability, engagement and overall experience provided by each interface for players with different gaming habits. Evidence collected suggest that players' preferences towards game interfaces varies depending on their previous gaming habits. While users with less experience tend to lean towards interfaces that are similar to web interfaces, frequent gamers prefer innovative interfaces because they pose a new challenge for them.

Several limitations of the research constrain confidence in the conclusions drawn. The games used for evaluating the interfaces were very short (around 10 minutes of completion time). Besides, the sequence in which the games were presented to each participant in the evaluation was not randomized. The reduced number of participants is also a limitation, but it is very difficult to recruit players from this target audience. Besides, although a 'think aloud' protocol was set out for the evaluation of the interfaces in order to enhance the amount of data collected, users were not very communicative, hindering our chances to make a qualitative analysis. All in all, this work can be considered the beginning of a promising research line, but further evaluation should be conducted with more and longer games involving more users and using a more rigorous research method.

These three interfaces could be scaled and repurposed for many game genres and other interactive Rich Internet Applications, albeit they were designed for *point-and-click* adventures. They could also be shipped along with mainstream game engines and authoring tools. This would require a considerable effort to make the interfaces more scalable, but it would help to increase the level of accessibility of the games by reducing the effort and cost required and raising visibility and awareness among developers (Torrente, Del Blanco, et al., 2009).

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7.10. Reusable Game Interfaces for People with Disabilities

7.10.1. Cita completa

Javier Torrente (2012): **Reusable Game Interfaces for People with Disabilities**. The 14th ACM SIGACCESS International Conference on Computers and Accessibility, 22-24 October 2012, Boulder, Colorado. **[Trabajo ganador del primer premio del *ACM Microsoft Student Research Competition* celebrado en el congreso]**.

7.10.2. Resumen original de la publicación

Computer games are a very popular media today, spanning across multiple aspects of life, not only leisure but also health or education. But despite their importance their current level of accessibility is still low. One of the causes is that accessibility has an additional cost and effort for developers that is in many cases unaffordable. As a way to facilitate developers' job, this work proposes the creation of specialized tools to deal with accessibility. The hypothesis defined was that it was possible to produce tools that could reduce the input needed to adapt the games for people with special needs but achieving a good level of usability, resulting in a reduction of the cost and effort required. As game development tools and approaches are heterogeneous and diverse, two case studies were set up targeting two different platforms: a high level PC game authoring tool, and a low-level Android game programming framework. Several games were developed using the tools developed, and their usability was tested. Initial results depict that high usability levels can be achieved with a minimum additional input from the game author.

Reusable Game Interfaces for People with Disabilities

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ABSTRACT

Computer games are a very popular media today, spanning across multiple aspects of life, not only leisure but also health or education. But despite their importance their current level of accessibility is still low. One of the causes is that accessibility has an additional cost and effort for developers that is in many cases unaffordable. As a way to facilitate developers' job, this work proposes the creation of specialized tools to deal with accessibility. The hypothesis defined was that it was possible to produce tools that could reduce the input needed to adapt the games for people with special needs but achieving a good level of usability, resulting in a reduction of the cost and effort required. As game development tools and approaches are heterogeneous and diverse, two case studies were set up targeting two different platforms: a high level PC game authoring tool, and a low-level Android game programming framework. Several games were developed using the tools developed, and their usability was tested. Initial results depict that high usability levels can be achieved with a minimum additional input from the game author.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, graphical user interfaces (GUI), natural language, screen design*;

Keywords

Accessibility, audio 3D, eyes-free games.

1. BACKGROUND AND MOTIVATION

Computer and video games have became a very popular kind of media, being part of modern culture. Besides, current uses of games have escaped the boundaries of leisure, as they are being applied to improve education [4], for advertising or health [1].

But games can be a significant source of digital divide, as their current level of accessibility is low, with a small number of titles coping with the needs of people with disabilities [6, 7]. The improvement of accessibility in games should be a priority to prevent the exclusion of a broad sector of our population from the ever-growing number of activities related to digital games.

The poor level of accessibility is not motivated by a single cause. Nevertheless, one of the most important is that improving game accessibility has a cost for developers, not only in economic investment but also in time and effort. From a technical perspective, accessibility increases the development time as new modules have to be created, such as in-game screen readers or speech input processing units. Moreover, from a design perspective accessibility demands dealing with alternative interaction paradigms or adapting parts of the content. Game developers live under great pressure as they are immersed in a highly competitive and risky industry where the production of each title requires huge investments. From this perspective, accessibility is unlikely to get to the top on their priority list.

Hence one of the approaches to improve the accessibility of games is to make dealing with accessibility easier for developers. If the cost of introducing accessibility is low in economic terms, but especially in effort and time needed, the chances of accessibility would raise substantially.

Tools to support developers should be created, not to be distributed as independent products, but integrated into the development environments developers use every day (e.g. Unity or Eclipse). Thus impact achieved would be maximum.

Ideally, tools provided for developers should automate design and implementation tasks related to accessibility. For example, having alternative interaction modules that can be configured for players with different abilities and integrated into the games with minimum effort would be a valuable asset for developers.

But to get to that point it is necessary to reach a higher level of abstraction and generalization of current game accessibility design guidelines [3, 7]. A growing body of research is exploring how to make games more accessible [6], but solutions proposed are usually focused on particular examples and they do not scale easily to fit other titles. It is necessary to conduct research that, building upon recent breakthroughs and successful stories on game accessibility, comes up with accessible interfaces that are general enough to be reused for different games but specific enough to be implemented into mainstream game creation tools.

An additional challenge comes from the diversity of environments and tools used by game developers, such as high-level authoring tools for creating levels or scenarios, where visual interfaces predominate, or low-level programming environments and libraries where code is the key. For example, tools like Unity or Eclipse can be used for game development, but they have very different characteristics.

The goal of the work presented was to investigate accessible interfaces that could be integrated into game development tools of different kind. First, several configurable interfaces were developed for a serious games authoring tool with a very high level of abstraction. Second, a low level programming library was developed for accessible mobile games.

2. HIGH-LEVEL APPROACH: A SERIOUS GAMES AUTHORING TOOL

The first approach was centered on the eAdventure game authoring tool [5, 8]. This tool is oriented to educators so they can create their own educational games. The tool interface is simple, with a high level of abstraction as programming is completely hidden from the end user. The strategy used in eAdventure to

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reduce the complexity of the tool is to narrow the type of games that can be produced to a limited number of genres. As opposed to more complex tools, like Unity, which allows development of a wide range of games, eAdventure allows development of only 2D, single player, adventure games.

Besides, many aspects of the games are preconfigured, although the user can perform some tweaks. This is the case of the interaction. By default, interaction is point-and-click, and these are the controls used:

- Mouse movements to explore the scene. When an interactive element is found, visual feedback is provided (the mouse pointer changes and a brief text is displayed).
- Mouse left button clicks: trigger interactions with some elements or makes the player's character move to the given location.
- Mouse right button clicks over interactive elements: display a contextual menu with available actions, if more than one.

Three alternative interaction modules that overrode the default point-and-click interaction were developed for eAdventure. These modules targeted three profiles of players: 1) screen reader users (i.e. blind), 2) players with limited vision that use high contrast settings, and 3) players with motor impairments in hands that use voice recognition software. Configuration of the interfaces produced was straightforward as game authors only needed to introduce a few parameters and some additional content as alternative descriptions. The eAdventure accessibility module, using these settings, was able to generate the interfaces required automatically for the game being produced.

These interfaces were evaluated by creating a serious game: "My first day at work". The goal of the game was to facilitate access to the labour market for people with disabilities. The game and its accessible interfaces were evaluated by 15 people with different motor, visual, and cognitive disabilities. In this study two parameters were analyzed for each of the interfaces: usability and enjoyment. Participants played the game for an hour and the sessions were video recorded for post analysis. The videos are currently being examined to complete the study. However, through a preliminary analysis two main findings can be outlined. First, most of the participants were able to complete the game without additional support from researchers, which is an indicator of high usability levels. Second, it seems that enjoyment experienced by participants vary depending on their gaming habits and experience, as participants who played digital games more frequently found the interfaces less appealing.

This suggested that the game experience was different for users with a similar disability but different experience with digital games. Nonetheless, it is unclear if this issue is caused by the interfaces used or by other factors, such as the game story or mechanics. To further explore this aspect, a second case study was conducted. This study targeted profiles of players sharing a common disability but with different gaming experience. The disability profile selected was screen reader users. Three interfaces were developed. The first one allowed interaction through short text commands. The second interface was similar to Web interaction, allowing users to browse through the elements and GUI controls with the arrow keys and use an action key (e.g. Enter) to trigger interactions. The last interface was the most innovative, being a 3D sonar that helped users in locating the elements with the mouse. These interfaces were evaluated by a limited number of users. Initial results seem to confirm the initial hypothesis, as users with higher gaming experience preferred the most challenging interface (the sonar) while novice users preferred the text commands interface.

The main limitation of all the interfaces developed for eAdventure is that they were designed for a specific type of game and could only be used within the eAdventure platform. A similar approach could be applied to other tools, whereas it is inapplicable to games where interaction is a key part of the game experience.

3. LOW-LEVEL APPROACH: ANDROID FRAMEWORK FOR ACCESSIBLE GAMES

As a second approach, a framework was developed to facilitate development of 2D accessible games for screen reader users in mobile devices. Android was chosen as application platform, as at the time of the start of the project it was a less accessible platform than its competitor, iOS. The outcome was a number of libraries and classes that could be integrated into Android game development projects. This framework is available for download from its Google Code repository [2].

Using this framework, four accessible games were produced. Three of them are available at Google Play. Currently the usability and accessibility of the games is being evaluated with end-users.

Compared to approach 1, this solution allows for developing games of different types, as adopting a low level strategy adds flexibility and scalability. While in approach 1 only point-and-click adventure games could be created, with this approach a minesweeper, a point-and-shoot game, a snake-like game and an interactive fiction game were developed. Besides, this approach is less platform dependent, as it could be reused in any Android project while interfaces developed in approach 1 could only be used within the eAdventure authoring tool. However, the cost of producing games in approach 2 was higher as the setup of the interfaces required coding, which is a significant drawback.

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7.11. Supporting Player Diversity: Game Interfaces for People with Disabilities

7.11.1. Cita completa

Javier Torrente (2013): **Supporting Player Diversity: Game Interfaces for People with Disabilities**. Enviado a la fase final mundial (*Grand Finals*)l del *ACM Student Research Competition 2013* (Versión extendida de *Reusable Game Interfaces for People with Disabilities*). Disponible en: http://src.acm.org/2013/JavierTorrente.pdf.

7.11.2. Resumen original de la publicación

Computer games are a very popular media, spanning across multiple areas of life, from leisure to fields such as education. Despite their social relevance, their current level of accessibility is still low. One of the reasons is that the additional cost and effort of accessibility makes it, in many cases, unaffordable. Besides, it is not always clear how to identify and address the barriers that people with disabilities experience playing games without breaking the immersion and engagement provided by the game. In this project we explore whether it is possible to produce tools that reduce the cost and effort needed to adapt games for people with special needs while also delivering an optimum player experience. The ultimate goal is to support the developer in dealing with accessibility issues. Game development is a very diverse activity with different approaches and tools available. To reflect this diversity we targeted two different platforms: an educator-oriented desktop game authoring tool, and a programmer-oriented mobile game development framework. We conducted three experiments using these tools to create games that were then tested by end users with different gaming habits and disabilities. Our approach can be generalized and applied to game interface optimization for wider and more diverse audiences.

Supporting Player Diversity: Game Interfaces for People with Disabilities

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ABSTRACT
Computer games are a very popular media today, spanning across multiple aspects of life, not only leisure but also in other fields such as education. But despite their social relevance their current level of accessibility is still low. One of the reasons is that accessibility has an additional cost and effort for developers that is in many cases unaffordable. As a way to support developers, we propose the creation of specialized tools to deal with accessibility. The hypothesis defined was that it is possible to produce tools that could reduce the cost and effort needed to adapt games for people with special needs while achieving a sufficient level of usability and a pleasant player experience. Because of the ambitious of the approach, the goal of the project is to explore if it is feasible through preliminary research. Three experiments were set up to cover and explore different alternatives, given the diversity of player characteristics and game development approaches. In these experiments we targeted two different platforms: a desktop game authoring tool oriented to educators, and a mobile game development framework oriented to programmers. In these experiments we used the tools developed to produce several games that were also tested by end users. While the project focuses on disability, the ideas proposed can be generalized and applied to support optimizing game interfaces for a wide and diverse audience.

1. PROBLEM AND MOTIVATION
Digital games have acquired extraordinary social relevance, becoming a very popular media in modern culture and life and constituting a massive industry of $16.6 billion per year in the U.S. alone (data from 2011) [5]. The popularity of digital games has resulted in a diversification of gaming, as new profiles of users are constantly starting to adopt gaming habits. This adds a burden for the developer, who needs to produce games that appeal to a wider audience.

Accessibility is one of the dimensions that create player diversity. There is a growing need for delivering game-play experiences that are optimized for users with different functional capabilities, especially in ageing populations (e.g. Western countries). But the current level of accessibility of digital games is low, with a small number of titles meeting the needs of people with disabilities [21, 23]. One of the reasons for this is, again, that dealing with the needs of people with disabilities is complex and involves significant extra work for the people who create the game.

As game development is already a very complex activity, our proposal is to explore how game development software can help the developer deal with player diversity, focusing on accessibility issues. The approach we describe in this project considers the (semi)-automatic adaptation of the gameplay experience depending on the characteristics of the player. The developer creates a base instance of the game, and then uses one or several tools to ensure different players will get the best experience possible. This approach is ambitious as the challenge is significant both from design and technical perspectives, raising two questions. First, it is unclear if the products obtained would be able to meet any quality criteria. Second: it is uncertain to what extent the effort required to produce adapted versions of the game may surpass the benefits in terms of cost reduction. The goal of this project was to conduct exploratory research to determine the actual feasibility of this approach. In summary, the next research questions are set out:

- RQ1: *Can (semi-)automatically generated interfaces deliver pleasant game experiences for a diverse target audience?*
- RQ2: *To what extent can game development software help reduce the cost of dealing with diversity?*

This project also considers other aspects of diversified gaming that have a considerable effect on the developer: the diversity of gaming platforms, development approaches, and applications.

As a limitation, this project only considers adaptation of the game interface. Adaptations related to the game design, content or flow are left out of the scope. As a result, only physical disabilities are considered, as barriers found by players with cognitive disabilities are usually related to those aspects.

2. BACKGROUND AND RELATED WORK

2.1 The Diversification of Gaming
This increased popularity of gaming is resulting in a diversification of the players. Segments of the population that did not use to show frequent gaming habits are now present in digital game usage figures. For example, in 2006 [6] gamers were unevenly distributed between males (62.0%) and females (38.0%), while in 2012 the difference has trimmed almost to zero (53% males, 47% females) [5]. The population of gamers is ageing as well. In 2011 29% of gamers were over the age of 50, in contrast to the 19% this segment represented in 2004 and the 9% in 1999 [7].

Gaming is also experiencing a *diversification of platforms*. Mobile devices have managed to capture a significant market quota and gaming devices are constantly evolving. Finally, there is also a *diversification in the application* fields where games are used. Currently digital games are not only being used for entertainment, but also in education [11], for advertising or health [2]. For the developer, this makes more difficult to get the player engaged.

2.2 The Importance of Accessibility
Accessibility is no longer a problem that affects a minority of the population. Instead, considering accessibility in the inception of the design of any product or technology may favor us all, especially in Western countries where populations are ageing

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rapidly. The same features that enable using a computer for a person with limited vision could help us when we get old. There are also environmental or contextual factors where anyone could take advantage of accessibility features. For example, in a noisy environment or when a headset is not available, a user can take advantage of having films subtitled. There are data available to support this claim. According to [12], *"57 % of computer users in the US ranging from 18 to 64 years old (74.2 million) are likely to benefit from the use of accessible technology due to disabilities and impairments that may impact computer use"*.

One of the main challenges of dealing with accessibility requirements is that the needs of users vary a lot depending on the type of disability. This makes it more difficult to propose holistic approaches that tackle more than a single profile of disability.

2.3 Game Development: Tools And Approaches

Game development tools and approaches have evolved as a response to the diversification of gaming. Currently there are a wide range of tools for all sorts of games and audiences, allowing not only professionals but also people without a lot of resources or a deep technical background to create their own games. For example, simple tools like *Scratch* [13] or *Game Maker* [15] were designed to be used by students, as a way to learn programming through game development in a highly visual, user-friendly environment. Other tools, like *GameSalad* or *Unity*, support enthusiastic developers to create their own games with a high level of autonomy and independence. There are even tools that enthusiastic teachers can use to create simple educational games for their students.

These scenarios have little in common with the development of AAA commercial games that cost millions of dollars, involve teams of hundreds of developers and take years to create, which are supported by professional toolkits that are much more complex (e.g. *Unreal Engine*). But in none of these cases game development is a straightforward activity. And in none of them accessibility is the main concern for the creator of the game. For that reason, these tools should facilitate dealing with player diversity in general and accessibility in particular as much as possible. However, there are few tools in the market that integrate accessibility features, and tend to be experimental rather than mainstream. For example, in [20] a framework that supports dynamic game adaptation for people with cognitive and physical disabilities is described. In [16] a framework for authoring interactive narrative-based audio only adventure games is presented.

2.4 Approaches to Game Accessibility

A growing body of research is exploring how to make games more accessible [21]. Advocators and communities of disabled users are producing guidelines that provide orientation and raise awareness among game developers [9, 23]. Accessible games have also been developed for different types of disabilities, integrating novel interaction techniques. For example, in [8] an action game developed for blind gamers is described. [14]. In [17] speech and humming interfaces are used to make a Tetris game accessible for people with limited mobility of their hands. In other cases, existing games are adapted for a specific type of disability. For example, in [1] the adaptation of the popular *RockBand* game for blind users is described. Another example is *Half Life 2*, that was fully captioned after the prequel (*Half Life*) was criticized for providing essential information to complete the game only through audio [10]. However, the solutions proposed are usually focused on a particular game and one or two types of disability, which makes it hard to scale the solutions proposed.

3. APPROACH AND UNIQUENESS

We have conducted three different experiments to answer our research questions. In these experiments we explore different aspects of gaming that contribute to diversity:

- *Player diversity*: We consider players with different accessibility requirements and also with different gaming habits (in one of the experiments).
- *Platform diversity*: We have explored both desktop and mobile games.
- *Application field*: In two experiments we considered educational games, where in the third experiment we addressed purely recreational games.
- *Development approach*: We explored two different ways of creating games. In the first two studies we used a high-level authoring tool for point-and-click educational games. In the third study we created a framework for mobile accessible games. In the first case the software created targets game authors with a low technical profile (e.g. educators) while the second case targets game programmers.

Figure 1 provides an overview of the three studies and how they cover the aforementioned four aspects.

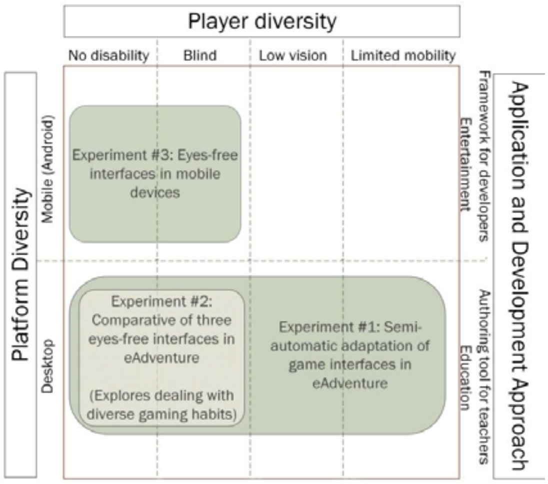

Figure 1. Scheme with the three experiments conducted and how they cover diversity of players, game development approaches, and platforms.

3.1 High-Level Approach: A Serious Games Authoring Tool

Our first approach was centered on the eAdventure game authoring tool [4, 18]. This tool is oriented to educators, allowing them to create their own educational games. The tool interface is simple, with a high level of abstraction as programming is completely hidden from the end user. The strategy used in eAdventure to reduce the complexity of the tool is to narrow the type of games that can be produced to a limited number of genres. As opposed to more complex tools, like *Unity*, which allows development of a wide range of games, eAdventure allows development of only 2D, single player, adventure games.

Besides, many aspects of the games are preconfigured, although the user can perform some tweaks. This happens also with the interaction settings. By default, interaction is *point-and-click*, and these are the controls used:

- Mouse movements to explore the scene. When an interactive element is found, visual feedback is provided (the mouse pointer changes and a brief text is displayed).
- Mouse left button clicks: trigger interactions with some elements or make the player's character move to the given location.
- Mouse right button clicks over interactive elements: display a contextual menu with available actions, if more than one.

3.1.1 Experiment #1: Diverse disability profiles

Three alternative interaction modules that overrode the default point-and-click interaction were developed for eAdventure. These modules targeted three profiles of players: 1) screen reader users (i.e. blind), 2) players with limited vision that use high contrast settings, and 3) players with motor impairments in hands that use voice recognition software.

Both blind users and users with limited mobility experience problems operating *point-and-click* devices, either due to the lack of missing feedback or to the lack of fine motor control. The adapted interfaces allowed blind users to introduce commands using the keyboard, while users with a motor disability use speech-recognition to achieve the same goal.

In both cases, players formulate short commands in natural language: (e.g. "grab the notebook" or "talk to the character"). An interpreter reads the commands, executes them if they pass a syntactic and semantic validation, and provides suitable feedback using the appropriate channel (auditory for blind users through a built-in text-to-speech engine, and text for users with limited mobility).

Command processing is driven by a grammar that defines valid commands, combined with a list of synonyms for relevant verbs (actions) and nouns (interactive elements) that includes built-in synonyms for common words (e.g. "use", "grab", "talk") and synonyms specified by the game author for each game element. The grammar is automatically generated from each game description, based on the game actions defined for each of the interactive elements available in each game scenario. An additional set of game-independent vocabulary provides access to always-available interactions such as opening menus, skipping dialogue lines, or exiting the game altogether.

Major barriers for low vision users are related to having interactive elements that blend into the background or elements and fragments of text that are too small. Additionally, color-blindness can result in nominally different colors blending into each other, and is especially problematic when color is used to encode important attributes.

We use a number of strategies to address these barriers. First, text size and small game elements are significantly enlarged. Second, a special rendering mode is used to improve the contrast of interactive elements over game-scenario backgrounds, applying a strategy similar to the high-contrast mode found in Terraformers [22]. We increase the luminosity of interactive elements using a light green filter, and add a dark purple filter to all other areas, decreasing their brightness. Font sizes and colors used for cursors, buttons and menus are also adapted automatically.

The system was built to be as easy to configure as possible. Game authors were only required to set up a few parameters and some additional descriptions for blind users. Optionally, and depending on the game, the author must also provide alternative versions of the art resources used to adapt the interface for users with low vision. The eAdventure accessibility module, using these settings, adapted the interfaces depending on the requirements of the player.

These interfaces were evaluated by creating a serious game: *My first day at work* (Figure 2). In this game, the player adopts the role of a person with a disability that is hired by a company. To complete the game, the player has to fulfill several assignments that allow him or her to get familiarized with colleagues and equipment. The game was developed in collaboration with experts in usability and accessibility from *Technosite* (ONCE group) and it was set up with the three interfaces described above.

Figure 2. Snapshot of the game "My First Day at Work".

3.1.2 Experiment #2: Diverse player preferences

A second experiment was conducted to explore game interfaces optimized taking into account the gaming habits of the user. As opposed to recreational gaming, in education the player does not choose to play, as it is one of the activities defined by the teacher. In this regard, it is necessary to produce educational games that appeal to avid gamers and also to students with little interest in games.

This study targeted profiles of players sharing a common disability (blindness) but with different gaming experience. Three interfaces were developed. The first interface was similar to Web interaction, allowing users to browse through the elements and GUI controls with the arrow keys and use an action key (e.g. Enter) to trigger interactions. The second interface was the most innovative, being a 3D sonar that helped users in locating the elements with the mouse. The third interface allowed interaction through short text commands [19].

3.2 Experiment #3: Android Framework For Mobile Accessible Games

As a second approach, a framework was developed to facilitate creation of 2D accessible games for screen reader users in mobile devices. Android was chosen as the application platform, as at the time of the start of the project it was a less accessible platform than its competitor, iOS. The outcome was a number of libraries and classes that could be integrated into Android game development projects. This framework is available for download from its Google Code repository [3].

Using this framework, four accessible games were produced. Three of them are available at Google Play. Compared to the previous approaches that focused on the eAdventure platform, this solution has advantages and disadvantages. On the one hand, it allows for developing games of different types, as adopting a low level strategy adds flexibility and scalability. While in the previous approach only point-and-click adventure games could be created, with this approach a minesweeper, a point-and-shoot game, a snake-like game and an interactive fiction game were developed. Besides, this approach is less platform dependent, as it could be reused in any Android project while interfaces described in section 3.1 could only be used within the eAdventure authoring tool. However, the cost of producing games increases as the setup of the interfaces required coding, which is a significant drawback. Besides, the software does not provide explicit guidance on how to make use of the accessibility features, which are just provided in the aim of being useful and its eventual use is left at the solely discretion of the developer.

4. RESULTS AND CONTRIBUTIONS

End-user evaluation was conducted in the three studies. An overview of the results obtained is provided in section 4.1. This helps us to answer the first research question: "Can (semi-) automatically generated interfaces deliver pleasant game experiences for a diverse target audience?". A discussion of the impact that dealing with player diversity had on the game author is also provided in section 4.2. These results will help us answer research question 2: "To what extent can game development software help reduce the cost of dealing with diversity?". Finally in section 4.3 we discuss how this project has contributed to the field of gaming in particular and Human-Computer Interaction in general.

4.1 End-User Evaluation

In the three studies an end-user evaluation session was conducted. In the first study (multiple disabilities, eAdventure platform) 9 users with different disabilities (3 with low vision, 3 blind, 3 with limited mobility) were recruited and played the game "My First Day at Work" in a controlled environment for 60 minutes. 5 users with no disability were also recruited as a control group.

In the second study (eyes-free interfaces, eAdventure), four middle-aged blind users with different gaming habits were recruited. They played three mini-games that were setup each with a different interface in a controlled environment.

In the third study (eyes-free interfaces, mobile games) evaluation is being conducted online. Three of the four games developed were published on the Google Play market on June 2012. A Likert end-user questionnaire was integrated in each game and responses are being collected. By April 2013 70 responses have been collected. 30 of the users reported to be legally blind; 8 reported to have low vision and 32 reported to have no visual disability.

All users recruited in the first and second studies were volunteers, which may have introduced noise in data collected. Recruitment may also have been biased study 3 as researchers have no means to verify the disabilities reported by the users.

4.1.1 eAdventure - My First Day at Work

In this study the end-user questionnaire had 9 Likert 4-point items. These items were oriented to rate aspects of the gameplay experience (e.g. Was it fun? Was it frustrating?) and the usability of some aspects of the game (Was sufficient guidance provided? Were texts appropriate? etc.). 7 of the 9 items showed strong correlation (Cronbach's alpha test: 0.905) and were added up to generate a scale ranging from 7 to 28. Results were compared across types of disabilities (see Figure 3). The group of users with no disability was used as a control group.

Responses collected from blind users and users with low vision were similar to the control group (medians: 20.00, 21.00 and 23.00 respectively; means: 20.00±5.66, 20.67±6.51 and 21.20±3.42). In contrast, users with reduced mobility scored significantly lower (Median: 17.00, Mean: 19.33±6.81). This difference is attributed to the speech recognition software used, which had produced unexpectedly low accuracy rates during the evaluation session, making users frustrated. Blind users and users with low vision also found barriers while playing, but they were able to overcome them and they had a minor impact on their play experience.

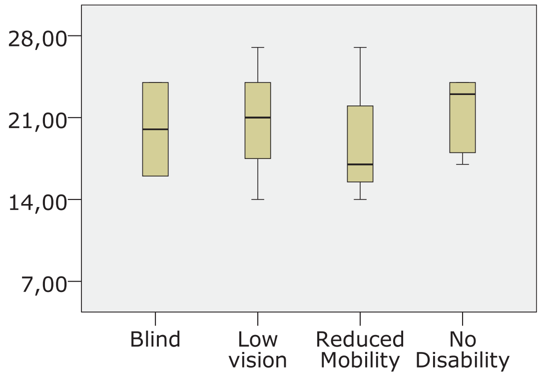

Figure 3. Boxplot with results of the end-user questionnaire for the interfaces developed in eAdventure for users with different disabilities. Vertical lines show min and max values. Boxes represent results between percentiles 25 and 75. Median is marked inside each box.

4.1.2 eAdventure - Eyes-free interfaces

In the second study, blind users were simply asked to rate using a 7-point Likert format the easiness of use and fun provided by the three game interfaces (keyboard navigation, sonar and conversational). They were also asked to elaborate on their decisions. For the users, the easiest interface was the first, but it was also the less fun. Surprisingly, they considered the sonar interface the most fun.

Table 1. Summary of data collected for each of the eyes-free game interfaces developed in eAdventure. #1: Keyboard navigation; #2: Sonar; #3: Conversational (commands)

	#1	#2	#3
No. Users completed the game	4/4 (100%)	3/4 (75%)	2/2 (100%)
Completion time (min:sec)	Mean: 3:21 Min: 2:54 Max: 3:48	Mean: 6:54 Min: 6:17 Max: 7:21	Mean: 4:26 Min: 4:19 Max: 4:34
Easiness of use (*)	**Median: 7/7**	Median: 5/7	Median: 5.25/7
Fun (*)	Median: 5/7	**Median: 6/7**	Median:5.5/7
(*) Results from a 7-point Likert questionnaire			

An interesting finding was that users that were not used to play digital games tended to prefer interface #1, probably because it resembles navigation via the Web, which is a sort of interaction they are familiar with. In contrast, users that were more used to playing digital games preferred the sonar, which was the hardest to control (see rates and avg. completion times in Table 1) and very unfamiliar to all of them. This suggests there is really a diversity of preferences regarding gaming in the population of blind users, although further research with a higher sample must be conducted to contrast the findings.

4.1.3 *Eyes-free games on Android*

The end-user questionnaire used to evaluate the eyes-free mobile games had 6 5-point Likert items. Items were oriented to evaluate the game-play experience (e.g. "Was the game engaging?" "How fun was it to play the game?", etc.) and the quality of different aspects of the game (e.g. "rate the accessibility of the controls", "rate the feedback provided by the game", etc.). Items were summed up to build a scale ranging from 6 to 30 (Cronbach's alpha: 0.903). Results are provided in Figure 4. Results are mostly positive in both blind and sighted users (Medians: 20.00, 16.5 respectively; Means: 21.15±4.92, 17.60±7.41), although they are higher for blind users. Results for sighted users show also more dispersion. The difference can be attributed to the design of the games that were developed thinking of blind users as the target population.

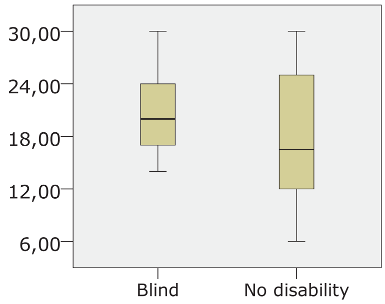

Figure 4. Boxplot with results of end-user questionnaires for the three Android eyes-free games developed. Vertical lines show min and max values. Boxes represent results between percentiles 25 and 75. Median is marked inside each box.

4.2 Analysis of the Cost.

The actual impact that dealing with diversity had on the game author (in terms of additional effort and cost) cannot be easily quantified. However, in Table 2 we provide some data on additional effort required during the process of creating the game "My First Day at Work" to support discussion.

To enable data collection, the game was first developed for users with no disabilities and in a second stage it was adapted for people with disabilities using the semi-automatic system built into eAdventure. This allows measuring how many additional game elements had to be manually produced (and how complex they are) as an indicator of the total effort dedicated to the task. As Table 2 reports, most of the aspects of the game that experienced a significant increase were additional text descriptions and synonyms produced to feed the natural language processing unit and the audio feedback system for blind users and users with reduced mobility. Fortunately, providing alternative pieces of text is inexpensive. It was also required to develop alternative tutorials for blind users and users with reduced mobility. Additional versions of some art resources were also produced for situations where the quality of the scenes rendered in high contrast mode was insufficient. These processes are more expensive, but they resulted only in a small cost increase.

4.3 Discussion of the Contributions

Results outlined in this project are promising and motivate further exploration of the possibilities that game development software can provide to simplify the creation of games that can be enjoyed by a wider audience. Although developed game interfaces are not free of barriers, the evaluation of the player experience and overall usability justifies further research in this line. Results also allows us to answer affirmatively to RQ#1, as it seems feasible to deliver good quality player experiences with this kind of interfaces. Regarding RQ #2, the analysis of the extra cost needed to introduce accessibility in one of the games shows the potential for cost reduction provided by this approach.

Table 2. Analysis of the effort needed by the game author to make the game "My First Day at Work" accessible using eAdventure. Effort is estimated through calculation of additional elements created.

Relative Cost	B=Before	A=After	I=Increase (I=A-B)	% Increase (%=I/B·100)
Game text (dialogues, conversations, descriptions of elements, etc.) for audio descriptions (No. of words)				
Low↓	6341	10208	3867	60.98%
Synonyms for the natural language input processing module				
Low↓	188	698	510	271.28%
Size of the tutorials implemented for blind users and users with limited mobility				
Medium↓	9220	10172	952	10.32%
Number of alternative art resources developed for the low vision mode				
High↑	638	700	62	9.71%

The three studies that constitute the body of this project have provided some insight on player diversity and accessibility that may be of interest for future research on gaming and HCI. The project has proposed game interface models that can be used to deal with a diverse target audience. In this project, diversity has been considered in three factors: player capabilities (i.e. disability), player gaming habits and target device (desktop Vs mobile). The interfaces proposed could help other researchers and practitioners in optimizing the gameplay experience under these conditions.

This project has also produced outcomes in the form of free, open source software products that the community of users with disabilities can take advantage of, including:

- Game development software that helps to produce games that are more accessible. Two different products were produced: an authoring tool that can be used in small to medium developments, and an Android game framework that can be used by developers in mobile platforms.
- A desktop game "My first day at work" that can be played by users with disabilities.
- Four games that can be played by blind and sighted users on the Android mobile platform (developed by two undergraduate students under our supervision).

Ultimately, we expect this work to raise awareness among other developers of the importance of making game interfaces that are optimized for diverse players.

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7.12. Development of a Game Engine for Accessible Web-Based Games

7.12.1. Cita completa

Javier Torrente, Ángel Serrano-Laguna, Ángel del Blanco, Pablo Moreno-Ger, Baltasar Fernández-Manjón (2013): **Development of a Game Engine for Accessible Web-Based Games**. Games And Learning Alliance Conference (GALA) 2013, 23-25 October 2013, Paris, France [En prensa].

7.12.2. Resumen original de la publicación

The Web is rapidly shifting towards more dynamic and interactive content. One clear example is the increasing use of web-based digital games. However, the more interactive a piece of content is, the more difficult it is to make it universally accessible. Besides, users are increasingly demanding ubiquitous access to the content and applications they use (including games), resulting in a need for ensuring that Web content is also multiplatform. These trends are adding an extra technology challenge for ensuring content accessibility. In this paper we describe our technical approach to create an accessible multiplatform game engine for the new version of the eAdventure educational game authoring platform (eAdventure 2.0). This approach integrates accessibility as a core design principle instead of adding accessibility features *a posteriori*. We expect this to facilitate the creation of web-based digital games that are accessible regardless of the context (device, assistive tools available, situation, etc.) in which they are being used. In this work we describe the general architecture, as well as some specific examples of accessibility adaptation plug-ins already available.

Games And Learning Alliance Conference (GALA) 2013

Development of a Game Engine for Accessible Web-Based Games

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Abstract

The Web is rapidly shifting towards more dynamic and interactive content. One clear example is the increasing use of web-based digital games. However, the more interactive a piece of content is, the more difficult it is to make it universally accessible. Besides, users are increasingly demanding ubiquitous access to the content and applications they use (including games), resulting in a need for ensuring that Web content is also multiplatform. These trends are adding an extra technology challenge for ensuring content accessibility. In this paper we describe our technical approach to create an accessible multiplatform game engine for the new version of the eAdventure educational game authoring platform (eAdventure 2.0). This approach integrates accessibility as a core design principle instead of adding accessibility features *a posteriori*. We expect this to facilitate the creation of web-based digital games that are accessible regardless of the context (device, assistive tools available, situation, etc.) in which they are being used. In this work we describe the general architecture, as well as some specific examples of accessibility adaptation plug-ins already available.

Selection and/or peer-review under responsibility of the scientific programme committee of GALA 2013
Keywords: Accessibility, accessible games, eAdventure, game engine, universally designed games.

1. Introduction

Rich Internet Applications (RIAs) and interactive content are gaining importance in modern web to enrich the navigation experience. In particular, digital games are increasingly being used in the web, not only for leisure but also for 'serious applications' like education [8], health [4], advertising [11] and even as an alternative to Captchas [1]. The drawback is that RIAs create new issues from an accessibility perspective. The problem grows for digital games where interaction cycles are extremely short and feedback is usually provided on multiple channels. Although the problem has been identified, and research is being conducted on how to address it [17], the fact is that the current level of accessibility of digital games is still rudimentary.

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The limited accessibility of digital games is not motivated by a single reason. An apparent lack of awareness of game developers and the cost overhead that accessibility adds to any game development project are surely among the most relevant. A proposed approach to address these issues, at least partially, is to integrate accessibility into game development software [14], instead of focusing on ad hoc solutions for each particular title. On the one hand, this increases the visibility of accessibility among developers, as it translates the problem to a language they are familiar with. On the other hand, it allows reusing previous efforts across different game development projects, resulting in significant savings and cost reductions.

When games are deployed in the web there are also further technical challenges that are difficult to address. Web content can be used (by definition) in different contexts and deployed on multiple platforms, which adds uncertainty to what technologies or assistive tools would be available. Besides, web content must be conformant to standards to ensure interoperability.

In this paper we present our ongoing development efforts in the eAdventure 2.0 game engine and how it is being designed and implemented to accommodate accessibility from its very inception. Once development is complete, game authors will be able to make accessible games more easily and automatically deploy them on the Web using HTML5 and WebGL. Most of the solutions proposed could also be applied to other types of RIAs and interactive contents.

This paper is structured as follows: section 2 provides a short overview of the state-of-the-art in digital game and RIA accessibility. Section 3 introduces the eAdventure platform: what is it, what prototypes have been already developed to explore accessibility in games, and why a new version is being developed based on Web technologies. Section 4 describes the technical design rationale to introduce accessibility in the eAdventure 2.0 game engine, with section 5 providing examples on how the architecture presented allows adapting the games for two specific user profiles. Finally section 6 wraps up our contribution and outlines future lines of research.

2. Background

Web accessibility has traditionally focused on granting equal opportunities of access to the vast majority of the content and applications that populate the Internet, which used to be rather static and not highly interactive. Interest on making RIAs accessible is more recent. This unbalanced distribution of efforts is reflected on current status of web accessibility standards. While the Web Content Accessibility Guidelines (WCAG), which deal with static content, are a mature and stable technical standard, its counterpart for RIAs, the Accessible Rich Internet Applications (WAI-ARIA) specification, is still a draft.

Concurrently the gaming field is gradually starting to explore how to increase accessibility of digital games, not necessarily focusing on the Web [17]. The first accessibility guidelines specifically targeted to digital games were proposed by the Special Interest Group on accessibility of the International Game Developers association [5] on 2005. These guidelines provided a compendium of good practices grouped by types of disability and exemplified through case studies of games that included features to support accessibility that were available at the time. Since then, the state-of-the-art on game accessibility recommendations has been pushed forward not only by IGDA but also by other advocators and dedicated institutions [2]. However, the field is not mature enough to produce an official standard or technical recommendation similar to W3C specifications, lacking of reference tools and appropriate conformance levels.

In the academia, research initiatives on digital games have also emerged [17, 18]. Some of these initiatives have focused on the production of games that could be enjoyed by players with and without disabilities alike, while others have focused on the special needs of players with disabilities only [12]. Other experiences have focused on making popular games accessible, instead of developing an accessible game from scratch [3].

Comparatively, very few cases have explored how game technologies and development software can support accessibility. For example, in [10] a Game Accessibility Framework is introduced from a conceptual perspective. Moreover, the additional requirements of Web games remain as an open issue.

3. eAdventure

eAdventure (formerly <e-Adventure>) is an open source, high-level game authoring tool [6]. Unlike more complex tools (e.g. Unity [16]) it targets low-profile and user-generated games that could be used in different contexts, especially 'serious applications' and education. The types of games that can be produced with eAdventure are limited to 2D point-and-click games and conversational adventures. This genre is typically considered more appropriate for educational settings (and more accessibility-friendly) due to the focus on exploration and reflection as opposed to time pressure or fast-paced action [7].

3.1. Versions 1.X and 2.0

eAdventure has been in development since 2005, being v1.5 the latest version available. On 2011 it was reaching its end of life. It is built on Java, which is rapidly becoming an obsolete technology for Web clients due to the need of installing browser plug-ins and recent security holes found in Java Applets. This presents a problem in online education (a.k.a. e-learning) environments, where everything lives on the web. For that reason, we started the development of a new eAdventure game engine from scratch (v2.0). The main aim in the development of eAdventure 2.0 is to provide an extensible and multiplatform engine to supports game deployment as HTML 5 (using WebGL) Web Applications. As HTML 5 cannot be fully deployed in some devices yet (e.g. computers with old browsers or some smartphones and tablets), the eAdventure 2.0 also has native support for specific platforms (e.g. Android devices).

Both branches of the eAdventure engine currently coexist. The internal architecture is completely different in both cases. The former one is referred to as version 1.X (stable but rapidly becoming obsolete) while the new one (unstable) is referred to as version 2.0.

3.2. Previous Work on Accessibility

Previous work has already explored the introduction of accessibility in the eAdventure platform using version 1.X. In [13] the development and integration of accessibility modules for adapting the game interface dynamically is described. Three user profiles were considered: (a) screen reader users (blind); (b) speech recognition users (limited mobility in hands) and (c) users that need high contrast settings (low or limited vision). Different alternatives for users requiring screen readers were further explored in a subsequent experiment [15]. The experience gathered on these previous research activities has been used to design the core set accessibility features that will be supported by eAdventure 2.0 out-of-the-box.

4. Implementation Proposed

The basic architecture of the new version of the eAdventure engine (2.0) was described in a previous publication, which can be consulted for further details [9]. In this paper we focus on how accessibility fits within this architecture.

4.1. Engine Architecture

The 2.0 engine is modular, multiplatform and extensible. It is built upon an API that supplies functionality (e.g. access to the data model and art resources, etc.) for all basic processes of the application (e.g. rendering, collision detection, etc.) to all internal components (see Figure 1), and enables cross-component communication. All the platform-independent functionality of the Engine API is implemented by the Engine Core, the main controller of the application. This way most of the code of the engine is implemented only once.

Platform-dependent components provide implementations for the rest of the Engine API (e.g. image rendering, video reproduction, input/output, etc.).

The eAdventure data model (the description of the game) is constituted by EAdElements. An EAdElement holds no computation logic, just a piece of the description of the game or one of its components. This includes characters, items or game scenarios, but also effects triggered in the game in response to user's interactions. These effects can produce feedback for the user. For example, eAdventure 2.0 supplies effects to display formatted text on the screen, or to play a sound track. At runtime, the game engine reads the EAdElements from a XML file and translates them to GameObjects, which are the minimal game functional units, that can be manipulated.

eAdventure 2.0 uses the concept of plug-ins to support functionality and platform extension. An eAdventure plug-in is a set of classes and interfaces extending and using the Engine API. Plug-ins are programmed as independent units that are loaded at start-up. For example, plug-ins can contain extensions of existing EAdElements or GameObjects, new implementations of parts of the API, etc.. A configuration file defines the plug-ins that the game engine must load at start-up.

The implementation(s) of all the parts of the Engine Core and API (e.g. EAdElements, Game Objects, Plug-ins, Core functionality, Platform-dependent components) are completely separated from the interfaces that define them. The interfaces are bound to the code components (i.e. classes) dynamically at start-up, using a technique called dependency injection (Google Guice is used for this purpose). This structure enhances the flexibility and adaptability of the engine, as the behavior of any component can be replaced dynamically (e.g. to better suit the needs of the user).

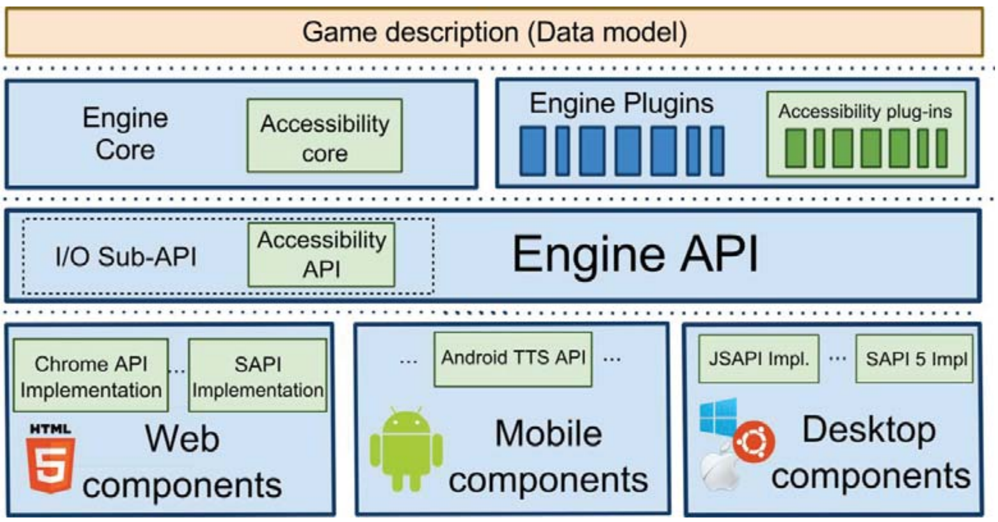

Figure 1. Architecture of the eAdventure 2.0 engine

4.2. Accessibility Support

Accessibility is present in different components of the game architecture, including: an Accessibility API (part of the main Engine API); an Accessibility Core, responsible for implementing part of the Accessibility

API and also for setting up accessibility features at start-up; Accessibility Plug-ins, a set of engine extensions to deal with particular functionalities; and Platform-dependent accessibility Components that implement parts of the Accessibility API that handle inputs and outputs, like speech recognition or text-to-speech (TTS).

Most of the code that deals with accessibility is implemented either as Accessibility Plug-ins or Platform-dependent Components. The Accessibility Plug-ins (a specific type of eAdventure plug-ins) allow changing the behavior of any component or element of the game engine. For example, a plug-in could adapt how the visual elements are rendered, or the complexity of the text or other pieces of game content. Platform-dependent Accessibility Components are designed to allow interoperability with external components by connecting the engine's I/O modules to different platform-dependent implementations of the Accessibility API (e.g. Android or HTML5). In this manner the game engine can take advantage of technologies or support tools that the user may already have installed (e.g. the JAWS screen reader, Mac Voice Over system, etc.). This favors using well-tested and implemented aiding technologies, and also allows the applications to be lighter and speed up loading times.

In the process of setting up a game for a particular user, some game content (e.g. images and text) may need to be adapted. Occasionally the content can be adapted dynamically (e.g. apply a filter to the image) but sometimes it is necessary that the engine is fed with alternative versions of these resources. For that reason, game content is highly decoupled and encapsulated. Using a namespace convention, different versions of the text scripts and images are organized in folders. When a resource is loaded in the game, the engine fetches the best version available for the characteristics of the user. If none of the versions for that resource suit the user needs, then it will attempt dynamic adaptation.

5. CASE STUDIES

To exemplify how the engine works, two case studies are presented, focusing respectively on color vision deficiency and screen reader users.

5.1. Adaptation for Color Vision Deficiency

Users with color vision deficiency (CVD) may have troubles playing a game if color schemes are used to convey information. The color schemes used may need to be adapted or replaced by other identification techniques (e.g. icons). Users with CVD may also have problems reading text if its color cannot be distinguished from the background.

These problems are solved using the dependency injection technique. GameObjects that are responsible for visual elements of the scenes are created using an alternative version that alters the rendering code. For example, at runtime, the GameObject used to control and render a game scenario (interface GOScene) is bound to an alternative implementation (e.g. class GOSceneCVDImpl) that overrides the draw() method making interactive elements more distinguishable. Similarly, the GameObject that represents effects for showing text in the game (interface GOTextEffect) is bound to a different implementation (class GOTextEffectCVDImpl) that draws the text on a clear background using a high-contrast color scheme.

5.2. Adaptation for Screen Reader Users

The most important needs of screen reader users are (1) avoiding the mouse as input device (they can use a keyboard) and (2) providing non-visual feedback (i.e. audio-based). While the first issue poses no significant challenge from a technological perspective, the second is a more complex issue. Dealing with non-visual feedback will typically require using text-to-speech technologies (a full voiced game may be too expensive).

Web-based TTS are cumbersome as no reference API or implementation is has been adopted and implemented for the HTML5 specification.

In the case of eAdventure, a TTS API was defined (as part of the Accessibility API) to abstract all this complexity. At start-up the Accessibility Core inspects the context where the game has been launched, gathers information about the guest operative system and platform, and starts a discovery process to investigate potential TTS engines and other assistive tools installed. Considering this information, the available implementations of the TTS API that were packaged with the game are analyzed, discarding those that are not applicable in the current context. Available options are prioritized and iterated through, trying to set-up the best alternative for the user.

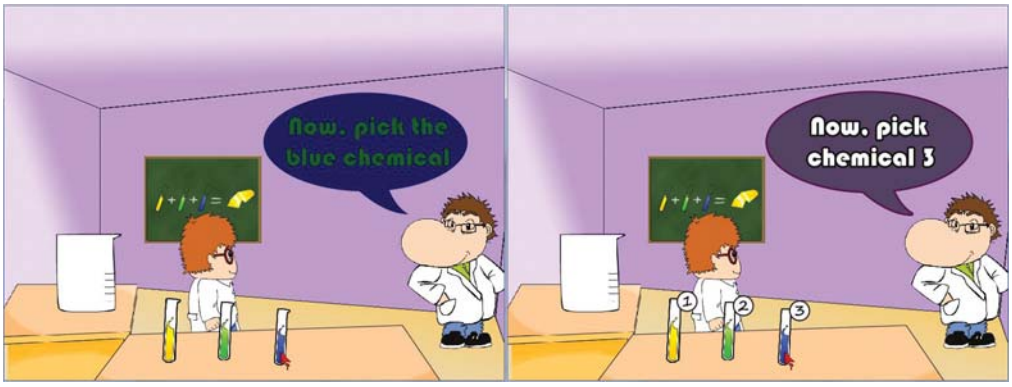

Figure 2. On the left, the original game screenshot. On the right, adapted version for CVD. Two adaptations are performed: (1) chemicals are identified with numbers instead of colors; (2) green-blue text color scheme, which may be hard to read, is replaced by a high-contrast alternative.

For example, suppose the game is launched in the Chrome Web browser on a Windows Machine (XP or above) and the Accessibility Core discovers, through a browser plug-in, that a screen reader (e.g. JAWS) is installed. It will first try to load an implementation of the TTS that connects to the screen reader, so that the voice used will be familiar to the player. If the process fails, it would try to take advantage of the TTS API Google Chrome browser provides. Next it would try to connect to Microsoft's Speech API (SAPI) provided by the OS, through another browser plug-in. Should all these alternatives fail, then the TTS feature would be disabled, as the game engine does not include a built-in TTS engine.

At start-up the Accessibility Core will also load alternative implementations of the GameObjects that show text on the screen, in a similar way as described in section 5.1. When these accessible objects are rendered, they also invoke the TTS API. In this manner, each piece of text that is displayed on the screen is also played back using the TTS API (if available). Other GameObject effects are also adapted to enhance the audio feedback that is conveyed to the user. For example, when the player enters in a new scene, the game engine will generate a textual description of the scene and reproduce it using the TTS API.

6. CONCLUSIONS AND FUTURE WORK

With the increasing presence of digital games on the web on one hand, and the need for ubiquitous access to content in the other, making accessible games is becoming even harder, as new technological problems are added (e.g. how to deal with text-to-speech technologies and screen readers on different platforms). The introduction of accessibility features could be facilitate by providing game development software that supports the production of games that can be delivered through the web on computers and also on other platforms, like mobile devices.

It can be assumed that HTML5 will eventually make Web games run on every single Internet-enabled device. However, the standard has not fully been debugged and adopted in several platforms, like smartphones and tablets. Thus it is still necessary to provide a native version of the games for some platforms.

In this paper we have presented the eAdventure 2.0 architecture that will allow development of accessible 2D serious games meeting these criteria. The architecture was designed with extensibility and flexibility as key drivers. The main advantage of this approach is that eAdventure 2.0 would easily support extensions to accommodate more types of disabilities and/or new platforms.

This work has only addressed the technical problems related to game accessibility. However, making a game that is enjoyable for players with different types of profiles requires more than having a technology that supports it (e.g. game authors also need to integrate players' special needs into the game design).

The features here presented are currently on a prototype state. We are currently working to reach a more stable status. The next steps will be development and evaluation of accessible games using the eAdventure 2.0 game engine.

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