UNIVERSIDAD COMPLUTENSE DE MADRID
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TESIS DOCTORAL

SISTEMATIZACIÓN DEL DESARROLLO DE SIMULACIONES EDUCATIVAS CON ESTRATEGIA DE JUEGO EN EL CAMPO MÉDICO

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

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Director

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Madrid, 2015

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Blanca B. Borro Escribano

Bajo la dirección del doctor

Baltasar Fernández Manjón

Madrid, noviembre de 2014

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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 de la Normativa de desarrollo del Real Decreto 1393/2007, de 29 de Octubre, por el que se establece la ordenación de las enseñanzas universitarias oficiales de la Universidad Complutense de Madrid[1] (Aprobada por el Consejo de Gobierno a 14 de Octubre de 2008, modificado por la Comisión Permanente del Consejo de Gobierno con fecha de 29 de Octubre de 2010, publicado en el BOUC el 20 de Noviembre de 2008) [2].

Los artículos presentados son los siguientes:

- Blanca Borro Escribano, Ángel del Blanco, Javier Torrente, Itziar Martínez Alpuente, Baltasar Fernández-Manjón (2014): *Developing game-like simulations to formalize tacit procedural knowledge: The ONT Experience.* Educational Technology Research & Development. Vol 62(2) pp 227-243. Springer. DOI: 10.1007/s11423-013-9321-6. [JCI-SCI: 0,919;2013; Education & Educational Research; 89/219]

- Javier Torrente, Blanca Borro Escribano, Manuel Freire, Ángel del Blanco, Eugenio J. Marchiori, Iván Martínez-Ortiz, Pablo Moreno-Ger, Baltasar Fernández-Manjón (2014): *Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education.* IEEE Transactions on Learning Technologies 7(1), pp 69-82. [JCR-SCI: 1,22, 2013, Computer Science, Interdisciplinary Applications, 62/102]

- Blanca Borro Escribano, Itziar Martínez Alpuente, Ángel del Blanco, Javier Torrente, Baltasar Fernández-Manjón, Rafael Matesanz Acedos (2013). *Application of game-like simulationes in the Spanish Transplant National Organization.* Transplantation Proceedings. 45(10), pp 3564-3569. [JCR-SCI : 0.984; 2013; Surgery 144/204]

- Blanca Borro Escribano, Ángel del Blanco, Javier Torrente, José María Borro Maté, Baltasar Fernández-Manjón (2014). *Applying Egda to a particular case: The donor's evaluation.* Transplantation Proceedings. (aceptado para publicación en Agosto 2014) [JCR-SCI : 0.984; 2013; Surgery 144/204]

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[1] http://www.boe.es/boe/dias/2007/10/30/pdfs/A44037-44048.pdf

[2] http://pendientedemigracion.ucm.es/bouc/completos/2008/14.pdf

Conferencias

- Blanca Borro Escribano, Ángel del Blanco, Baltasar Fernández-Manjón, Itziar Martínez Alpuente, Beatriz Domínguez Gil, Rafael Matesanz (2013). *Using Low - cost computer - based simulations in the Spanish National Transplant Procedures*. In Proceedings 2013 IEEE 15th International Conference on e-Health Networking, Applications and Services (Healthcom 2013), pp 76-80, ISBN 978-1-4673-5800-2.

- Blanca Borro Escribano, Javier Torrente, Ángel del Blanco, Baltasar Fernández-Manjón, Itziar Martínez Alpuente, Rafael Matesanz (2014): *Expert User Validation of Transplant Management Procedure Simulations*. IEEE 3rd International Conference on Serious Games and Applications for Health. Rio de Janeiro, Brazil (En prensa, May 2014).

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 seis artículos incluidos, relacionándolos con los objetivos mencionados. Adicionalmente, se presenta un capítulo en el que se analizan los resultados, se proporcionan unas conclusiones y se sugieren unas líneas de trabajo futuro. Finalmente, se incluye una bibliografía que integra y complementa las referencias de los artículos incluidos en esta tesis doctoral.

Resumen

Esta tesis doctoral, presentada como una recopilación de publicaciones aceptadas y editadas, tiene como objetivo principal presentar una metodología para sistematizar el desarrollo de simulaciones con estrategia de juego en el campo médico.

Para lograr este objetivo se han desarrollado un conjunto de simulaciones en colaboración con personal médico, fundamentalmente de la Organización Nacional de Trasplantes (ONT), para permitir su aplicación práctica y se han planteado una serie de sub-objetivos:

1. Desarrollo de simulaciones médicas en colaboración con la ONT que permitan capturar su conocimiento (know-how) para mejorar y sistematizar procesos formativos.

2. Validación de las simulaciones realizadas. Esta validación se realiza a dos niveles: con el personal de la ONT y mediante su aplicación en cursos de formación de la ONT para nuevo personal y para otros profesionales.

3. Propuesta de una metodología para el desarrollo de simulaciones con elementos de juegos en el campo médico. Esta metodología sistematiza el conocimiento adquirido en los dos sub-objetivos anteriores.

El proceso seguido para la consecución de estos objetivos ha sido el siguiente:

Inicialmente se planteó una metodología iterativa basada en desarrollo ágil para el diseño y creación de simulaciones educativas. Esta metodología surge tras estudiar el dominio y detectar que, a pesar de existir diversas metodologías de desarrollo de videojuegos, éstas eran difíciles de aplicar en este campo concreto y más integrando de forma efectiva al personal médico. La metodología propuesta pretende ayudar a los diseñadores y desarrolladores en la creación de simulaciones y juegos educativos, especialmente dentro del campo médico.

Esta metodología se aplicó en un contexto médico concreto, la Organización Nacional de Trasplantes (ONT), gracias a la cual se desarrollaron tres simulaciones médicas para desarrollar el proceso de donación y trasplante a nivel extra-hospitalario (aquellos procesos llevados a cabo desde la ONT). La aplicación de esta metodología en la ONT permitió mejorar la sistematización de sus procedimientos y los casos de uso utilizados en su sistema formativo.

Una vez desarrolladas las simulaciones, era necesario comprobar que el conocimiento había sido correctamente capturado. Para ello, se realizó un proceso de validación del conocimiento con personal experto de la ONT y se analizó el grado de comprensión y satisfacción de los usuarios de las aplicaciones en los cursos de formación de la ONT.

Todo este trabajo, junto con lo aprendido en experiencias previas por parte del grupo de investigación de la UCM (e-UCM) permitió definir una metodología para el diseño, desarrollo y evaluación de simulaciones con estrategia de juego en el campo médico conocida como EGDA (*Educational Game Development Approach*).

Finalmente, se creó una última simulación mejorada, la "Evaluación del Donante en un contexto hospitalario" siguiendo la metodología EGDA. Esta simulación ha sido validada por un experto médico. Para ampliar el público objetivo, esta simulación aborda el proceso clínico de preselección y evaluación de donantes. Se ha desarrollado en varios idiomas y con varios niveles de dificultad y cuenta con un asistente de ayuda para permitir llegar a un público mayor.

Abstract

This PhD project, presented as a collection of papers accepted for publication, has as its main objective the systematization of game-like simulations development in healthcare.

To achieve this objective, a set of game-like simulations have been developed in collaboration with medical staff, mainly from the Spanish National Transplant Organization (ONT). This objective can be divided into three sub-objectives:

1. Development of medical simulations in collaboration with the ONT representing its knowledge (know-how) to improve and systematize the ONT's instructional approach.
2. Validation of the developed simulations. This validation has been performed at two different levels: among the ONT staff and by using them as a support tool in the ONT courses held around Spain.
3. Proposal of a methodology for developing game-like simulations in healthcare. This methodology systematizes the knowledge acquired in the two previous objectives.

The process followed to accomplish these objectives was the following:

First, we described a methodology to produce game-like simulation built on the principles of agile software development. This methodology arises after studying the field and discovering that although there are several case studies of successful methodologies to develop videogames, these methodologies are not easy to apply in healthcare, and do not always promote domain experts' collaboration. The proposed methodology aims to help other developers and researchers produce educational games and collaborate with domain experts more efficiently, especially in healthcare.

We have applied this methodology to transform part of the (ONT)'s technical know-how into game-based educational content. Three game-like simulations have been developed representing the Process of Deceased Donation at a supra-hospitalary level. Thanks to the simulations developed following this methodology, the ONT has improved the systematization of its procedures and the teaching cases used in its instructional approach.

Once the simulations had been produced, a proper validation of them was needed to assure that ONT knowledge had been correctly represented. The main objective of this validation was to estimate how accurately the knowledge had been captured and transferred to the game-like simulations.

Finally, all this work along with the previous acquired experiences of the UCM research team (e-UCM) led to the definition of a methodology to design, develop and evaluate game-like simulations in healthcare, known as EGDA (Educational Game Development Approach).

Following EGDA, an improved simulation was developed, "The Donor's evaluation at the hospitalary level". A medical expert has validated this simulation. It is designed for any audience with medical knowledge and it has three levels of difficulty and language options. In order to help players understand the game and focus on the learning objectives, a tutorial to guide them throughout the game has been included.

Estructura del trabajo

El núcleo de este trabajo es una recopilación de publicaciones editadas que se reproducen en su totalidad en el capítulo 6. 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 arte.
- Capítulo 3. Objetivos y planteamiento del trabajo.
- Capítulo 4. Contribuciones.
- Capítulo 5. Conclusiones y trabajo futuro.
- Capítulo 6. Resumen traducido al 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

La motivación inicial por la que nace este proyecto de tesis surge a partir de mi trabajo como ingeniera informática en la Organización Nacional de Trasplantes (ONT). Es en la ONT donde entré en contacto con el mundo médico, y más en particular, con las peculiaridades y necesidades que existen en este ámbito en la formación de profesionales médicos. Por esta razón considero que es necesario comenzar este trabajo con una breve introducción sobre la ONT y lo que representa ya que es aquí donde se ha desarrollado, probado y aplicado una gran parte del trabajo llevado a cabo en esta tesis.

1.1 Organización Nacional de Trasplantes

Gracias al sistema organizativo de la Organización Nacional de Trasplantes, España ha logrado ser el único país en el mundo con un incremento progresivo y mantenido en el tiempo del número de donantes de órganos. Su tasa de donantes fallecidos por millón de habitantes es la mayor de todo el mundo (35,1 por millón de habitantes, con un total de 1.655 donantes en 2013 y casi 90 trasplantes por millón de habitantes en 2013) (ver Figura 1). Sus excelentes datos de donación y trasplante son el resultado del sistema de gestión de la ONT denominado genéricamente “Modelo Español de Donación y Trasplante” (R Matesanz et al., 2009; Rafael Matesanz et al., 2011; Scandroglio et al., 2011), un sistema que se encarga de garantizar la correcta identificación de posibles donantes y asegurar que se hace todo lo posible para que estos “posibles donantes” se conviertan en donantes reales.

Uno de los pilares de este Modelo Español es su sistema de formación, dirigido a todos aquellos

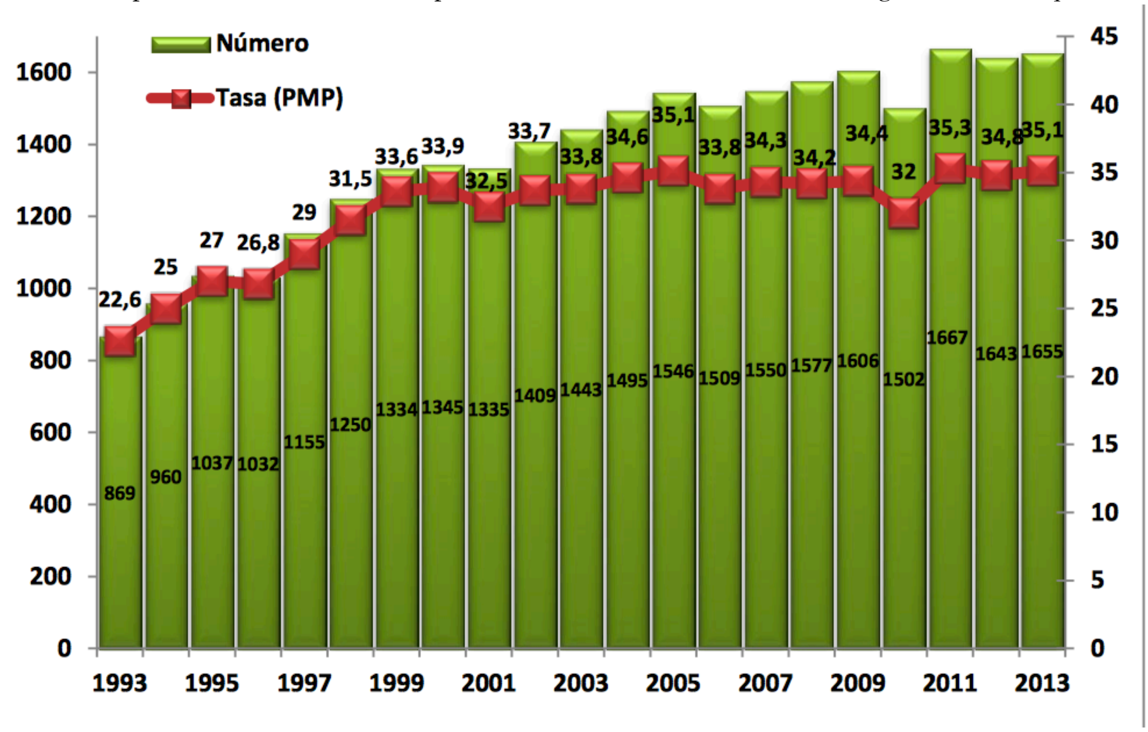

Figura 1 Número de donantes por año desde 1993

profesionales implicados directa o indirectamente en el proceso de donación y trasplante. Sin embargo, el limitado personal de la ONT, entre 13 y 15 enfermeros y unos 10 médicos, junto con la elevada demanda de formación por parte de otros países, hacen que sea necesario un continuo esfuerzo para mejorar la eficiencia de la formación, y llegar al mayor número posible de profesionales utilizando nuevas técnicas y minimizando los recursos.

El proceso de donación y trasplante, es un proceso complejo con una gran cantidad de profesionales implicados (alrededor de 100 profesionales se ven implicados desde que aparece un donante potencial[3] hasta que se realiza el/los trasplantes). Cada uno de los pasos de este proceso debe ejecutarse correctamente siguiendo un riguroso procedimiento para asegurar que no haya pérdida de posibles donantes. Gran parte de su éxito se basa en la elevada experiencia y el amplio conocimiento del personal implicado.

Sin embargo, transmitir este conocimiento entre profesionales no es sencillo y requiere de participación activa de los profesionales con experiencia así como de muchas horas, días e incluso meses de práctica por parte de los aprendices. En los cursos de formación de la ONT, no se dispone ni de tanto tiempo ni de la posibilidad de tanta implicación por parte de los pocos expertos existentes. Era por tanto necesario encontrar alguna solución que paliara dicho problema y permitiera dar soporte y continuidad a la labor de formación ejercida por la ONT.

1.2 Motivación de la investigación

A partir de esta experiencia en la ONT se identificaron distintas necesidades:

1. En primer lugar, era necesario encontrar herramientas para dar soporte, mejorar y sistematizar el sistema de formación existente que, a pesar de ser muy eficaz, es difícilmente escalable ya que está limitado por los escasos recursos de la ONT (i.e. personal).

2. Esta alternativa tenía que ser capaz de representar adecuadamente los procedimientos usados de la ONT incluyendo, dentro de lo posible, su conocimiento "tácito" (conocimiento fruto de la experiencia personal, que involucra factores intangibles como son creencias, valores, puntos de vista, intuición, etc., y que por tanto son difíciles de estructurar o almacenar) (Blandford & Rugg, 2002).

3. Además, la representación de este conocimiento ayudaría a mejorar la sistematización de los procedimientos de la ONT. Esto se logra mediante el uso de una metodología iterativa que permite corregir y mejorar los procedimientos en cada iteración.

Para dar respuesta a estas necesidades se decide desarrollar simulaciones educativas que representen el conocimiento de la ONT. Capturar este conocimiento y transformarlo en simulaciones

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[3] Donante potencial: Paciente en una Unidad de Cuidados Intensivos de un hospital que se encuentra en estado de muerte encefálica (muerte cerebral) o en proceso de estarlo.

fácilmente distribuibles simplificaría la transferencia de información y conocimiento a otras instituciones ayudando por tanto al sistema formativo de la ONT.

A pesar de que esta tesis nace de la necesidad de sistematización y mejora del sistema formativo de unos procedimientos médicos concretos finalmente se ha podido generalizar hacía la sistematización del desarrollo de simulaciones con estrategia de juego en el campo médico. A partir de este trabajo de tesis y, reutilizando la experiencia del grupo de investigación e-UCM obtenida en el desarrollo de otras simulaciones en el campo médico, se ha podido generalizar el método de desarrollo y ha dado lugar a la definición de una metodología de diseño y desarrollo de contenidos educativos con estrategia de juego, que se denomina EGDA (Educational Game Reseach Approach).

1.3 Objetivos de la línea de investigación

Esta tesis, y la línea de investigación en la que se desarrolla, aborda y propone soluciones a algunos de los problemas detectados en el ámbito de los videojuegos educativos descritos en el análisis del dominio que se presenta en el siguiente tema.

En particular, se realiza el trabajo de sistematización del desarrollo de simulaciones educativas con estrategia de juego en el campo médico y su aplicación en el caso particular de la ONT. Además, también se lleva a cabo el proceso de prueba de las simulaciones y de validación del conocimiento representado en ellas en colaboración con el personal experto de la ONT y los asistentes a los cursos de formación. Estas validaciones son necesarias para contrastar su eficacia y comprobar que el conocimiento representado por medio de simulaciones educativas es correcto. A partir de la experiencia adquirida se generaliza y define la metodología EGDA para el diseño y desarrollo de simulaciones en el campo médico.

El desarrollo e implantación de tres simulaciones concretas para representar los principales procedimientos de la coordinación supra-hospitalaria en la Organización Nacional de Trasplantes (ONT) permitió la consecución del primer sub-objetivo.

Durante el desarrollo de estas simulaciones, fue necesario resolver primero el problema de cómo plasmar este conocimiento tan complejo, y a veces, tácito en las simulaciones. El objetivo era tener una simulación que permitiera adquirir el conocimiento real que se usa en un equipo de la ONT para gestionar este proceso. Para ello, y después de realizar distintas pruebas sobre cómo se podía colaborar de forma más eficiente con los expertos para crear las simulaciones, se ha usado una metodología iterativa para capturar conocimiento tácito de manera más eficiente (Moreno-ger, Martínez-Ortiz, Sierra, & Fernández-manjón, 2008). Las simulaciones realizadas se basaron en casos de trasplantes reales que fueron anonimizados y mejorados para ser más representativos, de modo que ayudaron además a sistematizar los procedimientos y los casos de uso utilizados en los cursos de formación.

Una vez desarrolladas las simulaciones, se realizó un procedimiento exhaustivo de validación del conocimiento representado. Hay dos razones por las que esta validación era necesaria, en primer lugar las simulaciones no solo representaban procedimientos médicos complejos, sino que se habían incluido en ellas elementos para representar los errores comunes y el conocimiento implícito. En segundo lugar, sólo un experto de la ONT asignado al proyecto había participado activamente en las labores de especificación, diseño, construcción y validación de las simulaciones, por lo que era necesario implicar al resto del personal para obtener una validación completa. Esta validación supuso la consecución del segundo sub-objetivo.

El tercer sub-objetivo propone una generalización de lo aprendido en una metodología orientada a ayudar a otros desarrolladores de videojuegos educativos en el diseño, desarrollo y evaluación de simulaciones médicas. Esta metodología se conoce como EGDA (Educational Game Development Appoach) que una vez planteada formalmente se ha utilizado para crear una última simulación mejorada y orientada a la "Evaluación del donante en un contexto hospitalario" que está disponible de modo público y se está probando y evaluando con expertos médicos ajenos a la ONT,

Capítulo 2 Estado del arte

En el contexto de esta tesis, se utiliza la palabra videojuego (o simplemente "juego") en un sentido amplio, que abarca todo el campo de los juegos por ordenador/consola/móvil o cualquier otro dispositivo electrónico. En concreto, en esta tesis se hace referencia a estos términos siempre dentro del contexto educativo, es decir juegos o videojuegos, que a pesar de poder tener contenido lúdico, tienen un finalidad educativa, por lo que también se utilizará el término *serious game* o juego serio. Esta definición incluye también simulaciones educativas interactivas (aplicaciones informáticas de elevada interactividad con objetivos y reglas claras y ciclos de realimentación cortos) sin hacer distinción entre el tipo de software o hardware utilizado para su ejecución. En particular, las simulaciones médicas a las que se hace referencia más adelante en este capítulo son consideradas en esta tesis videojuegos educativos que, pueden resultar entretenidas si contienen los elementos de juego necesarios pero su fin es el entrenamiento de profesionales o la ayuda a pacientes en tratamiento.

Este capítulo tiene como objetivo discutir el ámbito en el que se desarrolla el trabajo de tesis doctoral para permitir contextualizar las aportaciones realizadas. En primer lugar se aborda el campo de los videojuegos educativos haciendo especial hincapié en sus características, beneficios y algunos de los resultados obtenidos. Además se abordan otros aspectos como la educación basada en juegos, el diseño efectivo de videojuegos y algunos de los modelos (*frameworks*) utilizados en su desarrollo de videojuegos.

La sección 2.2 se centra en los videojuegos educativos en medicina, donde se presentan algunos de los resultados de investigación obtenidos y ejemplos concretos que se han considerado especialmente adecuados para una mejor comprensión de los enfoques existentes.

Finalmente, siendo la Organización Nacional de Trasplantes (ONT) el caso de estudio principal de este trabajo de tesis, se ha dedicado la sección 2.3 para dar una idea de algunos aspectos relevantes como son sus procesos de coordinación de trasplantes y cuál es su sistema formativo.

No obstante, debido a la amplitud y variedad de los temas de videojuegos educativos en general y en medicina en particular, no se pretende en ningún caso hacer un estudio exhaustivo sino presentar y analizar aquellas propuestas que se consideran más relevantes para realizar una adecuada contextualización del trabajo realizado.

2.1 Videojuegos educativos

Los videojuegos han incrementado su importancia como elementos de entretenimiento, como contenidos culturales y como industria. Videojuegos como Pac-Mac (desarrollado por Namco en 1980) y Pong (creado por Atari Corporation en 1972) son iconos de la cultura popular del siglo XX. Estos videojuegos tenían gráficos muy sencillos y sin embargo entretuvieron a millones de jugadores. A medida que los videojuegos crecían en popularidad, los desarrolladores de juegos se dieron cuenta del potencial que tenían los videojuegos en la educación (Mcclarty, Frey, & Dolan, 2012). Como resultado, nacieron juegos como "¿Dónde está Carmen Sandiego? (producida por Brøderbund Software en 1985, ver Figura 2) o Oregon Trail (producida por MECC en 1974) desarrollados para enseñar geografía y la vida en la frontera americana.

Figura 2 Imágenes del juego ¿Donde está Carmen Sandiego?

En el balance económico sobre la industria del videojuego presentado anualmente por la Asociación Española de Distribuidores y Editores de Software de Entretenimiento (aDeSe) del año 2013, se calcula en 762 millones de euros el consumo en el sector (979 millones de € en 2011 y 822 millones de € en 2012), consolidando la industria del videojuego como la primera de ocio audiovisual e interactivo de España. Se calcula además, que más de 79 millones las personas en Europa de todas las edades juegan habitualmente, el 97% de los adolescentes americanos juegan a algún juego regularmente y el 40% de los adultos juegan a videojuegos.

Los videojuegos educativos, conocidos también como *serious games*, han crecido considerablemente en los últimos años y se puede incluso afirmar que están de moda (Wexler, Corti, Derryberry, Quinn, & Barneveld, 2008).

El concepto de videojuego educativo es un término muy amplio, e incluso se puede considerar un poco difuso, que en general hace referencia al aprendizaje realizado por medio de un ordenador que ayuda a los jugadores a sumergirse en un entorno artificial interactivo en el que tiene que tomar de decisiones para aprender cuales son las consecuencias de dichas decisiones. Existen otras definiciones aceptadas tales como, por ejemplo, "método de aprendizaje que requiere que el estudiante participe en una actividad de competición con reglas preestablecidas", "tipo de aprendizaje experimental donde el estudiante se involucra con cierta actividad, la observa de manera crítica, obtiene información sobre el análisis y finalmente aplica el aprendizaje en el trabajo" (Akl, Pretorius, et al., 2010), " juegos cuya finalidad no es sólo entretener sino cumplir unos objetivos educativos concretos" (Mehm, Hardy, Göbel, & Steinmetz, 2011) o "juegos diseñados específicamente para entrenamiento o educación"(Kato, 2010).

El aprendizaje basado en juegos (del inglés *game-based learning)* es un método de enseñanza que se aprovecha del potencial y los beneficios que proporcionan los juegos para mejorar y apoyar el aprendizaje. El informe NMC Horizon Report de 2011 clasifica los juegos educativos en tres categorías: los que no son digitales, aquellos que son digitales pero no colaborativos y aquellos son digitales y colaborativos (Johnson, Smith, Willis, Levine, & Haywood, 2011). Los primeros son los más utilizados en las aulas como herramientas de trabajo para hacer el aprendizaje más entretenido.

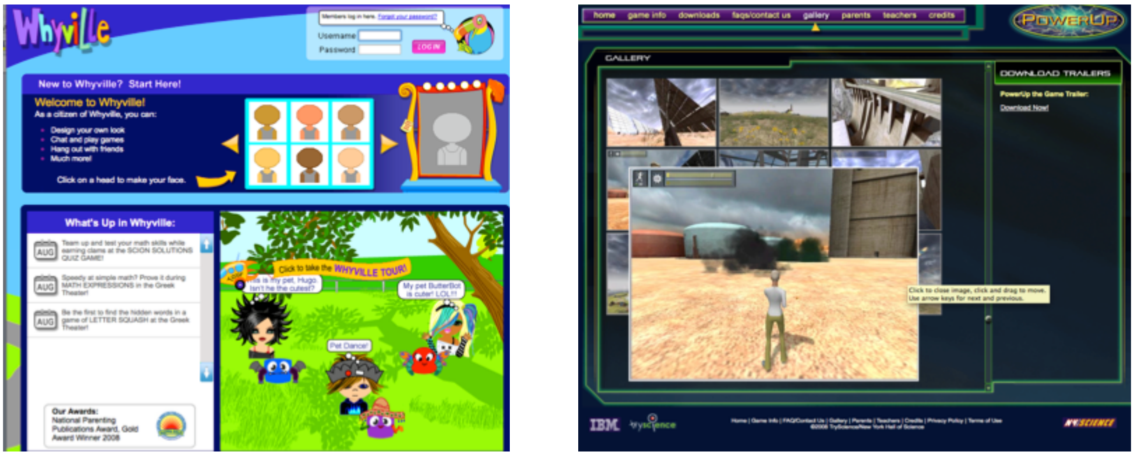

Figura 3 Imágenes de juegos educativos colaborativos

Los segundos son aquellos juegos o videojuegos diseñados para los ordenadores o consolas como, por ejemplo, la Wii. Y finalmente, la mayoría de los juegos online son colaborativos y es necesario acceder con un cliente específico o a través de una web (como por ejemplo Whyville o Power Up ver Figura 3). No obstante, esta clasificación no tenía en cuenta una circunstancia cada vez más frecuente: el juego en dispositivos móviles, actualmente muy importante debido a la generalización de los teléfonos inteligentes y de las tabletas.

A pesar de que la aceptación de la educación basada en juegos es cada vez mayor, es cierto, que muchos educadores todavía consideran esta técnica más como una aproximación prometedora que como una alternativa real. En la última década, numerosos artículos y estudios han destacado los beneficios de los juegos en el aprendizaje (Granic, Lobel, & Engels, 2014). Así, en la edición del informe NMC Horizon Report "NMC Horizon Report: Edición sobre Educación Superior 2013" (Johnson et al., 2013) y en la nueva edición del 2014 (Johnson, Adams Becker, Estrada, & Freeman, 2014) aparecen los términos "Juegos" y "Gamificación" como tendencias de adopción a corto plazo, adquiriendo cada vez una mayor importancia en el terreno de la educación y con potencial para una adaptación a gran escala (Hwang & Wu, 2012; Johnson et al., 2013, 2014). Este dato podría resultar muy esperanzador si no fuera porque es el cuarto año consecutivo (Johnson, Adams, & Cummins, 2012; Johnson et al., 2011) en el que aparece la educación basada en juegos y algunos de los conceptos asociados con ella como tendencia a adoptarse a corto o medio plazo y, sin embargo, parece que la adopción masiva a la que se hace referencia no acaba de llegar.

Factores como, por ejemplo, la dificultad que tiene el proceso de desarrollo de videojuegos para que sea escalables (Dede, 2009; F A S, 2006) o el coste de desarrollo y mantenimiento inasumible en muchos entornos educativos (Adkins, 2013), pueden ser algunas de las razones limitantes que expliquen, al menos en parte, esta situación (Rice, 2007; Van Eck, 2006). Por tanto, se considera necesario encontrar alternativas para poder desarrollar videojuegos educativos en respuesta a la demanda actual a un coste reducido o al menos razonable sin reducir el valor educativo de estos videojuegos (Torrente et al., 2014).

Existen numerosos estudios sobre el impacto y aporte de la educación basada en juegos (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Freitas, 2006; Graafland, Schraagen, & Schijven, 2012; Mcclarty et al., 2012). Algunos de los hallazgos destacables encontrados en estos estudios son:

- La motivación es fundamental para un aprendizaje efectivo, pero esta motivación requiere de apoyo y soporte a través de retroalimentación, implicación activa, etc. Para que el aprendizaje basado en juegos sea efectivo el jugador debe implicarse, consciente o inconscientemente, en el juego, y tener claro cuál es el objetivo educativo. Es por tanto clave y un reto al mismo tiempo para los diseñadores lograr el equilibrio adecuado entre un juego divertido y absorbente y que cumpla con las necesidades educativas del juego.
- Algunos factores que influyen en la motivación de los jugadores son: la sensación de tener retos, que el juego sea realista o que el jugador tenga oportunidades para explorar y descubrir nueva información en el juego.
- Herramientas cognitivas, como son los foros de discusión, los tablones de información, etc. pueden ser de utilidad para ayudar en estos juegos mediando hacia la interacción social y fomentando la discusión.
- Este tipo de educación ya no supone siempre sentarse enfrente de un ordenador, nuevas formas y dispositivos de juegos (móviles y realidades virtuales por ejemplo) favorecen el uso de los juegos en otros entornos (Klasnja & Pratt, 2011).
- Uno de los principales obstáculos de la educación basada en juegos es la falta de resultados empíricos que demuestren que este tipo de educación funciona, así como la falta de comprensión sobre cómo deben ser usados estos juegos en distintos contextos formales e informales.
- Otro problema importante detectado en los centros educativos es la falta de recursos (p.ej. suficientes ordenadores) y sobre todo que estos recursos no sean suficientemente actuales como para que los juegos se ejecuten correctamente (tarjetas gráficas obsoletas, mantenimiento del software etc.).

2.1.1 Características de los videojuegos educativos

La característica principal de un juego educativo debe ser lograr el objetivo de enseñanza para el cual fue desarrollado. Un juego educativo debe mostrar claramente lo que se va a enseñar, el jugador debe saber qué hacer y cómo hacerlo para lograr los objetivos, el juego debe proporcionar al jugador una retroalimentación de su práctica y debe evaluar su aprendizaje (Blumberg et al., 2014).

Algunas de las características en las que existe un amplio acuerdo y que deberían estar presentes en un buen juego educativo son:

- Que esté centrado en el objetivo de aprendizaje que quiere lograr y que el juego esté diseñado en torno a este.
- Que proporcione un equilibrio adecuado entre las capacidades del jugador y el nivel del juego.
- Que genere retroalimentación (en inglés, *feedback*) es la capacidad de los juegos de utilizar la información obtenida a partir de las acciones del jugador para informar o modificar las siguientes acciones. El uso del feedback en los videojuegos es una potente herramienta educativa, así, se puede utilizar para remarcar acciones del usuario, para destacar acciones correctas o subir el nivel de juego en función de éstas.
- Que fomente la competitividad sana entre los jugadores y que permita comparar resultados y aprender de los jugadores más experimentados (esto no implica que no pueda haber juegos cuya principal característica sea la colaboración).
- Que se utilice en situaciones o casos correctamente preseleccionados y filtrados para enriquecer el juego educativo. (Khan, 2007) sugiere que el uso de casos de uso adecuados es valioso para crear un entendimiento profundo de situaciones particulares. Del análisis de un caso concreto, uno puede identificar y describir fenómenos básicos así como descubrir nuevas relaciones y nuevas perspectivas.

Otras características deseables en los juegos educativos son:

- Evaluación (en inglés, *assessment*), se conoce como la capacidad de realizar informes o análisis de la interacción del alumno con el juego. Gracias a esta característica, se pueden conocer los resultados del jugador sin necesidad de realizar entrevistas o exámenes posteriores para verificar si se ha obtenido el resultado educativo deseado (Shute, Ventura, Bauer, & Zapata-Rivera, 2009; Squire, 2004). Otra ventaja de la evaluación es que los jugadores no necesitan de la continua presencia del profesor para evaluar su progreso.
- Adaptación es la capacidad que tienen los juegos para adecuarse en tiempo de ejecución a las necesidades de los diferentes alumnos (Carro, Breda, Castillo, & Bajuelos, 2006; Peirce, Wade, & Conlan, 2008). Por ejemplo, si es la primera vez que se accede al juego puede ser conveniente que se active una ayuda para guiar al jugador e informarle de las reglas y objetivos. Sin embargo, si el jugador ya ha accedido en otras ocasiones, se puede obviar esta información. Adaptaciones más complejas pueden permitir que el juego se adapte a diferentes estilos de aprendizaje (p.ej. más repeticiones frente a más análisis).

Finalmente, hay otros factores a tener en cuenta, como son las emociones, actitudes, intereses, y las influencias sociales y culturales. Los mejores juegos educativos envuelven al jugador emocional, social y culturalmente en formas que el aprendizaje tradicional no siempre puede.

2.1.2 Beneficios de los videojuegos educativos

El potencial ya mencionado de los juegos educativos ha hecho que éstos se conviertan en un campo de investigación muy activo. Así, hoy en día existen numerosos estudios que comienzan a aportar algo de luz a la razón por la que los videojuegos son tan atractivos.

La teoría del flujo (del inglés *"flow theory"*) fue propuesta por Mihaly Csikszentmihalyi para describir el estado de concentración, interés y disfrute de las personas que se involucran voluntariamente en una actividad que les resulta motivadora. Algunos autores (A Amory, Naicker, Vincent, & Adams, 1999; Cordova & Lepper, 1996; Lepper & Cordova, 1992; T. Malone, 1981) destacan la capacidad que tienen los videojuegos para proporcionar mecanismos que incrementen el interés de los estudiantes por adquirir conocimientos mediante esta "motivación intrínseca"(del inglés "*intrinsic motivation*"), donde son los elementos del juego en sí los que atraen y conducen al jugador a utilizarlo.

Shaffer (Shaffer, Squire, Halverson, & Gee, 2004) destaca otros posibles beneficios como son el aprendizaje situado, las prácticas sociales efectivas y el desarrollo de valores compartidos. Estas características son replicables a la hora de diseñar juegos educativos, aunque no siempre es tarea sencilla (Johnson et al., 2011).

Existen además numerosos estudios, como los citados en (Rosas, Nussbaum, Cumsille, Marianov, & Lo, 2003; Rosas, Nussbaum, López, Flores, & Correa, 2000) que defienden que los juegos tienen un papel muy importante en el proceso de desarrollo de las personas en general, pero sobre todo de los niños, quedando suficientemente probado que favorece distintas habilidades sociales y cognitivas. Vygotsky (Vigotsky, 1976), presenta el juego como un espacio de ensayo para los niños que promueve el desarrollo general del niño ya que ensaya reglas, capacidades y limitaciones que después podrá extrapolar a situaciones reales con cierta garantía de éxito.

Los juegos estimulan la curiosidad gracias a la presencia de retos, elementos de fantasía y novedades e influencian el aprendizaje a través de la visualización, experimentación y creatividad y, a menudo, ayudan al desarrollo del pensamiento crítico a través del descubrimiento y la resolución de problemas, la manipulación de objetos, los logros y la competición.

Granic (Granic et al., 2014), presenta un resumen de algunos de los beneficios de los juegos educativos centrándose en 4 aspectos principalmente:

- Beneficios cognitivos: Algunos tipos videojuegos estimulan el desarrollo o la mejora de habilidades cognitivas. Estas habilidades adquiridas se pueden extrapolar al mundo real.

- Beneficios motivacionales: Los entornos de juego pueden ayudar a desarrollar un carácter persistente y optimista en los jugadores gracias a la retroalimentación inmediata que informa a los jugadores de los esfuerzos concretos o avances que han realizado. Este carácter adquirido puede trasladarse a contextos reales.
- Beneficios emocionales: Aunque está claro que los juegos son divertidos y que generan emociones positivas normalmente, todavía no hay evidencia científica de las consecuencias de las experiencias emocionalmente positivas mientras jugamos. Los videojuegos no solo generan emociones positivas, también activan emociones negativas, incluyendo la frustración, el enfado, la ansiedad o la tristeza.
- Beneficios sociales: En los juegos actuales, los jugadores parecen adquirir importantes habilidades pro-sociales cuando juegan a juegos diseñados para recompensar la cooperación efectiva, el apoyo entre compañeros o los comportamientos de ayuda.

2.1.3 Diseño efectivo de videojuegos educativos

La gran mayoría de los estudios de investigación realizados sobre la educación basada en juegos se centran en los resultados obtenidos, en la efectividad de los juegos en la retención de conocimientos, en la motivación o en la actitud de los jugadores pero no está tan estudiado ni existen metodologías ampliamente probadas y aceptadas sobre como diseñar correctamente un videojuego para potenciar al máximo estas características educativas.

Por tanto, para tener una referencia se puede acudir a algunas de las teorías de aprendizaje que se utilizan a la hora de definir los principios de diseño de juegos:

1. Constructivismo: La teoría de constructivismo, o *"learning by doing"*, de Piaget, es una aproximación clásica a la educación que ha retomado protagonismo con la nueva era digital. La herramientas digitales actuales pueden adaptarse a las necesidades y las habilidades de los estudiantes individualmente y motivarles con tareas interactivas que les suponen un desafío o que simulan situaciones de la vida real, dejando atrás prácticas en las cuales los profesores les dicen a los alumnos que tienen que aprender y como tienen que aprenderlo en lugar de fomentar la curiosidad natural de cada uno y propio estilo de aprendizaje. Varios estudios de investigación demuestran que los videojuegos correctamente diseñados se alinean con los principios del constructivismo (Dickey, 2006; Gee, 2003). En el constructivismo los estudiantes son participantes activos de su propio aprendizaje, construyendo su propia comprensión de nuevos conceptos y experiencias y relacionándolos con las estructuras de conocimiento existentes. Los estudiantes interiorizan la información, crean hipótesis y toman decisiones de la misma forma que cuando juegan a videojuegos (Donovan, 2012).
2. Construccionismo: La teoría del construccionismo propuesta por Seymour Papert, defiende que el conocimiento es construido por quien aprende. El construccionismo expresa la idea de que esto sucede particularmente cuando el aprendiz se compromete en la elaboración de algo

que tenga significado social para él y que, por tanto, pueda compartir. Esta teoría puede resultar una herramienta de diseño muy potente para convertir las actividades pasivas en altamente interactivas, generando experiencias educacionales muy ricas. Ya ha sido utilizada con éxito para animar a los niños a desarrollar videojuegos, pero también puede utilizarse a la hora de jugar con ellos fomentando la formación de identidades y el desarrollo de habilidades de resolución de problemas. El jugador puede por ejemplo crearse sus propios personajes u objetos y compartirlos con otros jugadores. Diseñar niveles de juego en los cuales se utilizan "componentes" y no objetos completos, para superar obstáculos permiten al jugador construir sistemáticamente diferentes soluciones a los problemas y desarrollar relaciones entre sus construcciones. Además, compartir los objetos y personajes construidos puede fomentar la creación de una comunidad de aprendices en la cual unos "deconstruyen" lo que otro ha construido y proponen nuevas ideas y soluciones (Holbert, Penney, & Wilensky, 2010; Kafai, 2006)

3. Aprendizaje situacional: La teoría del aprendizaje situacional tiene sus raíces en el conocimiento situado. Esta teoría propone que el aprendizaje efectivo ocurre a través de actividades y contextos auténticos. El aprendizaje basado en juegos facilita este tipo de aprendizaje, ya que los alumnos tienen que resolver problemas del mundo real en contextos similares. Hay evidencias de que el aprendizaje situacional mejora la transferencia de aprendizaje (Halverson, Shaffer, Squire, & Steinkuehler, 2006).

Los elementos más importantes a tener en cuenta a la hora de diseñar un videojuego educativo son descritos en las siguientes subsecciones (Dondlinger, 2007):

2.1.3.1 Motivación e Implicación

Según (Donovan, 2012) la implicación y la motivación son claves en el diseño de los videojuegos. Los diseñadores utilizan teorías y modelos motivacionales como ARSC (Keller, 2000) para el desarrollo de sus *frameworks* para el aprendizaje efectivo. Como ya se explicado anteriormente los videojuegos son capaces de motivar a los estudiantes de forma intrínseca. Malone y Lepper (T. W. Malone & Lepper, 1987) defienden que los juegos logran un nivel de motivación tan elevado en los estudiantes gracias a una combinación de factores personales (control, objetivos, retos, curiosidad y dominio…) y de factores interpersonales (cooperación, competitividad y reconocimiento).

2.1.3.2 Contexto narrativo

El contexto narrativo es fundamental para el diseño efectivo de los videojuegos. (Dickey, 2006) demostró que los entornos educativos 3D no solo tienen un contexto narrativo para situar y ayudar al estudiante a entender el contexto, sino que también facilitan las relaciones espaciales en lugar de las lineales. Los contextos narrativos ofrecen al estudiante un "entorno cognitivo para la resolución de problemas", esto es debido a que las historias en los juegos proveen a los jugadores de un contexto y entorno en el cual pueden identificar y construir patrones integrando lo que ya conocen (la historia previa, las reglas, el entorno etc.) con lo que se está suponiendo o puede pasar a medida que avance el juego.

Dickey propone un método para el uso de elementos de narración en el diseño de videojuegos que tiene los siguientes pasos:

- Reto inicial: Es fundamental que la historia se centre en el objetivo educativo que es el problema a resolver.
- Obstáculos y retos: otros obstáculos y retos más pequeños en la historia que cuando se abordan se convierten en los procedimientos, habilidades y conocimientos que ayudarán a los estudiantes a completar el reto en un entorno educativo.
- Roles: Cada personaje de la historia deber tener uno o varios roles (Vogler, 1998). Normalmente, el rol más importante lo adquiere el protagonista, el jugador.
- Entorno: Es fundamental definir las distintas dimensiones del juego para establecer un entorno adecuado (Rollings & Adams, 2003). La dimensión física define el espacio donde se mueve el jugador, la dimensión temporal define que función tiene el tiempo en el juego, la dimensión ambiental define si la apariencia del entorno será real o ficticia, el contexto histórico y la localización geográfica del juego. Es importante tener en cuenta también la dimensión emocional que permitirá definir qué emociones sienten cada uno de los personajes. Gracias a la definición de estas dimensiones se mejora la credibilidad de la historia y se incrementa la motivación al lograr una mayor inmersión en el juego.
- Antecedentes y contexto*:* Es necesario proporcionar al jugador un contexto para que se sepa quién es el personaje principal, cuál es su rol y que pueda entender mejor la situación en la que se encuentra.
- Uso de escenas intermedias: Las escenas intermedias son partes del juego no interactivas que ayudan a unir puntos separados de la historia y además se pueden utilizar para dar información importante sobre los objetivos a lograr. Esta información puede consistir, por ejemplo, en un video de retroalimentación sobre cómo ha realizado el jugador sus tareas o en otro tipo de información sobre los retos con los que debe enfrentarse.

2.1.3.3 Objetivos y Reglas

El jugador necesita tener unas reglas a seguir así como unos objetivos claros a lo largo del juego. Está demostrado que en los juegos educativos efectivos, el tener varios niveles ayuda al jugador a mantener la motivación. Así, los diseñadores suelen buscar objetivos a corto plazo (lograr recompensas, o bonus sorpresa), a medio plazo (lograr una vida extra por acumulación de puntos) y a largo plazo (salvar el mundo, curar al paciente etc.), este último objetivo suele durar todo el juego. Los niveles permiten también adecuar mejor la dificultad a las capacidades del usuario de modo que se incrementa la motivación y se evita la frustración.

2.1.3.4 Interactividad y Control

El grado de control del usuario en el juego suele estar íntimamente relacionado con su nivel de interactividad. Algunos de los mejores juegos educativos son aquellos altamente interactivos que logran un equilibrio entre el grado de control que impone el juego con la capacidad de decisión del jugador. Si en un juego, el jugador tiene completa libertad de interacción, este se puede volver aburrido y dejar de suponer un reto interesante. Por otro lado, si el control que ejerce la lógica del juego es excesivo, el jugador puede pasar a ser un observador pasivo y dejar de ser un participante activo del aprendizaje. Así que es necesario encontrar el equilibrio adecuado entre estos dos extremos para que los jugadores crean que son libres de interactuar, a pesar de que sus opciones estén limitadas por el juego. (Gee, 2003) llama a este concepto el principio del "Régimen de competencia", que establece que el juego pone al jugador al límite de sus habilidades.

2.1.4 Modelos de desarrollo de videojuegos educativos

En la literatura no existen modelos o *frameworks* ampliamente aceptados y probados que definan como se debe desarrollar correctamente un videojuego educativo para que sea exitoso y efectivo. No obstante, se han encontrado dos trabajos en esta línea que nos parecen especialmente relevantes.

En primer lugar, (Alan Amory, 2006) en su trabajo "Game object model version II: a theoretical framework for educational game development" presenta una evolución del framework que ya propuso en el año 2001 para el desarrollo de juegos. Propone un "modelo de juego basado en objetos" (GOM II, *Game Object Model II*), este framework consiste en un sistema de objetos complejos interrelacionados para describir juegos educativos (ver Figura 4).

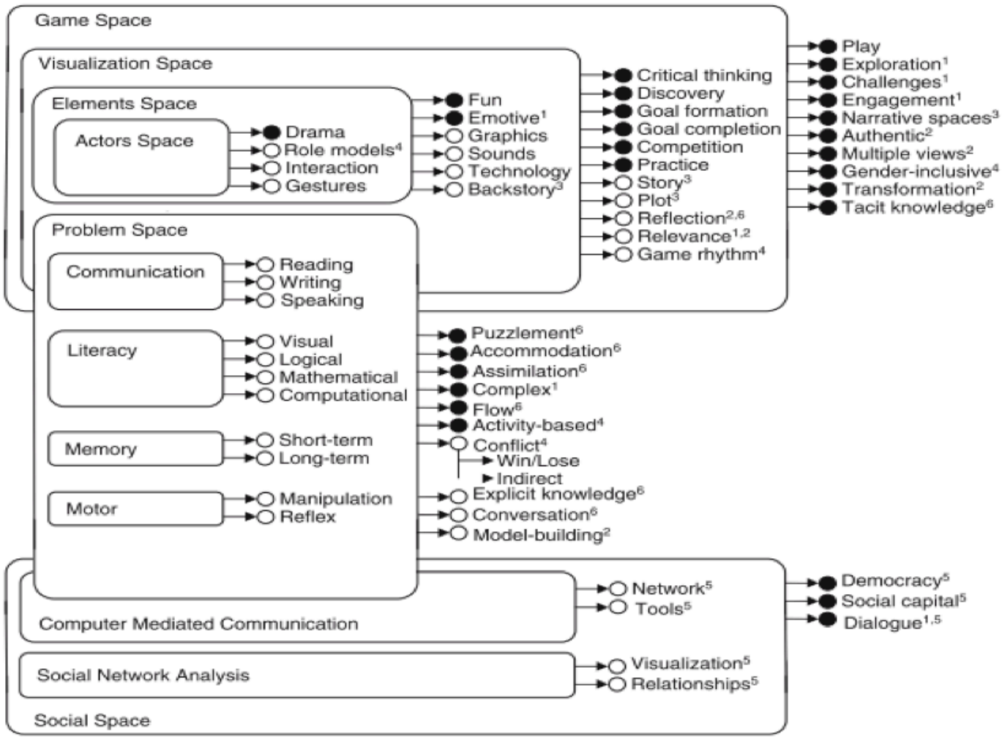

Figura 4 Modelo de Juego basado en Objetos II (Amory)

El segundo framework para diseñar juegos serios es SGDA (Serious Game Design Assessment) (Mitgutsch & Alvarado, 2012). Este framework defiende la importancia de analizar primero el diseño conceptual de un juego, sus elementos y establecer una relación entre ellos basada en el objetivo del juego. Es un intento de ofrecer una base de estudio sobre como el diseño de elementos se configura formalmente y conceptualmente en función del objetivo. Se identifican 6 componentes esenciales de la estructura conceptual de un juego serio (ver Figura 5). Estos 6 componentes son:

- El objetivo del juego. Este objetivo debe quedar reflejado en todos los elementos del sistema. Todo juego tiene ciertos objetivos y los diseñadores deben seguir una serie de instrucciones explícitas e implícitas para que se cumplan a la hora de diseñarlo.
- El contenido e información. Se refiere a la información, hechos y datos ofrecidos y utilizados en el juego. Esta información muestra todos los datos visibles por los jugadores, debe ser válida y de fácil acceso.
- Mecanismos de juego. Son los métodos invocados por los diversos agentes (jugador u otros personajes) para interactuar con el mundo virtual. Los mecanismos implican el establecimiento de reglas. Además, en este framework se incluye un sistema de recompensas y un conjunto de retos y obstáculos.
- Ficción y la narrativa. Mientras el contenido tiene la información y los mecanismos de juego impactan en las posibilidades de juego, la dimensión de la ficción y la narrativa introduce el contexto ficticio. Este framework se centra en crear un espacio de ficción que debe mantener una estrecha relación con el objetivo del juego. La ficción y narrativa

implica la descripción de un contexto, una historia, un escenario, personajes, historias previas, problemas y conflictos, etc.

- Estética y gráficos. Se refiere al lenguaje audiovisual (características estéticas, imágenes, preferencias de estilo, medios artísticos y las técnicas gráficas utilizadas) elegido por los diseñadores para la visualización de los elementos del juego. La estética y los gráficos definen de manera general como se va a mostrar el contenido (información), la ficción (el contexto y caracteres), el marco (los jugadores objetivo), y los mecanismos (instrucciones y recompensas).
- El marco del juego. Este aspecto contempla el tipo de personas que van a utilizar este juego serio y su experiencia con el juego.

La relación entre estos 6 componentes impacta en la coherencia y la cohesión global del sistema.

Figura 5 SGDA Framework

2.1.5 Resultados obtenidos con los videojuegos educativos

A continuación se resumen algunas conclusiones de diversos estudios de investigación sobre los resultados obtenidos en el uso de videojuegos educativos. Aunque la mayoría de los estudios presentan conclusiones razonablemente positivas, el tema no se puede considerar cerrado debido a que los casos son relativamente pequeños, en entornos muy concretos, en muchos casos difíciles de generalizar a otros entornos o volúmenes más grandes, así como el hecho de que existan algunos estudios con resultados directamente negativos o que identifican aspectos problemáticos del uso de este enfoque.

Hay diversos estudios sobre la mejora de los resultados de aprendizaje y de la motivación. Por ejemplo, en 1997, Wolfe (Wolfe, 1997) presenta un meta-análisis, en el cual examinó 7 publicaciones de investigación sobre el uso de videojuegos educativos para enseñar gestión estratégica. En los 7 estudios, la aproximación basada en juegos mejoró los resultados de aprendizaje y de conocimiento en comparación con las aproximaciones convencionales. En el año 2006, Vogel (Vogel et al., 2006) presenta un meta-análisis donde defiende que los juegos promueven una mejor actitud frente al aprendizaje que otros métodos tradicionales.

En (Sitzmann, 2011), se realiza un estudio de 65 publicaciones relativas al uso de la educación basada en juegos para analizar la efectividad de los juegos educativos para el aprendizaje de conocimientos y habilidades en el trabajo. Sitzmann concluye que el [4]conocimiento procedimental era una 14% superior y el conocimiento declarativo un 11% superior en estudiantes que utilizaban aproximaciones de educación basada en juegos en comparación con estudiantes que utilizaban otras aproximaciones (incluyendo e-Learning). Además, comprobó que los niveles de motivación e implicación mejoraban cuando se implicaba activamente al jugador en el juego. Visto que la edad media entre los jugadores en 55 de los trabajos analizados era 23, consideró esto como un hecho importante, ya que hoy en día, casi todas las organizaciones encuentran problemas a la hora de motivar, implicar e incluso retener a los jóvenes. Esto sugiere que si se identifican maneras de lograr un cambio de actitud por medio de los juegos esto podría beneficiar a las organizaciones. Finalmente, Sitzmann, en su estudio comprobó que la educación basada en juegos también tenía impacto en la retención y transferencia de información, viendo que los estudiantes que usaban estos métodos tenían un 20% más de confianza y creían poder realizar las tareas asignadas. Este es un hecho interesante, ya que gracias a las entrevistas realizadas como parte de este estudio por Sitzmann a los responsables de los programas de e-Learning, se sabe que las compañías son conscientes de que los conocimientos, habilidades y comportamientos requeridos o deseados por éstas no estaban siendo correctamente transmitidos por medio de los sistemas actuales.

Connolly (Connolly et al., 2012) realiza un análisis de las publicaciones sobre *serious games* y juegos educativos para determinar el impacto positivo del juego en usuarios de más de 14 años, centrando su investigación en los resultados de aprendizaje, adquisición de habilidades y motivación. Connolly concluye que aunque parece que hay indicios positivos todavía es necesaria una evidencia más rigurosa sobre la efectividad de los juegos y su impacto real.

Finalmente, hay otros estudios con resultados mixtos. Por ejemplo, en (Girard, Ecalle, & Magnan, 2013) se estudian 11 juegos educativos diferentes. Tres de estos juegos (dos juegos serios y un juego

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virtual) demostraron tener un efecto positivo en el aprendizaje en comparación con otros tipos de entrenamiento. Otros siete juegos (tres juegos serios y cuatro juegos virtuales) no tuvieron ningún efecto beneficioso en el aprendizaje. Por último, los resultados obtenidos para un juego concreto (Triage Trainer) fueron mixtos, debido a la falta de precisión cuantitativa y cualitativa de muchos estudios, no fue posible evaluar formalmente el aprendizaje.

Vale la pena remarcar que, como es evidente, también existen numerosos estudios contrarios a los juegos educativos. La mayoría de estos estudios se centran en los resultados negativos que los juegos en general pueden proporcionar como, por ejemplo, la dificultad para regular la cantidad de tiempo que se dedica al juego, la adicción o el aislamiento social que los juegos pueden generar (Connolly et al., 2012). Otros estudios argumentan que el uso de los portátiles puede dificultar el aprendizaje en la clase tanto para aquellos que los utilizan como para sus compañeros (Sana, Weston, & Cepeda, 2013), los más críticos aseguran que el aprendizaje digital afecta seriamente a la lectura.

Una vez presentadas las principales características de los juegos educativos en general, en la siguiente sección se analizan los juegos educativos aplicados al campo de la medicina.

2.2 Los juegos educativos en medicina

Los juegos educativos en medicina no difieren demasiado de las características, beneficios y resultados de los juegos educativos presentados en las secciones anteriores. Así, en esta sección se abordaran aquellas diferencias significativas, características remarcables, y los mayores retos a los que se enfrentan este tipo de juegos educativos hoy en día.

Aunque en medicina los juegos educativos se han empezado a generalizar en los últimos años, las simulaciones si están ampliamente aceptadas y se han estado usando (sobre todo basadas en maniquíes médicos) durante mucho más tiempo (Rosen, 2008). Esto ha hecho que en medicina exista una frontera difusa entre las simulaciones software, las simulaciones con estrategia de juego o los juegos serios de modo que en muchos casos estos términos se utilizan de forma casi equivalente (Alinier, 2007).

En el año 2010 (McGaghie, Issenberg, Petrusa, & Scalese, 2010) proponen doce características y buenas prácticas para el uso de simulaciones educativas en medicina:

1. Retroalimentación: Ya definida en secciones anteriores.
2. Practica deliberada (del inglés "*deliberate practice*"(Ericsson, 2008; McGaghie, Issenberg, Cohen, Barsuk, & Wayne, 2011): Es uno de los conceptos más recurrentes en los juegos educativos en medicina. Es una variable educacional que respalda la idea de que las prácticas deben ser consistentes y orientadas a promover el dominio de las habilidades y la adquisición del conocimiento. Esta variable tiene las siguientes características:
    - Estudiantes muy motivados con buena concentración.

- Implicación con un objetivo educativo bien definido a un nivel de dificultad adecuado con una práctica repetitiva controlada.
- Retroalimentación objetiva donde los estudiantes también monitorizan sus experiencias y corrigen estrategias y errores, con lo que se implican aún más en la práctica deliberada.
- Finalmente, se evalúa el aprendizaje para ver si se ha alcanzado un estándar de maestría para poder continuar con la siguiente tarea.

3. Integración en los planes de estudio: Las simulaciones médicas deberían ser introducidas en los planes de estudio médicos (Akl, Gunukula, et al., 2010). La figura 6 representa el uso de los juegos educativos en los programas de residencia americanos. La educación basada en simulaciones médicas es una aproximación educacional que tiene una gran efectividad a la hora de lograr los objetivos educativos en comparación con otros métodos. Sirve como complemento a la educación clínica pero no puede sustituir a las prácticas con pacientes real en un entorno real.

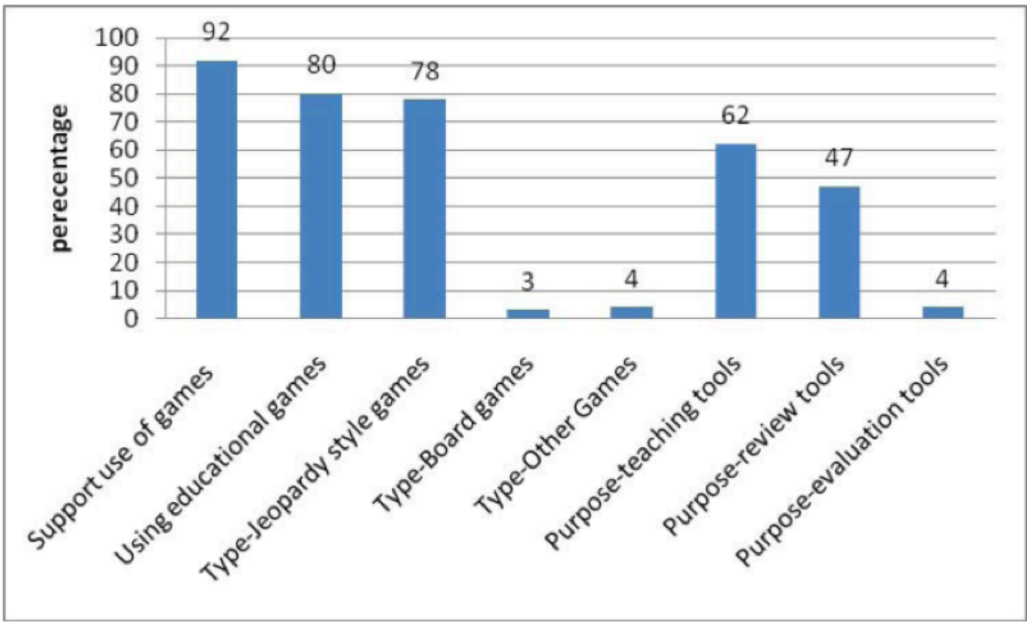


Figura 6 Uso de los juegos educativos en USA por parte de los residentes. Akl EA, Gunukula S, Mustafa R, et al. Support for and aspects of use of educational games in family medicine and internal medicine residency programs in the US: a survey. BMC medical education. 2010;10:26.

4. Medida de resultados: Que facilitan la obtención de "datos fiables" del entrenamiento o práctica. Estos datos fiables tienen una relación de "señal frente a ruido" muy elevada, en donde la señal se refiere a información sobre la capacidad del aprendiz y el ruido representa los errores aleatorios no válidos (excluibles). Estos datos fiables son la base que necesitan los educadores para tomar decisiones válidas, juicios o conclusiones bien fundamentadas sobre los estudiantes. Son fundamentales para proveer al estudiante de una realimentación precisa sobre su progreso y para obtener argumentos que apoyen los resultados de investigación. Destacan tres formas de medir los resultados en simulaciones médicas: la

observación, las respuestas de los estudiantes y los sensores de los simuladores que miden, por ejemplo, la sensibilidad del estudiante en las intervenciones.

5. Simulación fiel (*simulation fidelity*): Un principio clave es que los objetivos educativos son los que dictan las decisiones sobre la complejidad tecnológica de las simulaciones médicas a utilizar.
6. Adquisición de habilidades y su retención: Este es el objetivo más común de las simulaciones médicas. La adquisición de habilidades es una de las habilidades que más atención consigue por parte de los investigadores, también el análisis del tiempo que se retienen estas habilidades. Parece que las habilidades adquiridas se olvidan más o menos rápido dependiendo del tipo de habilidad, el grado de aprendizaje de la habilidad y el tiempo pasado entre el aprendizaje y el momento de comprobar si se mantiene. Todavía es necesario realizar más investigación en este campo.
7. Dominio de lo aprendido (del inglés "*mastery learning*"): El mastery learning contiene un conjunto de ideas teóricas y prácticas sobre la enseñanza individualizada que ayudan a la mayoría de los estudiantes a aprender mejor, más rápidamente y con mayor seguridad en sí mismos. Estas prácticas e ideas dan lugar a una enseñanza sistemática, que ayuda a los estudiantes cuando se presentan dificultades en el aprendizaje, les permite tener todo el tiempo que necesiten para adquirir el dominio y les proporciona un criterio claro de lo que constituye ese dominio (López, 2006). Al final, el objetivo es asegurarse que todos los aprendices consiguen todos los objetivos educativos con poca variación de resultado. Sin embargo, el tiempo que se necesita para lograr estos objetivos varía dependiendo del estudiante.
8. Transferencia a la práctica real: Es necesario que las habilidades aprendidas se puedan aplicar en un entorno real. Este es un aspecto difícil de probar formalmente.
9. Entrenamiento de equipo: El 70% de los errores en las prácticas clínicas son debidas a problemas de comunicación. Otros signos de problemas de trabajo en equipo en la práctica clínica son la falta de objetivos comunes, la claridad de los roles, el liderazgo, coordinación, respeto mutuo etc., que provocan resultados adversos en pacientes. Lograr un buen trabajo en equipo es un objetivo educacional importante. Las simulaciones médicas permiten ejercitar tanto las relaciones entre el equipo como las tareas a realizar en un entorno seguro, y de nuevo, sin consecuencias sobre el paciente.
10. Evaluaciones finales: La estandarización, fidelidad y reproductibilidad de las simulaciones médicas hace que esta técnica sea buena para las evaluaciones formativas y finales (*summative assessment*). Las evaluaciones formativas son para la práctica y retroalimentación, sin embargo, las finales son para otro tipo de decisiones, como conseguir una certificación o aprobar un examen.
11. Entrenamiento con instructor: El rol que tiene el instructor en las simulaciones médicas todavía no está completamente claro. La educación basada en simulaciones médicas no es

sencilla ni intuitiva, el hecho de tener experiencia clínica no es una garantía absoluta para ser buen instructor en este tipo de educación, los instructores de simulaciones médicas no tienen ni siquiera que tener la misma especialidad médica que enseñan.

12. Contexto educacional y profesional: El contexto educativo y profesional tiene efectos muy significativos en la calidad y cantidad de aprendizaje adquirido y en como la competencia profesional se transfiere a la realidad clínica.

En el año 2010, Adams (Adams, 2010) realizó un estudio sobre el uso de los juegos educativos en el campo medico donde definió dos usos claramente diferenciados, con objetivos muy distintos y que es necesario tener en cuenta a lo largo del resto de sección. Es por ello que a continuación se presentan dos subsecciones, una dedicada a los juegos educativos para el entrenamiento médico de profesionales y otra para los juegos educativos diseñados para ayudar a pacientes de diversa índole.

2.2.1 Juegos educativos para profesionales

El sistema educativo en el campo de la medicina, se enfrenta en las últimas décadas a cambios muy significativos derivados, entre otras cosas, de la disminución del tiempo de estancia de los pacientes en los hospitales, de la reducción de las horas de trabajo de los médicos en formación o, en algunos países, de las dificultades de realizar formación con pacientes reales. Esto lleva a una consecuente disminución de tiempo de práctica y aprendizaje de los residentes de medicina que adquirían su experiencia gracias a la interacción con los pacientes.

Una forma de paliar este problema es mediante la utilización de simulaciones médicas. Las simulaciones permiten realizar prácticas con pacientes virtuales durante tanto tiempo como necesite cada profesional, es decir, practicar y realizar procedimientos en un entorno seguro hasta que se logra un adecuado conocimiento o rendimiento (y siempre sin riesgo para el paciente) (Dawson, 2006). Por ejemplo, el *Massachusetts General Hospital,* uno de los hospitales de referencia en Estados Unidos creó en el año 2010 el *Learning Laboratory* (http://www.massgeneral.org/learninglab/) donde ha centralizado toda la simulación para aplicarla como elemento principal en sus procesos formativos tanto para personal médico como para residentes.

Sin embargo, representar procedimientos médicos tanto por medio de simulaciones como de juegos educativos no es tarea sencilla, ya que estos procedimientos suelen incluir el ya mencionado y elusivo conocimiento "tácito" (Friedrich & Poll, 2007; Kothari et al., 2012). Sólo se ha encontrado en la bibliografía una metodología que intenta extraer este tipo de conocimiento de los procedimientos quirúrgicos (Neumuth, Pierre, Strauss, Meixensberger, & Burgert, 2009) para validar la correcta representación del conocimiento por medio de simulaciones. Además, los simuladores médicos (al igual que otros como, por ejemplo, los simuladores de vuelo) tienen condiciones añadidas ya que necesitan representar los procedimientos de forma muy precisa y con un alto grado de realismo para permitir un aprendizaje correcto (p.ej., para el caso de los simuladores quirúrgicos), lo cual suele requerir el uso de la tecnología más avanzada, que suele tener un elevado coste (p.ej. simuladores hápticos en los que el usuario puede incluso percibir la fuerza realizada).

En (Lammers et al., 2008) se analizan cuáles son las condiciones óptimas para el aprendizaje de procedimientos médicos por medio de simuladores. Algunas de las conclusiones obtenidas son:

- Los métodos más efectivos y eficientes para aprender procedimientos médicos a través de simulaciones son aquellos que:
    - Proveen al estudiante de retroalimentación mientras están realizando la práctica.
    - Permiten repetir la práctica tantas veces como sea necesario.
    - Presentan distintos niveles de dificultad durante la práctica.
    - Se realizan en un entorno controlado, con aprendizaje individualizado y con resultados medibles y claramente definidos.
- El número de veces que es necesario repetir un procedimiento para dominarlo no está claramente definido, ya que varía dependiendo del procedimiento y del estudiante que lo practica.
- Todavía no existen métodos para medir la curva de aprendizaje de los procedimientos médicos aprendidos por medio de simulaciones. Uno de los objetivos de los simuladores es transferir una porción de la curva de aprendizaje a las prácticas en laboratorio, permitiendo que la primera vez que los estudiantes estén realizando los procedimientos con un paciente real, tengan un dominio adecuado del procedimiento.

A continuación se presentan algunos de los resultados obtenidos para este tipo de videojuegos educativos.

2.2.1.1 Resultados obtenidos con profesionales

En esta sección se presentan algunos estudios sobre cuál es la eficiencia de aplicar juegos o simulaciones con profesionales del campo de la medicina. La conclusión general es que aunque hay resultados prometedores, e incluso pruebas de que son efectivos, sigue siendo un campo abierto en el que hace falta más investigación para poder probarlo formalmente.

En el año 2010 en (Akl, Pretorius, et al., 2010) se presenta un estudio para analizar el efecto de los juegos educativos en los estudiantes de medicina tratando de analizar si con el uso de los juegos se obtenían mejores resultados o no. Lamentablemente, su estudio concluye con que todavía no existían datos suficientes como para afirmar la utilidad de los videojuegos educativos como estrategia de enseñanza para los estudiantes de medicina. Akl sugiere que se necesitan más estudios y mejor diseñados para analizar y evaluar la efectividad de estos juegos. También en el año 2010, (Cook, Erwin, & Triola, 2010) realizaron un estudio sobre el uso de pacientes virtuales para el entrenamiento de profesionales médicos en comparación con otras técnicas. Cook también llega a la conclusión de que aunque el uso de pacientes virtuales tiene muchos efectos positivos, no hay pruebas de que sus efectos sean mejores o peores que otros métodos tradiciones, por lo que recomienda ampliar y continuar con la investigación.

Un año más tarde, Cook presentó otro estudio (Cook et al., 2011) para comparar el uso de las simulaciones con otros métodos educativos en medicina. Entre las conclusiones obtenidas, Cook, que sigue afirmando que son necesarios más estudios de investigación, afirma que salvo por excepciones contadas, el uso de simulaciones mejora los resultados de aprendizaje, el conocimiento, las habilidades y la confianza.

En (Cunningham, Fernando, & Berlingieri, 2010) se presentan los resultados obtenidos en el aprendizaje de la realización de endoscopias por medio de simulaciones informáticas, donde los aprendices demuestran un aprendizaje más rápido de las etapas iniciales, viéndose también afectada la transferencia al paciente real, con mejoras en el rendimiento y una disminución de las disconformidades en los procedimientos. Las limitaciones identificadas son el coste de los simuladores y la falta de consenso sobre el rol que adquieren estos simuladores para certificar el entrenamiento.

Finalmente, en el año 2012, (Graafland, Schraagen, & Schijven, 2012) se presentó una revisión sobre el uso de juegos educativos en medicina y para el entrenamiento de habilidades quirúrgicas donde se remarcó la necesidad de realizar procedimientos de validación de las simulaciones. Se revisaron 30 juegos educativos en medicina, de los cuales 17 tenían fines educativos concretos y otros 13 eran juegos comerciales que podían ser útiles para desarrollar habilidades médicas. Ninguno de los 30 juegos había seguido un proceso de validación completo para comprobar que el objetivo educativo para el que se habían desarrollado se adquiría finalmente.

2.2.2 Juegos educativos para pacientes en tratamiento

El juego es fundamental en el desarrollo social, especialmente en niños, donde su formación depende del desarrollo de ciertas habilidades y roles y de probarse a sí mismos. Hoy en día los niños (y no tan niños) juegan en su tiempo libre con videojuegos. A pesar del miedo que en ocasiones han generado los videojuegos por poder fomentar la violencia, es cierto que se ha demostrado que en general ayudan a los jugadores a aprender y adquirir habilidades(Thai, Lowenstein, Ching, & Rejeski, 2009). Los videojuegos también son efectivos para mejorar la salud de los jugadores fomentando la actividad física o modificando actitudes frente a enfermedades.

Desde los años 80, se pueden encontrar diferentes artículos en la literatura que describen el uso de los videojuegos para uso terapéutico en diferentes tipos de pacientes. Muchos de estos trabajos son para niños ya que en esa época la media de edad de los jugadores de videojuegos era bastante baja. Con el tiempo, estos videojuegos han ido adquiriendo mayor sofisticación y el mercado fue ampliándose hacia todas las edades.

Es importante estudiar qué tipo de habilidades y roles tienen que ser enseñados por medio de un juego, por ejemplo se pueden utilizar para enseñar cómo vivir con una enfermedad crónica o sencillamente para explicar pautas de alimentación. Existen numerosos videojuegos educativos orientados a pacientes con tratamiento, quizás el más representativo y conocido es Re-Mission (juego que se puede descargar gratuitamente en http://www.re-mission.net/), que sitúa al jugador dentro del cuerpo humano y cuyo objetivo principal es la identificación y destrucción de las células cancerígenas. Otro videojuego relevante es Playmancer, que trata un tema completamente diferente ya que está orientado a pacientes con problemas psicológicos.

2.2.2.1 Resultados obtenidos con pacientes en tratamiento

En esta sección se presentan algunos estudios sobre cuál es la eficiencia de aplicar videojuegos con pacientes en tratamiento. La conclusión general es que los videojuegos educativos pueden ser efectivos para pacientes en tratamiento por su capacidad para incrementar la motivación de los pacientes, los cuales tiene en ocasiones que seguir procedimientos dolorosos (p.ej. quimioterapia) o rutinarios (p.ej. tomar pastillas diariamente, ejercicio constante etc.) que no favorecen su continuidad.

- Nauseas en el cáncer pediátrico: Se ha demostrado que los videojuegos tienen efectos terapéuticos en los efectos secundarios provocados por el tratamiento del cáncer (p.ej. nauseas, vómitos, ansiedad, y dolor asociados con la quimioterapia y la radiación).

  En (Redd et al., 1987), se presentan dos experimentos con niños en tratamiento oncológico de diferentes grupos de edad. En este experimento, un grupo experimental jugó con videojuegos durante al menos 10 minutos durante el tratamiento de quimioterapia, mientras que el grupo de control pudo utilizar libros, juguetes o incluso ver la televisión. Los niños del grupo experimental mostraron menor sensación de nauseas que los del grupo de control, lo cual sugiere que los videojuegos de alguna forma tienen la capacidad de distraer y abstraer más que otro tipo de juegos u objetos de entretenimiento.

  Otro estudio (Vasterling, Jenkins, Tope, & Burish, 1993) similar realizó una comparación que pretendía ver si los videojuegos tienen más capacidad de distracción que las técnicas de relajación empleadas en los pacientes con cáncer. Sin embargo, en este trabajo no se encontraron diferentes entre los diferentes grupos, ambos mostraron menor sensación de nauseas, indicando que ambas técnicas son efectivas. Sin embargo, es cierto que las técnicas de relajación necesitan ser guiadas por un especialista, cuyo coste, tiempo y disponibilidad suele ser limitado y muchos hospitales no pueden utilizar estar técnicas. Los videojuegos, por el contrario son menos caros a largo plazo y siempre están disponibles.
- Gestión de la ansiedad: En (Patel et al., 2006) , se realiza un estudio con 112 niños (entre 4 y 12 años) que iban a recibir anestesia general. Se dividió a los pacientes en tres grupos: con sus padres, con sus padres y se les dio un sedante oral, y con sus padres y una Gameboy. Todos aquellos pacientes que no jugaron con la consola mostraron incrementos en su

ansiedad al acercarse el momento de la anestesia. Estos hallazgos son significativos ya que el uso de una consola de mano como es la Gameboy es barato, sencilla de conseguir, transportable y un método efectivo para ayudar a gestionar la ansiedad.

- Terapia física y ejercicio físico: El éxito de los videojuegos como apoyo a las terapias físicas se puede atribuir en gran parte al incremento de motivación y abstracción que éstos añaden a los ejercicios repetitivos y "aburridos" de las terapias. En (O'Connor et al., 2000), se utilizaron videojuegos de carreras con 35 pacientes con daños en la espina dorsal. Se creó un interfaz en el cual la silla de ruedas actuaba con el joystick y, por tanto, los jugadores podían controlar el juego por medio del movimiento de las ruedas de las sillas. Los resultados demostraron que los pacientes mejoraban sus resultados físicos. El desarrollo de nuevos dispositivos de interacción con juegos (p.ej. mandos inalámbricos que disponen de acelerómetros y detectores de posición, cámaras que detectan la posición y movimiento del usuario, o tableros que permiten determinar el peso o equilibrio del usuario) está provocando toda una revolución en estos tipos de videojuegos que se denominan bajo el término genérico de *exergames* (Flynn, Richert, Staiano, Wartella, & Calvert, 2014; Ruivo, 2014).
- Desarrollo de habilidades en grupos con necesidades especiales: Se han utilizado videojuegos para ayudar a desarrollar habilidades sociales en grupos de niños y adolescentes con retrasos severos o problemas de desarrollo como autismo. Los videojuegos proporcionan patrones visuales e historias que ayudan a los niños a desarrollar habilidades básicas. Algunos de los beneficios terapéuticos encontrados son (Griffiths, 2002) mejoras en las habilidades sociales y de comunicación, aprendizaje de matemáticas básicas y lecturas sencillas.

A continuación se presentan algunos de los resultados de investigación de este tipo de videojuegos:

2.2.3 Algunos ejemplos de juegos médicos

En esta sección se presentan, a modo de ejemplo, algunos ejemplos relevantes de juegos médicos tanto orientados a pacientes como a profesionales.

2.2.3.1 Re-Mission

Re-Mission (Kato, 2010) es un juego desarrollado para mejorar el seguimiento de la quimioterapia en adolescentes y jóvenes con cáncer.

Algunos de los elementos de juego incluidos son:

- Objetivo: El objetivo principal de este juego es mejorar el tratamiento.
- Contexto narrativo: En el juego, el jugador controla un nanobot llamado ROXXI que navega por el cuerpo destruyendo células cancerígenas y tumores con quimioterapia y radiación (ver Figura 7). Además, este nanobot también combate los efectos del

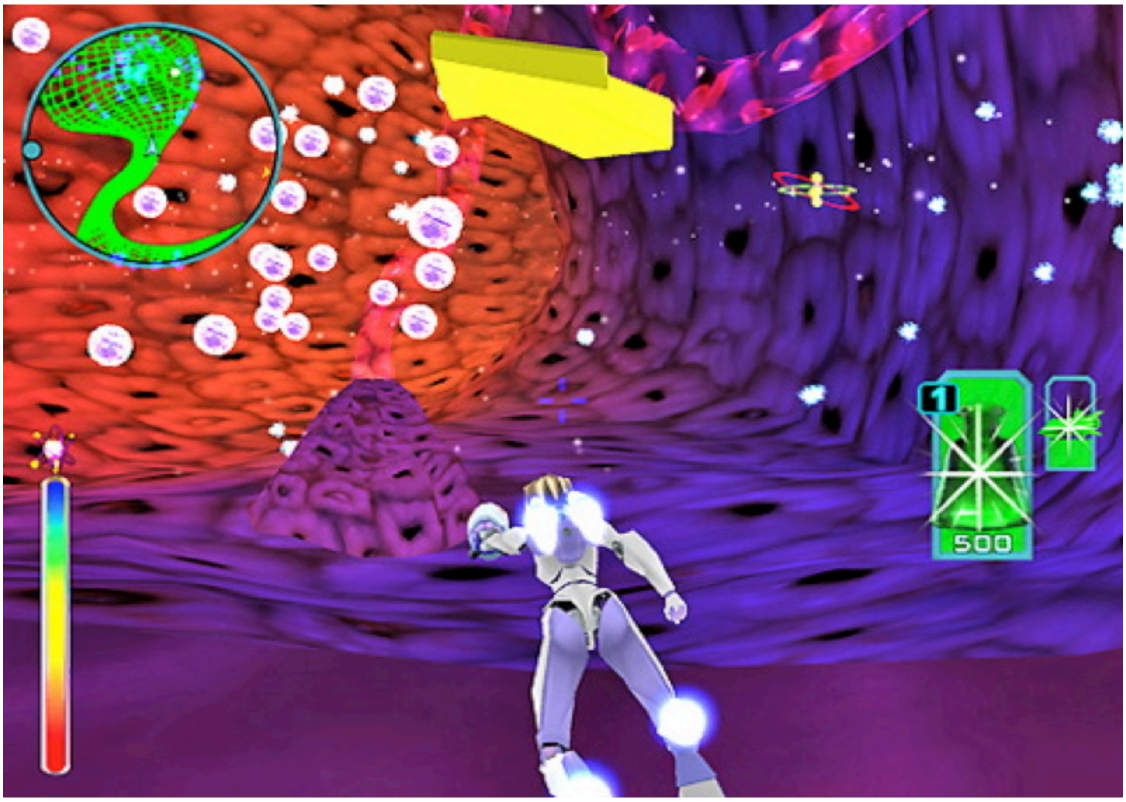


Figura 7 Imagen del videojuego Re-Mission

tratamiento como el dolor, las náuseas, la infección o el estreñimiento. La información se proporciona directamente a través de animaciones e interacciones directas con el entorno.
- Motivación e implicación: Mediante un sistema de puntuación y diferentes niveles de dificultad.
- Retroalimentación: Cada vez que se completa un nivel, el jugador obtiene una retroalimentación básica sobre su actuación.

En un estudio realizado entre 374 pacientes entre las edades de 12 y 29 años en 34 hospitales diferentes se vio que los pacientes que habían jugado con Re-Mission mantuvieron niveles de quimioterapia más elevados en la sangre y tomaron el antibiótico más frecuentemente lo cual sugiere que este tipo de videojuegos puede tener un impacto positivo importante en el comportamiento de los pacientes que se puede relacionar con los resultados de supervivencia.

2.2.3.2 Packy and Marlon

Packy and Marlon(Brown et al., 1997) es un juego orientado a niños con diabetes en el cual los jugadores deben eliminar las ratas que atacan un campamento de verano.

Algunos de los elementos de juego incluidos son:

- Objetivo: Para ganar, los jugadores deben controlar y gestionar correctamente sus niveles de insulina así como la cantidad de comida que comen para mantener los niveles de glucosa.
- Motivación e implicación: Mediante un sistema de puntuación y diferentes niveles de dificultad. Además, el juego permite la partida entre dos jugadores lo cual fomenta la competitividad.
- Evaluación: Durante el juego, se realizan preguntas de diversa dificultad sobre la diabetes.

Este juego fue evaluado durante 6 meses, al final del estudio, los pacientes mostraron una gran capacidad para autogestionar sus niveles de glucosa e insulina, y mejoró la comunicación con los padres sobre la diabetes. No solo eso, sino que este grupo redujo en un 77% las emergencias por diabetes y las visitas a la unidad de cuidados intensivos. Sugiere por tanto que este tipo de videojuegos afectan positivamente en el comportamiento de los pacientes con enfermedades crónicas.

2.2.3.3 Bronkie the Bronchiasaurus

Bronkie the Bronchiasaurus (Griffiths, 2002) ha sido desarrollado para niños con asma, el juego se desarrolla en la prehistoria en un mundo cubierto por polvo.

Algunos de los elementos de juego incluidos son:

- Objetivo: Los jugadores deben ayudar a los personajes a mantener su asma a salvo evitando el polvo y el humo.
- Contexto narrativo: El jugador adquiere el rol de un dinosaurio asmático, Bronkie. Otro dinosaurio rex ha robado la máquina que limpia el aire y Bronkie necesita encontrar la máquina para sobrevivir.
- Motivación e implicación: Mediante un sistema de puntuación y diferentes niveles de dificultad.
- Evaluación: Se incluyen preguntas que el jugador debe responder correctamente para avanzar.

Los estudios demostraron que los pacientes que jugaron al juego demostraron más y mejor conocimiento de los cuidados personales necesarios. Estos hechos continúan demostrando que los videojuegos pueden ayudar a mejorar los conocimientos de salud y fomenta las prácticas saludables entre los jóvenes.

2.2.3.4 SnowWorld

SnowWorld (Hoffman, Patterson, Carrougher, & Sharar, 2001) es un videojuego diseñado exclusivamente para distraer a los pacientes en las curas de quemaduras importantes.

Algunos de los elementos de juego incluidos son:

- Objetivo: Disminuir o disimular el dolor de pacientes con quemaduras durante sus curas.
- Contexto narrativo: El juego presenta a los jugadores una realidad virtual en la cual vuelan sobre un mundo helado, mientras avanzan en el juego pueden lanzar bolas de nieve a los diferentes objetos que aparecen en escena.

Los estudios realizados demostraron que el juego era efectivo para reducir la sensación de dolor en comparación con las intervenciones de anestesia habituales. Aunque no queda claro es si esto es

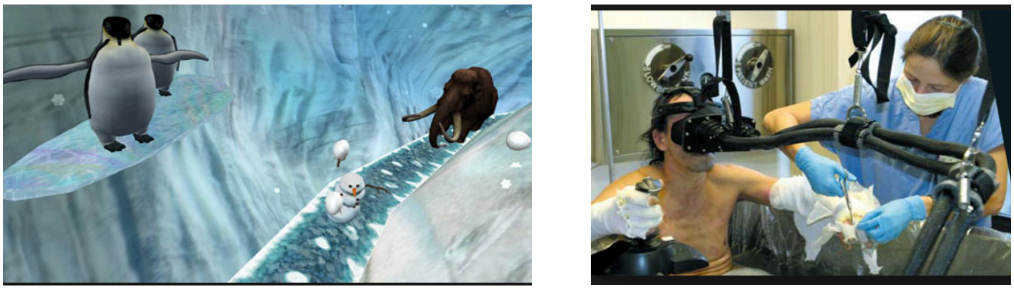


Figura 8 Imágenes del juego SnowWorld.

debido a que temperatura imaginaria del juego indujo un nivel extra de tolerancia al dolor en los pacientes, si es evidente que los pacientes que se sintieron inmersos en el mundo helado reportaron menos dolor. Esto sugiere que los videojuegos de realidades virtuales pueden ayudar a gestionar el dolor en otros pacientes (ver Figura 8). En la figura 8, la imagen de la izquierda es una imagen del juego. La imagen de la derecha muestra cómo un paciente está siendo curado mientras juega.

2.2.3.5 Punción guiada por ultrasonido

En (Chan, Qin, Chui, & Heng, 2012) se presenta un *"serious game"* para el aprendizaje de la punción guiada por ultrasonido. La punción guiada por ultrasonido es fundamental en intervenciones radiológicas como son biopsias o anestesia local donde la precisión es primordial para el éxito de la intervención.

Algunos de los elementos de juego incluidos son:

- Objetivo: Las habilidades básicas a adquirir son el correcto alineamiento de la aguja, el control de la visibilidad de la aguja y la selección del camino adecuado de inserción.
- Motivación e implicación: El juego comienza con escenarios sencillos y, poco a poco, incrementa su dificultad para mejorar las habilidades.
- Evaluación y Retroalimentación: Los resultados obtenidos se muestran al jugador tras cada sesión. Se listan diferentes aspectos en los cuales el jugador puede revisar cómo ha sido su

actuación, y entre otras informaciones, se muestra el tiempo que se ha tardado en terminar y la calidad de las acciones.

Además, este trabajo defiende la importancia de realizar un trabajo de diseño del juego serio previo al desarrollo. Los resultados obtenidos en esta evaluación demuestran que un diseño cuidadoso y detallado ayuda a los estudiantes a adquirir habilidades con mayor eficiencia.

2.2.3.6 Guide-O-Game

En (Akl et al., 2008) se presenta el videojuego educativo Guide-O-Game para enseñar a estudiantes de medicina y residentes las guías de práctica clínicas en medicina.

Algunos de los elementos de juego incluidos son:

- Motivación: Al ser un juego multi-jugador fomenta la competitividad entre los jugadores y ayuda a mantener la motivación.
- Evaluación: Un aspecto interesante es el uso del concepto de la evaluación al final del juego, donde se puede observar qué jugadores han acertado qué preguntas (ver Figura 9). En la Figura 9 la imagen de la izquierda muestra un ejemplo de las preguntas que se le hacen al jugador. La imagen de la derecha, muestra el informe de resultados obtenidos entre dos jugadores.

Este juego toma la forma de un programa de televisión con preguntas basadas en las recomendaciones de las guías. El desarrollo del juego consistió en la creación de una herramienta multimedia interactiva, el análisis de las preguntas a realizar y la definición de las reglas del juego.

Este juego presenta algunos problemas como son la necesidad de actualizaciones cada vez que las guías son actualizadas o el coste del juego y el tiempo dedicado a su desarrollo que aunque en este caso no se puede considerar muy elevado comparado con otros juegos si lo es comparado con el coste del desarrollo de un libro o de fichas de aprendizaje en papel.

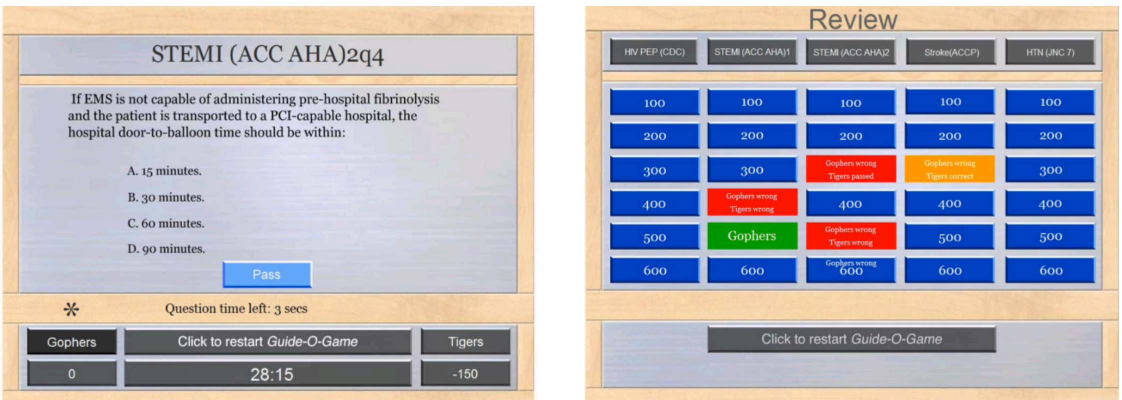


Figura 9 Imágenes del juego Guide-O-Game.

2.2.3.7 Z-DOC

Z-DOC (Shewaga, Knox, Ng, Kapralos, & Dubrowski, 2013) es otro juego serio o "*serious game*" orientado a mejorar el entrenamiento de los residentes y profesionales de la cirugía plástica(ver Figura10).

Algunos de los elementos de juego incluidos son:

- Objetivo: El objetivo de esta simulación es que los jugadores logren una mejor comprensión del procedimiento a través de un entorno de juego divertido, interactivo y seguro.
- Motivación e implicación: El juego cuenta con un sistema de puntuación que se basa en la velocidad, la linealidad y la correcta ejecución del procedimiento para corregir cicatrices. Además las puntuaciones de los jugadores se comparan para motivar la competitividad y la necesidad de mejora.

Figura 10 Imagen del juego educativo Z-DOC

Este videojuego utiliza interacciones point-and-click y está desarrollado para ser usado con dispositivos táctiles. Los jugadores utilizan los dedos de todas sus manos para hacer zoom, rotar y acercarse a cicatrices o defectos de la piel. Se han incluido en el juego instrumentos de cirugía como bisturí o sutura para que el jugador los seleccione y utilice en el procedimiento.

2.2.3.8 Simulador OPCAB

Esta simulación (Cowan et al., 2011; Cristancho et al., 2011) es un "*serious game*" interactivo y multi-jugador que pretende entrenar a los cirujanos cardiacos, y a todo personal médico interesado, en los pasos necesarios a seguir para realizar correctamente el procedimiento quirúrgico de un bypass coronario sin bomba (sin circulación extracorpórea) (OPCAB).

Algunos de los elementos de juego incluidos son:

- Objetivo: El objetivo de la simulación es realizar correctamente el procedimiento siguiendo los pasos en el orden adecuado y utilizando los utensilios correctos, minimizando el tiempo utilizado para terminar el proceso y maximizando la puntuación final (los puntos se suman o se restan dependiendo de la corrección de las acciones del jugador).
- Contexto narrativo: En esta simulación los jugadores inician el juego en una sala de operaciones, donde jugarán y verán las escenas desde una perspectiva en primera persona, es decir, el mundo virtual creado se verá a través de los ojos del avatar (protagonista) y solo se verán sus manos en caso necesario. El jugador interactuará con otros personajes como, por ejemplo, el paciente, los asistentes y las enfermeras. Es una interacción con ratón (point-and-click) de modo que al clicar sobre alguno de los objetos o personajes de la escena se habilitará un menú con las opciones disponibles (p.ej. al hacer click sobre la enfermera se activan las acciones de pedir que acerque algún utensilio de trabajo o que ejecute alguna acción etc.).
- Reglas: El jugador debe conocer los pasos a seguir para terminar el procedimiento y debe seguir una serie de reglas de juego.
- Motivación e implicación: Mediante un sistema de puntuación y varios niveles de dificultad.
- Evaluación: Cada vez que avance en el juego, se le harán una serie de preguntas multi-respuesta para evaluar al jugador sobre el paso del procedimiento que acaba de superar. Contestar correctamente supondrá la acumulación de puntos.

El desarrollo de esta simulación se ha centrado en intentar desarrollar un juego lo más realista posible invirtiendo gran cantidad de esfuerzo y dinero en los diseños gráficos.

2.2.3.9 Playmancer

Playmancer (Fernández-Aranda et al., 2012) es un proyecto europeo que utiliza el videojuego como complemento para las terapias de enfermedades mentales, programas relacionados con trastornos de impulsividad, como los trastornos alimentarios y juego patológico.

Algunos de los elementos de juego incluidos son:

- Objetivo: este proyecto pretende demostrar la capacidad de cambiar la actitud, el comportamiento y los procesos emocionales de los pacientes con trastornos de impulsividad. En este juego el objetivo final no es ganar, sino lograr un mayor autocontrol.
- Contexto narrativo: El videojuego sitúa al jugador en una isla que forma parte de un archipiélago. El jugador se enfrenta a lo lago del juego a diferentes retos y situaciones con el objetivo de mejorar las habilidades y actitudes que se intentan cambiar (p.ej. resolución del problemas, control de los impulsos, enfrentarse a situaciones asociadas con la frustración o gestión de las emociones etc.).
- Motivación e implicación: Las diferentes actividades que presenta el juego varían de dificultad en función de los niveles del juego..
- Retroalimentación: El jugador recibe en todo momento retroalimentación de sus logros. Además, se incluyen biosensores (saturación de oxígeno, ritmo cardiaco, frecuencia respiratoria …) para ayudar a los pacientes a aprender técnicas de relajación, adquirir estrategias de auto-control y desarrollar nuevas estrategias para regularse emocionalmente.

2.3 Organización Nacional de Trasplantes

2.3.1 ¿Qué es un trasplante?

Un trasplante según la Organización Nacional de Trasplantes (ONT) es sustituir un órgano o tejido enfermo por otro que funcione adecuadamente, pero para ello se necesita obligatoriamente la existencia de donantes. El trasplante se ha convertido con los años en una terapia consolidada que salva y/o mejora la calidad de vida de cerca de 100.000 receptores anualmente según el Observatorio Mundial de Donación y Trasplante (http://www.transplant-observatory.org). Sin embargo, la escasez de órganos/donantes sigue siendo el principal obstáculo en el proceso de Donación y Trasplante, esta escasez hace que todavía sean muchos los pacientes que fallecen mientras están a la espera de recibir un trasplante.

La optimización del proceso de Donación y Trasplante es fundamental para paliar este problema. Sin embargo, para que este proceso finalice con éxito el mayor número de veces posibles, es necesaria una correcta cooperación entre todos los profesionales involucrados. La Organización Nacional de Trasplantes Española (ONT), creada en 1989, tiene como finalidad la coordinación de las actividades de donación, extracción, preservación, distribución, intercambio y trasplante de órganos, tejidos y células en el conjunto del Sistema Sanitario Español, para hacer posible la realización del máximo número de trasplantes con el fin de mejorar la calidad de vida de los pacientes. Desde su creación, la tasa de donantes en nuestro país se ha incrementado en un 150%, pasando de una media de 14 donantes por millón de población (pmp) a tasas entre 33-35 donantes pmp. Se trata, del único ejemplo en el mundo de un país de tamaño grande con un incremento continuo de los índices de donación, con aumentos paralelos de los índices de todos los trasplantes de órganos sólidos. En ese tiempo, se han realizado alrededor de 70.000 trasplantes de órganos sólidos y más de 200.000 de tejidos y células.

Al conjunto de medidas adoptadas en España para mejorar la donación de órganos se le conoce internacionalmente como "Spanish Model" o modelo Español de Donación y Trasplante (Domínguez-gil et al., 2010; R Matesanz et al., 2009; Rafael Matesanz & Dominguez-Gil, 2007). La implementación de todas las medidas que plantea el modelo español en un país no es sencilla, ya que no basta con poner un coordinador de trasplantes al cargo, hay que gestionar todas y cada una de las medidas, tanto en su conjunto como individualmente, de manera correcta. Este modelo E centra sus esfuerzos en la detección de potenciales donantes en las unidades de vigilancia intensiva (UVI) de los hospitales, ya que según la legislación, un donante de órganos es una persona que fallece en situación de muerte encefálica, y este tipo de fallecidos se encuentran en su mayoría en las UVIs (Matesanz-Acedos, 2009).

Por tanto, la base del éxito del modelo español es disponer en todos los hospitales de profesionales específicamente entrenados en la consecución de todos los pasos encaminados a potenciar la donación. El Modelo Español ha sido trasladado con éxito a otros países y regiones del mundo.

2.3.2 El proceso de donación y trasplante

El proceso de donación y trasplante es un proceso largo y complejo, en el que se involucran

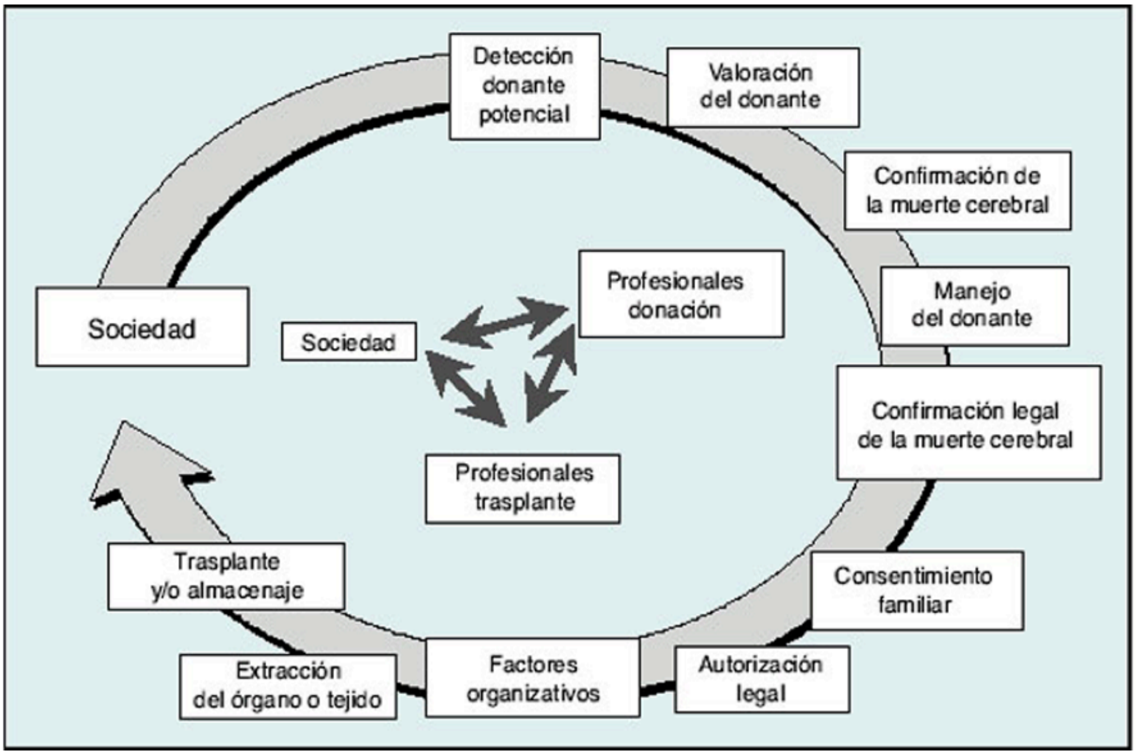


Figura 11 El proceso de donación y trasplante..Alcázar Arroyo, R., Alcázar de la Osa, J. M., Aljama García, P., & Álvarez Moreno, M. C. (2003). *Nefrología clínica*. (L. Hernando, P. Aljama, M. Arias, C. Caramelo, J. Egido, & S. Lamas, Eds.) (2da edición.).

muchos profesionales sanitarios y no sanitarios. Es un proceso que se diferencia de otros procesos técnicos, ya que no puede progresar solo con más infraestructura, recursos o tecnología, sino que la implicación de toda la sociedad es fundamental para su buen funcionamiento y su continuo progreso. Con cada una de las donaciones se inicia todo el proceso (ver Figura 11). Este proceso, complejo por naturaleza, necesita un control exhaustivo y una cuidadosa protocolización y seguimiento para evitar que un fallo menor en cualquier de sus múltiples pasos pueda conllevar a la pérdida de un donante o un órgano y como consecuencia el fracaso del proceso. Cada vez que se inicia el proceso, intervienen alrededor de 100 personas tanto del ámbito sanitario como no sanitario, y concluye con el trasplante correspondiente y con la consecuente exclusión del receptor de la lista de espera correspondiente. Es fundamental una continua monitorización que permita identificar los problemas que existen en el proceso e idear soluciones con el fin de mantener el nivel de eficacia.

Para entender bien el proceso de donación y trasplante, hay que explicarlo desde dos niveles diferentes. El nivel hospitalario, coordinado por el coordinador hospitalario y desarrollado desde el hospital donde se encuentra el potencial donante y el nivel supra-hospitalario, coordinado por la ONT (en la Oficina Central de Trasplantes):

2.3.2.1 Nivel hospitalario.

El nivel hospitalario es coordinado por el coordinador hospitalario cuya misión principal y fundamental es la obtención de órganos (con la necesaria autorización de la familia del donante).

Para que no se pierdan donantes potenciales, el primer paso es tener un procedimiento adecuado para facilitar la correcta detección de éstos. Una vez detectado, es fundamental la consecución de un mantenimiento adecuado para evitar el deterioro de los órganos o que se produzca la parada cardíaca antes de finalizar el proceso. El siguiente paso es la realización del diagnóstico de muerte cerebral que deberá ser efectuado siempre por tres médicos distintos a los del equipo de trasplante. El coordinador de trasplantes se limitará a solicitar su colaboración y facilitar la tarea de los mismos, empleando los procedimientos diagnósticos más adecuados en cada caso de acuerdo con la legislación vigente. Tras el diagnóstico de muerte puede ser necesario conseguir la autorización judicial en caso de causa no médica y, siempre y en todo caso, lograr la autorización familiar.

.Es en este momento cuando se contacta con la oficina central de la ONT y empieza una colaboración en paralelo entre los dos niveles que se explica en la siguiente sección..

2.3.2.2 Nivel supra hospitalario.

La ONT es la institución encargada de coordinar el nivel supra hospitalario del proceso de donación y trasplante. Para el nivel supra hospitalario, el proceso comienza en el momento en el que el coordinador de trasplantes del hospital donante (coordinador hospitalario) comunica a la ONT la existencia de un posible donante en su hospital.

El personal de enfermería de la ONT, junto con el coordinador hospitalario, valora detenidamente al posible donante registrando los datos generales (sexo, edad, grupo sanguíneo, datos antropométricos...), los datos clínicos (causa de muerte, antecedentes...) y como se ha realizado el diagnóstico de la muerte encefálica. Es necesario confirmar la obtención del consentimiento familiar y/o judicial por parte del coordinador hospitalario así como que el donante no presente alguna contraindicación para la donación mediante el estudio de los posibles procesos infecciosos, marcadores serológicos y la situación hemodinámica del mismo que han sido comunicados por dicho coordinador.

Después, se procede a la evaluación de cada uno de los órganos para ver si son aptos para ser trasplantados. Desde la primera llamada, se inicia un registro único para cada donante donde se anota toda la información relativa al proceso de la forma más detallada posible.

A continuación, desde la ONT se realizan las ofertas de órganos a trasplantar siguiendo unos criterios clínicos y geográficos establecidos anualmente para asegurar la equidad entre todos los hospitales receptores. La decisión final de aceptación o no de una oferta, dependerá del equipo trasplantador en función de las características de los receptores en su lista de espera y del donante. En caso de no aceptación la oferta pasará al siguiente equipo en el ámbito que corresponda. Una vez aceptados los órganos por los diferentes equipos y según la disponibilidad de cada uno de ellos para desplazarse, se fijará la hora de extracción de acuerdo con el coordinador del hospital donante. Para el desplazamiento de los equipos, la logística, variará en función de la distancia entre el hospital donante y hospital receptor, si se envía el órgano extraído o se desplazan los equipos a extraerlo. Los medios utilizados para el desplazamiento de los equipos/órganos, están condicionado por la distancia y los tiempos de isquemia (tiempo que pasa desde que un órgano deja de recibir sangre). En función de estos criterios se podrán realizar los desplazamientos con ambulancia, avión o helicóptero según las condiciones del lugar y distancia.

Confirmada la llegada de todos los equipos implicados e iniciada la extracción, desde la ONT se mantiene informado al coordinador del hospital trasplantador de tres circunstancias muy importantes: la validez del órgano, la hora de clampaje y la de salida del hospital donante, con la hora prevista de llegada al hospital o aeropuerto, para que se inicie la preparación del receptor y disponga el medio de transporte necesario. Una vez concluido el trasplante, el coordinador informa del receptor a la oficina de la ONT y se procede a su exclusión de la lista de espera.

El destino de los órganos se transmite al coordinador del hospital donante para que pueda informar al personal que participó en todo el proceso.

2.3.3 El sistema de formación de la ONT

Uno de los objetivos principales de esta tesis es mejorar, ayudar y dar soporte al sistema formativo de la ONT. Por tanto, y sin ahondar exhaustivamente en su amplio sistema formativo, para contextualizar este trabajo es necesario describir brevemente sus diferentes cursos de formación a otros profesionales. Existen en la actualidad tres tipos diferentes de cursos:

- Cursos generales de formación de coordinadores: El principal objetivo de estos cursos es formar a los nuevos Coordinadores hospitalario para que puedan afrontar sus funciones de forma satisfactoria. Se les enseñan las habilidades y destrezas adecuadas para enfrentarse al proceso de donación y trasplante desde un punto de vista multidisciplinar.

- Cursos "Familia y Donación": Estos cursos tienen como finalidad/objetivo el preparar a los Coordinadores de trasplante en una actividad formativa específica para abordar la entrevista de donación. Las negativas familiares a la donación son la principal limitación en los programas de trasplante. Es fundamental la realización de una buena entrevista, para obtener el consentimiento familiar. De ello se deriva la necesidad de formar específicamente a los entrevistadores.

- Programa europeo para la promoción de la donación: El Programa Educacional Europeo para la Donación de Órganos (EDHEP), va dirigido a profesionales sanitarios de las Unidades de Críticos con el objetivo de proporcionar las técnicas de comunicación que les ayuden a mejorar la relación con las familias, al mismo tiempo que pueda servir para que dichos profesionales conozcan más del proceso de donación, y sobre todo, la importancia que tiene el proceso de comunicación con las familias en su percepción del tratamiento recibido.

En concreto en los juegos realizados en esta tesis se aborda la mejora del proceso de formación del propio personal de la ONT, con tres simulaciones orientadas al aprendizaje del proceso de coordinación supra-hospitalaria, y el proceso de formación de coordinadores hospitalarios mediante una simulación que les ayuda a detectar posibles donantes y en el proceso de selección de órganos válidos para trasplante.

2.4 A modo de conclusión

Los videojuegos educativos, impulsados por objetivos de enseñanza y la adecuada utilización de los mecanismos de juego, tienen la capacidad de motivar, implicar a los jugadores e influenciar sus comportamientos. Sus historias absorbentes, sus retos alcanzables, las recompensas, el reconocimiento, la sensación de control y el entorno seguro de juego hacen que sean herramientas muy potentes para el aprendizaje (Donovan, 2012). Bien diseñados, los juegos pueden convertir el aprendizaje en una actividad divertida, desafiante y gratificante, donde los jugadores no se dan cuenta de que están aprendiendo o modificando sus comportamientos mientras juegan, sino que están centrados en lograr los objetivos, competir y colaborar con otros jugadores y divertirse mientras se sumergen en el juego y terminar por dominarlo (e implícitamente dominan también el conocimiento intrínseco del juego) sin darse cuenta.

Estas son algunas de las carencias detectadas en este capítulo:

- A pesar de todos los estudios de investigación existentes, todavía queda mucho trabajo por hacer en muchos de los campos, entre ellos en la medicina, para poder afirmar taxativamente que los juegos educativos son una alternativa adecuada o un buen soporte para la formación tradicional (o bajo qué condiciones concretas lo serían). No obstante, se puede aprender de los casos de éxito presentados y tratar de reutilizar dichas experiencias para tratar de sistematizar el desarrollo de juegos y simulaciones con estrategia de juego en el campo médico. El reflejo de esta sistematización en una metodología de desarrollo contribuirá a hacer que el desarrollo de éste tipo de juegos sea más estructurado y previsible de modo que se puedan reducir costes y se traten de evitar errores.
- Un problema en la literatura presentada es la necesidad de establecer procedimientos de validación de los juegos serios para asegurar que se cumplen los objetivos educativos para los cuales se han desarrollado (Graafland et al., 2012). En este trabajo, se presenta además una metodología para validar que el conocimiento representado por medio de simulaciones es correcto y preciso y que el objetivo educativo para el cual fueron desarrolladas se consigue.
- Existen pocas metodologías de diseño y desarrollo de juegos educativos, y las existentes no siempre se centran en potenciar la inclusión de aquellas características de los juegos educativos que los hacen atractivos a la par que efectivos, características como el uso de elementos de juego o la potenciación de la retroalimentación inmediata. La metodología presentada en este trabajo pretende fomentar el uso de muchas de estas características mediante la inclusión progresiva de estos.
- Otro problema de las metodologías existentes es que no resuelven dos de los problemas actuales que tiene el desarrollo de juegos educativos: la necesaria dedicación e implicación por parte del experto en la materia que se quiere “enseñar” jugando y la representación del conocimiento tácito incluido en muchas ocasiones en los procedimientos que se quieren representar /enseñar. Así, en los trabajos presentados en esta tesis, se explica cómo obtener esta información fomentando sobre todo la comunicación entre las partes implicadas en el proyecto y fomentando también la creación de un conocimiento común en el cual todas las partes dominen los términos que se tratan.
- Finalmente, el coste de desarrollo y producción de los juegos educativos sigue siendo un problema. Como se muestra en la metodología presentada, el coste de los juegos desarrollados es muy inferior a la media del coste de los juegos educativos sin por ello reducir la calidad y la efectividad del juego.

Capítulo 3 Objetivos y planteamiento del trabajo

En el Capítulo 1 se introdujeron los objetivos principales de esta tesis así como la motivación. Este capítulo desarrolla dichos objetivos, enmarcando su alcance y presentando las metodologías y estrategias complementarias utilizadas para conseguirlos.

Se plantea de una manera más formal el objetivo principal de esta tesis que es el de sistematizar el desarrollo de simulaciones con estrategia de juego en el campo médico. Para lograr este objetivo se propone una metodología de diseño y desarrollo de simulaciones y se plantean otros objetivos parciales, como son el desarrollo de simulaciones concretas para la organización nacional de trasplantes y el procedimiento de validación de simulaciones que representan procedimientos complejos con conocimiento tácito.

3.1 Objetivos de la tesis

El objetivo principal de esta tesis coincide con el propio título de esta:

Sistematizar el desarrollo de simulaciones con estrategia de juego en el campo de la medicina.

Se considerará satisfecho este objetivo si se logra presentar una sistematización eficaz para el desarrollo de simulaciones educativas con estrategia de juego en el campo de la medicina.

Esta sistematización constituye el núcleo de la tesis y se explica en este trabajo a través de la consecución de 3 sub-objetivos concretos. El primer sub-objetivo es:

1. Desarrollo de simulaciones en la ONT que representen de modo adecuado su modo de trabajo y permitan mejorar y sistematizar su proceso formativo.

Este objetivo se considerará satisfecho si se obtiene como resultado el desarrollo de simulaciones médicas con estrategias de juego que representen correctamente los procedimientos utilizados en la ONT y que sirvan de apoyo a su sistema formativo. En concreto se plantea el desarrollo de tres simulaciones orientadas al aprendizaje del proceso de coordinación supra-hospitalaria de la ONT.

Estas simulaciones deben representar de manera precisa los procedimientos de la ONT, incluyendo aspectos habitualmente no contemplados en la descripción de procedimientos médicos como son los errores más comunes del día a día o el conocimiento implícito usado en la ejecución de dichos procedimientos. Las simulaciones deben permitir a los jugadores comprender los procedimientos, entender mejor el contexto en el que se encuentran los coordinadores de trasplantes diariamente así como comprender de manera general los criterios generales de evaluación, distribución y transporte de órganos.

Estas simulaciones deben además ampliar el alcance de los cursos formativos de la ONT, permitiendo acceder a un mayor número de estudiantes en un contexto seguro y fiable.

A partir desarrollo de estas simulaciones surge el segundo sub-objetivo:

2. Validación de las simulaciones realizadas tanto con el personal de la ONT como mediante su aplicación en cursos de formación de la ONT para nuevo personal y para otros profesionales.

Este objetivo se considerará cubierto si se puede confirmar que el procedimiento utilizado para validar el conocimiento de las simulaciones es eficaz. Esta validación debe permitir analizar si el conocimiento representado en las simulaciones es suficientemente preciso y completo, así como proporcionar métodos de corrección iterativos para conseguir la adecuada y precisa representación de los procedimientos de la ONT. Además, mediante los estudios de satisfacción y usabilidad realizados entre los asistentes a los cursos de formación se podrá saber si las simulaciones permiten un mejor acercamiento de los asistentes al know-how de la ONT.

Finalmente, de la experiencia obtenida con el desarrollo de estas tres simulaciones para la Organización Nacional de Trasplantes, de la experiencia de todo el equipo de investigación e-UCM en el desarrollo de simulaciones en el campo médico y de la necesidad de realizar una validación exhaustiva del conocimiento representado surge la necesidad de sistematizar y establecer un procedimiento de trabajo, una secuencia de pasos a seguir y de normas o recomendaciones que permitan simplificar el desarrollo de este tipo de simulaciones. Así nace el tercer sub-objetivo:

3. Propuesta de una metodología para el desarrollo de simulaciones con elementos de juego para la formalización de procedimientos médicos

Este objetivo se considerará alcanzado si se define de forma satisfactoria una metodología para el diseño, desarrollo y evaluación de simulaciones con estrategia de juego en el entorno médico.

Para lograrlo se plantea una metodología concreta de desarrollo denominada EGDA (Educational Game Development Approach) y pretende sentar las bases que permitan a otros desarrolladores de juegos serios representar procedimientos médicos de manera precisa evitando cometer los mismos errores cometidos a lo largo de nuestra experiencia. Esta metodología plantea una aproximación iterativa que debe permitir, gracias a la estrecha colaboración entre los expertos del dominio (diseñadores y desarrolladores y médicos), el desarrollo de simulaciones con estrategia de juego que permita incorporar también otros tipos de conocimiento (p.ej. errores comunes, conocimiento tácito).

3.2 Planteamiento y desarrollo del trabajo

El planteamiento de este trabajo intenta lograr el objetivo principal a través de la consecución de 3 sub-objetivos. Como se ha visto en los apartados anteriores, los tres sub-objetivos se relacionan y complementan entre sí, de manera que de las necesidades planteadas por el primer sub-objetivo nace el segundo, y de los resultados y aprendizajes de los estos dos primeros nace la definición del tercer sub-objetivo.

Así, el trabajo a realizar en esta tesis se plantea como una evolución a lo largo del tiempo:

- Durante mi etapa trabajando en la Organización Nacional de Trasplantes, pude conocer, observar y aprender las principales características de sus procesos formativos y de trabajo. Así comenzó un proceso de desarrollo de simulaciones educativas para dar soporte a su sistema formativo. Se desarrollaron tres simulaciones representando cada uno de los procesos principales desarrollados en la ONT diariamente en su tarea de coordinación supra-hospitalaria. Estas simulaciones se desarrollaron siguiendo la metodología ya mencionada anteriormente (aunque en ese momento todavía no estaba completamente sistematizada y no se denominaba EGDA).
- Estas simulaciones fueron validadas inicialmente por un experto de la ONT asignado al proyecto. Una vez que se disponía de simulaciones suficientemente fiables, se pasó a un proceso de validación del conocimiento con el resto de los expertos de la ONT. Para esta segunda etapa se realizó una preparación previa que implicó el estudio de metodologías de validación de procedimientos, así como la preparación de las entrevistas y la generación de tablas de codificación para facilitar el estudio cuantitativo y cualitativo de las respuestas obtenidas.
- Tras validar las simulaciones, se empezaron a utilizar en los cursos de formación de la ONT, donde se realizaron estudios de satisfacción y usabilidad.
- Basándonos en la experiencia aprendida con los desarrollos de simulaciones en el contexto médico (tanto las desarrolladas para la ONT como otras desarrolladas en el seno del grupo de investigación e-UCM), se realizó un proceso de conceptualización y sistematización por el cual se define la metodología de desarrollo EGDA.
- Finalmente, para validar la eficacia de EGDA, se desarrolló una nueva simulación aplicando esta metodología. Esta nueva simulación está dirigida a los coordinadores hospitalarios.

Capítulo 4 Contribuciones

En este capítulo se proporciona una descripción de los artículos publicados que forman el núcleo de 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 tres secciones que muestran las contribuciones en cada uno de los sub-objetivos de trabajo que se describen en el capítulo anterior. De esta manera, cada discusión y análisis de las contribuciones de las publicaciones se realiza en su propia sección independiente.

Por tanto, las contribuciones concretas para lograr el objetivo general de la sistematización del desarrollo de simulaciones educativas se subdividen en:

1. Desarrollo de tres simulaciones educativas para la Organización Nacional de Trasplantes (ONT) con el objetivo de mejorar la sistematización de sus procedimientos y apoyar su sistema formativo. Las publicaciones que presentan esta parte del trabajo son:
    a. Developing game-like simulations to formalize tacit procedural knowledge: The ONT Experience (sección 4.1.1 y sección 4.1.2)
    b. Application of game-like simulations in the Spanish Transplant National Organization. (sección 4.1.2)
    c. Using Low - cost computer - based simulations in the Spanish National Transplant Procedures. (sección 4.1.2)
2. Definición de un procedimiento de validación del conocimiento representado en las simulaciones. La publicación en la que se presenta esta parte del trabajo es:
    d. Expert User Validation of Transplant Management Procedure Simulations. (sección 4.2)
3. Definición de una nueva metodología para el desarrollo de simulaciones en el campo de la medicina (denominada EGDA) y su aplicación a un caso particular, la evaluación del donante desde el punto de vista del coordinador hospitalario. Las publicaciones que presentan esta parte del trabajo son:
    e. Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education. (sección 4.3)
    f. Applying Egda to a particular case: The donor's evaluation (sección 4.3.2)

4.1 Desarrollo de tres simulaciones educativas para la organización nacional de trasplantes

Este apartado contiene tres contribuciones que se detallan a continuación:

4.1.1 Propuesta de una metodología para ayudar a la sistematización de procedimientos médicos. Primera aproximación a EGDA.

En (Blanca Borro-Escribano, Del Blanco, Torrente, Alpuente, & Fernández-Manjón, 2013), se presenta cómo el desarrollo de simulaciones educativas con estrategia de juego puede ayudar a la formalización de procedimientos médicos. Para ello, se realiza una primera aproximación de lo que posteriormente se denominaría la metodología EGDA y se describe como se aplican cada una de las fases de esta metodología inicial al caso particular de la Organización Nacional de Trasplantes ONT.

Esta contribución se orienta en todo momento hacia la definición de una metodología de diseño y desarrollo de simulaciones que ayude a plasmar correctamente el conocimiento tácito existente en muchos procedimientos médicos. No intenta cubrir otros objetivos como son, por ejemplo, analizar el aprendizaje, los beneficios o incluso los resultados de estas simulaciones. Estos objetivos se presentan en otras contribuciones que se describen en apartados posteriores.

El objetivo principal de este artículo es proponer una metodología de diseño y desarrollo de simulaciones educativas con estrategia de juego y describir su aplicación en un caso concreto, el de la ONT. Adicionalmente, esta metodología ha permitido una mayor sistematización de los casos de uso utilizados en la creación de esta simulación de modo que posteriormente puedan también ser usados en la formación presencial.

a) Escena principal de la ONT

b) Personaje de la simulación

c) Acción point-and-click para evaluar los órganos

Figura 12 Escenas de la simulación

Para poder comprender la metodología, es necesario entrar en mas detalle sobre en qué consiste la simulación desarrollada. En esta simulación, el jugador adquiere el rol de un coordinador de trasplantes de la ONT (personaje principal), razón por la cual la escena principal utilizada en la simulación es una foto real de la oficina central de coordinación de trasplantes de la ONT (ver Figura 12.a). El jugador tendrá que interaccionar con otros personajes como, por ejemplo, con los distintos coordinadores hospitalarios implicados en el proceso (ver Figura 12.b) o los coordinadores de trasplantes de los diferentes hospitales receptores. Se deben respetar unas reglas determinadas (secuencia de pasos a seguir, realización de ciertas acciones para activar otras etc.) y tener claro cuál es el objetivo de la simulación (evaluar todos los órganos del donante potencial y justificar correctamente las causas de no donación de los órganos).

Además el jugador debe explorar la escena en busca de objetos con acciones asociadas. Al hacer click en estos objetos, se muestran las acciones asociadas (ver Figura 12.c para ver un ejemplo de la acción de evaluar los órganos). Algunos de los objetos que tienen acciones asociadas son el teléfono para llamar o para recibir llamadas, el fax para recibir faxes de los hospitales, o la hoja de donante para consultar y estudiar la información del donante (ver Figura 13).

Figura 13 Descripción de los objetos y personaje de la escena

4.1.1.1 Metodología propuesta

La metodología seguida para el diseño y desarrollo de estas simulaciones se basa en las metodologías agiles aplicadas en el desarrollo de software, donde se ejecutan procesos cortos y se obtienen resultados concretos rápidamente. Es una metodología iterativa que al crear prototipos rápidos que se pueden probar ayuda a capturar el conocimiento tácito incluido en muchos procedimientos médicos fomentando entre otras cosas una mejor comunicación entre los profesionales implicados en el desarrollo (en este caso, desarrolladores de juegos y médicos o enfermeros de la ONT).

La metodología está representada gráficamente en la figura 14, en cada iteración de la metodología se realizan tareas de cada uno de los 4 procesos siguientes: Especificación, Diseño, Desarrollo y Calidad. Estos 4 procesos son dependientes unos de otros, pero la importancia de cada uno varía en función de la fase del desarrollo en la cual se encuentre la simulación. Así, en las primeras iteraciones, la parte de especificación y diseño tiene un gran peso. Sin embargo, este peso va disminuyendo a medida que se avanza en el desarrollo, de modo que cuando se acerca el final, adquieren gran importancia los procesos de desarrollo y calidad de la simulación.

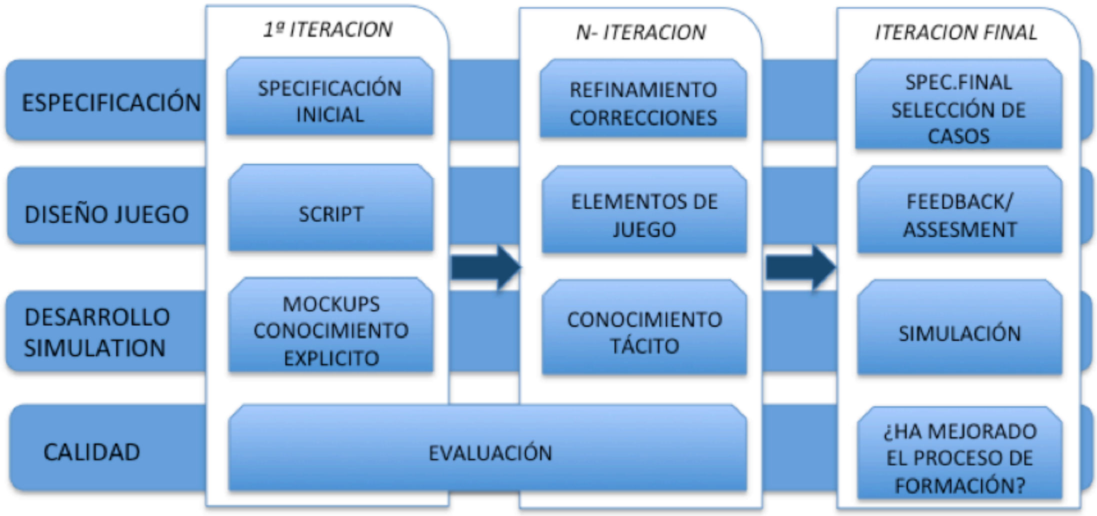


Figura 14 Metodología iterativa

El desarrollo de esta metodología se aborda en 4 fases:

1. Se realiza un estudio en profundidad del procedimiento, este estudio se basa principalmente en el análisis de la documentación del procedimiento y en la observación del día a día de la ONT así como de entrevistas informales, y en ocasiones formales, con los expertos para capturar el conocimiento tácito (es decir, aquel que no se encuentra documentado).
2. Se diseña un primer flujo/secuencia de pasos del procedimiento a representar. Esta secuencia se hace sobre el procedimiento general, sin entrar en casos particulares.
3. Se desarrolla un primer prototipo de la simulación, este prototipo se basa en la aplicación de este procedimiento general a un solo caso de uso sencillo (p.ej. un donante concreto). Así el experto conoce y se identifica con el caso y puede contrastar la secuencia de pasos definida y validar si es correcta o sugerir correcciones o mejoras. Las primeras versiones de las simulaciones son sencillas, con complejidad limitada. A medida que se va validando el conocimiento, se va añadiendo nuevas características tales como errores y otros elementos de juego. Finalmente cuando ya se tiene un caso completo se añaden el resto de casos de

ejemplo o de uso (en este se usaron 10 casos de trasplantes obtenidos de los casos reales de la ONT –en algunos casos mejorados para hacerlos más significativos-).

4. Finalmente comienza la fase de calidad, en la que es necesario comprobar que las simulaciones resultantes cumplen unos requisitos mínimos de usabilidad, fiabilidad, jugabilidad y que, por supuesto, se alcance un objetivo educativo deseado. Esta fase incluye también un proceso de validación del conocimiento (sub-objetivo 1.2 explicado en la sección 4.2).

4.1.1.2 Sistematización de los casos de uso

Una parte importante en el desarrollo de estas simulaciones fue la selección de los casos de uso realizada durante la etapa de especificación. Para seleccionar estos casos de uso, se siguen algunas de las ideas propuestas en (Gordon, Oriol, & Cooper, 2004; Kim et al., 2006) para asegurar la relevancia de los casos utilizados. Los expertos de la ONT seleccionaron y modificaron los casos de uso para maximizar el aprendizaje en cada caso (Khan, 2007). Se enfatizó la selección de casos donde la evaluación de los órganos no fuera evidente y que supusieran algún reto para el estudiante. El objetivo era conseguir que después de practicar con cada uno de estos casos, el estudiante fuera capaz de conocer de manera general que aspectos de una hoja de donante son importantes y cuales determinan si un órgano es o no donable.

Los expertos de la ONT revisaron además los casos seleccionados para asegurar que hubiera casos de diferente dificultad, que se incluyeran también casos infrecuentes pero muy relevantes; que la información de las hojas de donante fuera consistente y que se asemejara a la de los casos reales. Como resultado, se obtuvieron 10 casos de uso. Aunque es difícil de calcular, los expertos consideraron que con estos 10 casos se cubren, al menos, más del 60% de los casos que llegan diariamente a la ONT.

Para evitar conflictos morales, respetar la LOPD y, sobre todo evitar toda posibilidad de trazabilidad posterior al caso real, los datos de estos donantes han sido debidamente anonimizados e incluso modificados (eso sí, sin alterar los parámetros clínicos relevantes). A continuación se analiza uno de los diez casos de uso seleccionados. En primer lugar se presenta la hoja de donante que tiene que estudiar el jugador y a continuación se explican los pasos que hay que seguir para terminar el juego en función de las diferentes opciones existentes (secuencia de juego).

En la primera simulación se deben evaluar todos los órganos, sin embargo en la segunda y tercera simulación sólo se realiza la distribución y gestión de los transportes del corazón, pulmones e hígado, dejando el páncreas y riñón para versiones posteriores de estas simulaciones. El objetivo de describir esta secuencia de juego es dar una idea de la complejidad del conocimiento representado en las simulaciones.

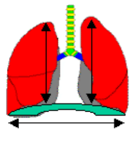
4.1.1.2.1 Caso de uso Donante 2

GOBIERNO DE ESPAÑA — MINISTERIO DE SANIDAD, SERVICIOS SOCIALES E IGUALDAD — ONT

Nº Anual	Nº SIUL
	DONANTE 1

Día........	Hora........
Llamada........	Hospital **H. GALDAKAO (Bilbao)**
Coordinador........	Tfno ....

	ORGANOS Y TEJIDOS QUE SE DONAN:	DIAGNÓSTICO ME Hora
Sexo..........**VARÓN**..........	FAX RR........	Exploración Clínica...........**X**........
Edad..........**30 a**..........	FAX H........	EEG..........**X**........
G.S............**B+**...... **FAX**	FAX C........	Gamma........
Peso.........**75 kg**..........	FAX PUL........	Arterio........
Talla..........**180 cm**..........	FAX PAN........	Eco Doppler........
Périmetro Torácico..........**99**..........	FAX NT........	P.Evocados........
Périmetro Abdominal.......**99**..........	Tejidos : Córneas........	Otros........
Dcho **Izqo**	Huesos........	C. Familiar...........**SI**........
		C. Judicial........
	H.CLAMPAJE........	Origen…España o **INGLATERRA**



Causa de Muerte................**HEMORRAGIA INTRAVENTRICULAR**........

Hora prevista para la extracción .... Hora real de la extracción........

ANTECEDENTES PERSONALES

ADICCIONES
TABACO...............**NO**...................Cantidad.....................Tiempo........
ALCOHOL.............**NO**...................Cantidad.....................Tiempo........
OTROS.......**CANNABIS + ANFETAMINAS + KETAMNA (ocasional)**........

HTA ....**NO**........
DIABETES......**NO**........ANT. FAMILIARES..........**NO**........
CIRUGÍA PREVIA......**NO**........
OTRAS PATOLOGÍAS......**NO**........

Tº en U.C.I ....**13 Horas**........ Tº de Intubación ....**13 Horas**........

RX TORAX.........**NEUMONÍA ASPIRATIVA BASAL DCHA**........

ECG...........**NORMAL**........

ECO ABD.: **HEMANGIOMA HEPÁTICO (21*12*25mm). RIÑONES NORMALES, RESTO NORMAL**....

ECO CARD: **NORMAL. NO DERRAME PERICÁRDICO. FE 67%. CONTRACTILIDAD NORMAL**..........

Figura 15 Donante 2 – Cara A

Tª actual **36ºC**	FIEBRE.......**NO**........		
	ANTIBIOTICOS......**AMOXI-CLAVULÁMICO 1gr/8h**........		
HEMOCULTIVOS........			
UROCULTIVOS........			
Cult.BAS.....(**Secreciones : SI NO**)........**PURULENTAS**........			
OTROS........			

T.A. **100/65**	Hipotensión SI NO	TAS mínima.................	Tiempo........................
PVC FC			
P.C. NO / SI	Tiempo..................................	RCP : Básica RCP : Avanzada	Tiempo :............................
Drogas :			
DOPAMINA			
DOBUTAMINA			
NORADRENALINA	**0,5 microgr/kg/min**		
DIURESIS : **POLIURIA**		DESMOPRESINA..**SÍ**..................................	
INSULINA: NO		(Perfusión continua SI No)	
Transfusiones : (Fecha / Cantidad) **NO**			

H:	DATOS ANALÍTICOS		Hora	
GOT............**22**..................	NA................**139**..................	HTO.........**42**.....................	PH......................	**7,33**.....................
GPT.............**12**..................	K....................**4,1**................	HB............**14,2**..................	PO_2....................	**375**....................
GGT.............**18**..................	Creat…**2,59 (Ingreso 0,8)**...		PCO_2....................	**45**....................
BD.............**0,16**.................	Urea.....**73 (Ingreso 29)**.......		CO_3H....................	**24**....................
BT..............**0,7**....................	CL................**108**..................	Leuc.......**20600**..................	FiO_2..................	**100%+PEEP 5**
PT..............**6,1**....................	Glucosa........**118**.................	Neut..........**84,4%**..............	EB......................	**-1,5**....................
Albúmina.....**4,5**.................	Colesterol........................	Linf............**10,5%**..............	Sat O_2..................	**99%**....................
FA................**77**...................	Amilasa.........**74**..................	Basóf.........**0,2%**..............		
LDH......................................	....	Eosin......... **0,1%**...............	HIV................(**NEG**)	
CPK..........**386**................	....	Monoc..........**4%**................	Ag HBs.........(**NEG**)	
CPK- MB................................	....		Ac HBc (**POS**) Ac HBs (**NEG**)	
Troponina……**0,05**………..	....	Plaq.........**110000**..............	CMV.............(**POS**)	
		Ac. Prot.......**76%**.................	Ac VHC.........(**NEG**)	
		INR………..**1,2**……………		
Proteinuria		Fibrinógeno....**348**.............		
Sedimento......**NORMAL**...		APTT..........**32,4**.................	Sólo obligado para donantes (mujeres) en edad fértil	

Figura 16 Donante 2 - Cara B

4.1.1.2.2 *Secuencia de Juego*

Como se puede ver en la Figura 15, este caso de uso corresponde a un donante del hospital de Galdakao, de 30 años y grupo sanguineo B+. Para la primera simulación "Evaluación del donante y sus órganos" nos será util toda esta información.

Simulación 1 - Evaluación del donante y sus órganos

En este caso de uso se le ha ocultado al jugador la información relativa a la radiografía de torax para enfatizar la importancia que tiene esta información para poder evaluar correctamente los pulmones. Una vez el jugador recupera la información oculta y comprueba que la radiografía de torax muestra una neumonía aspirativa basal derecha sabrá que los pulmones no pueden donarse. En este caso, el resto de órganos son válidos.

Simulación 2: Distribución de los órganos

En este caso concreto hay que distribuir sólo el corazón y el hígado:

- Higado: Se consulta primero la hoja de correspondencia de hospitales (ver Figura 17) para ver a que hospital corresponde el hospital de Galdakao para el hígado. Corresponde a Cruces por turno de comunidad autonóma. Se consultan las listas de espera (ver Figura 18) y se comprueba que sí hay receptores con grupo sanguíneo compatible en el hospital de Cruces, por lo que se procederá a ofertar el hígado a este hospital. En caso de que Cruces rechazara la oferta, se consultaría la hoja de turno de zona donde se observa que el primer hospital asignado para la zona Norte es Asturias, se realiza el mismo proceso de comprobación de lista de espera y, como tambien hay receptores posibles, se ofertaría a este hospital.

    - Opción 1: Turno de CCAA a Cruces.
    - Opción 2: Turno de Zona Norte a Asturias.

MURCIA		Higado		Pulmon		Páncreas		Corazón		Riñones	
H.VIRGEN DE LA ARRIXACA	MURCIA	V. ARRIXACA	DON LOCAL	Zona Centro	T. Zona	V. ARRIXACA	DON LOCAL	V. ARRIXACA	DON LOCAL	V. ARRIXACA	DON LOCAL
H.GENERAL/ H. REINA SOFÍA	MURCIA	V. ARRIXACA	T.CCAA	Zona Centro	T. Zona	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA
H.DEL ROSELL	CARTAGENA	V. ARRIXACA	T.CCAA	Zona Centro	T. Zona	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA
H.MORALES MESEGUER	MURCIA	V. ARRIXACA	T.CCAA	Zona Centro	T. Zona	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA
H.RAFAEL MENDEZ	LORCA	V. ARRIXACA	T.CCAA	Zona Centro	T. Zona	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA	V. ARRIXACA	T.CCAA
NAVARRA		**Higado**		**Pulmon**		**Páncreas**		**Corazón**		**Riñones**	
CLINICA UNIV.DE NAVARRA	PAMPLONA	CUN	DON LOCAL	Zona Norte	T. Zona	Clinic Barcelona	SECTOR	CUN	DON LOCAL	CUN	DON LOCAL
H.DE NAVARRA		CUN	T.CCAA	Zona Norte	T. Zona	Clinic Barcelona	SECTOR	CUN	T.CCAA	CUN	T.CCAA
H. Virgen del Camino	PAMPLONA	CUN	T.CCAA	Zona Norte	T. Zona	Clinic Barcelona	SECTOR	CUN	T.CCAA	CUN	T.CCAA
PAIS VASCO		**Higado**		**Pulmon**		**Páncreas**		**Corazón**		**Riñones**	
H.DE BASURTO	BILBAO	CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA
H.CRUCES	BILBAO	CRUCES	DON LOCAL	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	DON LOCAL
H.CRUCES INF		CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES INF	DON LOCAL
H.DE GALDAKAO	BILBAO	CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA
DONOSTIA OSPITALEA	S.SEBASTIAN	CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA
H.SANTIAGO APOSTOL	VITORIA	CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA
H.TXAGORRITXU	VITORIA	CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA
[illegible]		CRUCES	T.CCAA	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	M. VALDECILLA	SECTOR	CRUCES	T.CCAA

Figura 17 Correspondencia Hospitales (Murcia, Navarra, País Vasco)

LISTA DE ESPERA
HÍGADO

H. DE CRUCES							PAÍS VASCO					
12670404	10/03/11	X	X	X	2	A +	55	166	33 a	Re-Trasplante	Hígado	PAÍS VASCO
12289383	24/03/11	X	X	X	2	B +	65	168	34 a	Enfermedad De Caroli, Re-Trasplante	Hígado	PAÍS VASCO
12758685	29/09/11	X	X	X	2	O +	93	182	57 a	Cirrosis Alcohólica	Hígado	PAÍS VASCO
12762712	20/10/11	X	X	X	2	A	68	168	50 a	Cirrosis Por Virus C	Hígado	ANDALUCÍA
12766013	10/11/11	X	X	X	2	O -	76	163	57 a	Cirrosis Alcohólica	Hígado	PAÍS VASCO
12779910	12/01/12	X	X	X	2	A +	71	156	56 a	Carcinoma Hepatocelular Y Cirrosis,	Hígado	PAÍS VASCO
12781575	19/01/12	X	X	X	2	B +	66	159	60 a	Carcinoma Hepatocelular Y Cirrosis,	Hígado	PAÍS VASCO
12781564	19/01/12	X	X	X	2	A +	90	167	49 a	Cirrosis Por Virus B	Hígado	PAÍS VASCO
12769955	01/02/12	X	X	X	2	O +	90	178	47 a	Cirrosis Por Virus C, Otros	Hígado	PAÍS VASCO
12783723	02/02/12	X	X	X	2	A +	83	173	45 a	Carcinoma Hepatocelular Y Cirrosis,	Hígado	PAÍS VASCO
12785226	09/02/12	X	X	X	2	AB +	82	178	49 a	Cirrosis Alcohólica, Cirrosis Por Virus	Hígado	PAÍS VASCO
12785204	09/02/12	X	X	X	2	A -	66	178	65 a	Cirrosis Alcohólica	Hígado	PAÍS VASCO
12785230	09/02/12	X	X	X	2	O -	101	169	51 a	Carcinoma Hepatocelular Y Cirrosis	Hígado	PAÍS VASCO

Figura 18 Lista Espera Hígado anonimizada

- Corazón: Se consulta primero la lista de urgencias de nivel 0 (pacientes en peligro de muerte inminente si no se les trasplanta), hay una urgencia en el Chuac y los grupos sanguíneos son compatibles, por lo que la primera oferta será a este hospital (ver Figura 19) En caso de que el Chuac rechazara la oferta, se consultaría la hoja de turno de zona donde se observa que el primer hospital asignado para la zona Norte es la clinica de Navarra, se realiza el mismo proceso de comprobación de lista de espera y, como tambien hay receptores, se ofertaría a este hospital.

    - Opción 1: Turno de Urgencia 0 al Centro Hospitalario Universitario A Coruña (CHUAC).
    - Opción 2: Turno de Zona Norte al Clínica Universitaria de Navarra (CUN).

Simulación 3: Logística de los transportes

Al distribuirse dos órganos hay que sincronizar a todos los equipos implicados en el trasplante ya que la extracción tiene que efectuarse a la misma hora. Existen las 4 casuísticas siguientes:

- Opción 1: Hospital Receptor Hígado Hospital Cruces (Bilbao) y Hospital Receptor Corazón Hospital CHUAC (La Coruña).

URGENCIAS O

CARDIACAS Infantiles								
URGENCIAS CARDIACAS CERO								
F. Inclusión	Centro	GS	Peso		Perfil Donante			
URGENCIAS CARDIACAS GRADO UNO								
F. Inclusión	Centro	GS	Peso	ZONA	OBSERVACIONES			
CORAZON - PULMON								
CARDIACAS Adultos						Ofertas		
URGENCIAS CARDIACAS CERO								
F. Inclusión	Centro	GS	Peso	Fecha limite Asistencia V	Perfil Donante	1ª	2ª	3ª
	CHUAC	AB	70					
URGENCIAS CARDIACAS GRADO UNO								
F. Inclusión	Centro	GS	Peso	ZONA	OBSERVACIONES			
HEPATICAS INFANTILES								
HEPATICAS								
	LA FE	0+	55	FUHE	COMPATIBLE			
PREFERENTES NACIONALES PULMONARES (Urg.)								
	LA FE INF.	O+	35	BP 14 a	< 30 a < 150 cm < 65 Kg			

Figura 19 Urgencias 0

Para el hígado, la extracción la realiza el equipo de trasplantes del H. Cruces y el transporte será por tierra con ambulancia al haber una distancia inferior a 300 km.

Para el corazón, La extracción la realiza el Hospital CHUAC, el transporte es por avión, es necesario organizar la logística de los vuelos, para ello el jugador deberá contactar con la compañía aérea que deberá ir hasta Coruña, recoger al equipo extractor, trasladarle a Bilbao, y llevarles de vuelta a Coruña una vez finalizada la extracción.

La hora de extracción se cuadrará antes de comenzar la logística de vuelos para que coincida.

- Opción 2: Hospital Receptor Hígado: Hospital Cruces (Bilbao) y Hospital Receptor Corazón: Clinica Universitaria Navarra

  Para el hígado, La extracción la realiza el equipo de trasplantes del H. Cruces y el transporte será por tierra con ambulancia al haber una distancia inferior a 300 k.

  Para el corazón, la extracción la realiza el equipo de trasplantes de la CUN y el transporte será por tierra con ambulancia al haber una distancia inferior a 300 km.

- Opción 3 Hospital Receptor Hígado: Hospital Central de Asturias y Hospital Receptor Corazón: Hospital CHUAC (La Coruña).

  Para el hígado, la extracción la realiza el equipo de Asturias. Transporte con avión, es necesario organizar la logística de los vuelos, que deberá ir hasta Asturias, recoger al equipo extractor, trasladarle a Bilbao, y llevarles de vuelta a Asturias una vez finalizada la extracción.

  Para el corazón, la extracción la realiza el Hospital CHUAC. Transporte con avión, es necesario organizar la logística de los vuelos, que deberá ir hasta Coruña, recoger al equipo extractor, trasladarle a Bilbao, y llevarles de vuelta a Coruña una vez finalizada la extracción.

- Opción 4: Hospital Receptor Hígado Hospital Central de Asturias y Hospital Receptor Corazón Clinica Universitaria Navarra

  Para el hígado, la extracción la realiza el equipo de Asturias. Transporte con avión, es necesario organizar la logística de los vuelos, que deberá ir hasta Asturias, recoger al equipo extractor, trasladarle a Bilbao, y llevarles de vuelta a Asturias una vez finalizada la extracción.

  Para el corazón, la extracción la realiza la CUN. Transporte por tierra con ambulancia.

4.1.2 Aplicación de simulaciones en la Organización Nacional de Trasplantes

En (B Borro-Escribano et al., 2013; Blanca Borro-Escribano, Del Blanco, et al., 2013) se presentan las tres simulaciones desarrolladas para la Organización Nacional de Trasplantes.

En (Blanca Borro-Escribano, del Blanco, et al., 2013) se describe como se ha intentado reforzar y sistematizar el sistema formativo de la ONT por medio del desarrollo de simulaciones. En este

artículo se estudian también los resultados obtenidos de los primeros análisis de satisfacción realizados entre los asistentes a los cursos de formación.
Así, el artículo presenta dos resultados distintos, por un lado las simulaciones y su desarrollo y por otro lado los resultados de satisfacción de los asistentes a los cursos.

- Simulaciones: Se presentan dos simulaciones, una orientada a la evaluación de órganos y la otra orientada a la distribución de los órganos válidos para trasplante. En ambas el jugador adquiere el rol de un coordinador de trasplantes de la ONT.
  La primera simulación, la evaluación del donante, comienza con la llamada de un coordinador hospitalario para notificar un posible donante (donante potencial), el jugador deberá solicitarle los datos (la hoja de donante). En este primer punto, el jugador también podría optar por decirle al coordinador hospitalario que le llamará más tarde, lo cual llevará a una penalización y pérdida de puntos, cuando llega un donante es prioritario ya que el tiempo es crítico.
  Una vez con la hoja de donante, el jugador deberá analizar los datos que hay, determinar qué información indica la donabilidad o no de los órganos y evaluarlos cuanto antes. En los 10 casos se ha ocultado parte de la información relevante que impide la evaluación de uno o todos los órganos, el jugador deberá darse cuenta y utilizar el teléfono (mediante la acción *point-and-click* "Usar teléfono") y solicitarle al coordinador hospitalario la nueva información.
  Si decide que un órgano es no donable deberá dar una causa de no donación, entre cinco posibles causas.
  Cuando haya evaluado todos los órganos, la simulación le dirá si ha terminado correctamente la evaluación o no, en caso de haber cometido errores tendrá que volver a comenzar el juego, si ha terminado correctamente, obtendrá una puntuación y podrá pasar a realizar la segunda simulación
  La segunda simulación consiste en la distribución de los órganos, para ello, el jugador deberá analizar una información completamente diferente. Todos los órganos donables deberán ser ofertados a los hospitales donde corresponda en función de los criterios clínicos y geográficos (como se ha descrito en la casuística concreta en el apartado anterior). El jugador deberá observar el hospital donde se encuentra el donante y su grupo sanguíneo y con estos datos consultar los criterios de compatibilidad, las listas de turnos de hospitales para ver las prioridades, y las listas de espera por órganos entre otra información. En base a toda esta información, deberá decidir a qué hospital ofertar el órgano. El hospital elegido puede rechazar o no la oferta, si la rechaza, el jugador deberá volver a ofertarlo al siguiente hospital que corresponda.
  Siguiendo la misma política que en la simulación anterior, si el jugador se equivoca, deberá volver comenzar la simulación. Si acaba correctamente obtendrá una puntuación final.
- Análisis de las encuestas de satisfacción:
  Se realizaron encuestas de satisfacción entre todos los asistentes a dos cursos de formación diferentes: el TPM en Febrero 2013 y curso de coordinadores de Trasplantes de Alicantes en

Marzo de 2013. Como se indica en el artículo, los asistentes a estos cursos jugaron dos veces con las simulaciones, una primera vez guiados por el profesor y con la explicación teórica del proceso correspondiente. Luego jugaron una segunda vez ellos solos, con casos de donante distintos, para ver si habían comprendido el proceso correctamente.

Tras jugar y aprender con las simulaciones, los asistentes rellenaron una encuesta en la cual se les pedía también información para mejorar las simulaciones. Muchas de las mejoras sugeridas por los usuarios han sido implementadas y detalladas en trabajos posteriores como se describirá más adelante.

En (B Borro-Escribano et al., 2013) se presenta muy brevemente la metodología seguida para detallar un poco más las simulaciones. Al ser una revista exclusivamente de trasplantes, el foco de interés estaba en ver el procedimiento desarrollado a través de las simulaciones, así que se detalló cada una de las simulaciones, explicando los distintos pasos a seguir por el jugador así como los elementos de juego incluidos. Se presenta también la primera versión de la tercera simulación desarrollada.

La tercera simulación se enfoca en cómo organizar la logística de los transportes una vez ofertados y aceptados los órganos. El jugador, que continúa siendo el coordinador de la ONT deberá decidir si cada uno de los órganos válidos y aceptados se va a transportar por ambulancia o por avión y, en todos los casos, deberá cuadrar con todos los equipos de trasplante la hora de extracción que debe ser única. A pesar de ser la simulación inicialmente más sencilla, entraña una cierta dificultad debido al elevado número de llamadas que tiene que hacer el jugador. Por eso, en esta simulación se ha reducido mucho la complejidad de elección de modo que el jugador es guiado en casi todo momento hacia las opciones correctas.

Las tres simulaciones resultantes están orientadas a un tipo de jugadores muy concreto, personal médico relacionado con el mundo de trasplante o nuevo personal de la ONT. El procedimiento representado en estas simulaciones es complejo y requiere de una explicación previa por parte de personal experto para contextualizar a los alumnos/jugadores. Es por esta razón, por lo que estas simulaciones no se encuentran disponibles al público en general. Para poder hacer uso de ellas es necesario asistir a los cursos de formación de la ONT o bien solicitarlas a la ONT.

4.2 Validación del conocimiento

En (Blanca Borro-Escribano et al., 2014) se presenta el proceso de validación de conocimiento seguido con los expertos de la ONT para comprobar que las simulaciones representaban el conocimiento de manera precisa y sin errores de concepto o de detalle.

Realizar una correcta validación del conocimiento es de gran importancia cuando se desarrollan simulaciones con estas características, ya que el conocimiento a representar es complejo y además pertenece a un campo muy distinto al de los desarrolladores de la simulación. De hecho, en la comunicación entre los expertos sanitarios y los desarrolladores de la simulación se producen habitualmente malentendidos y dificultades en la comunicación, ya que los expertos usan vocabularios muy diferentes o asumen un conocimiento que los otros no tienen.

La validación se ha realizado con los máximos conocedores del proceso de la ONT que además son los que han documentado casi toda la literatura existente sobre el proceso de donación y trasplante español (el previamente descrito "Modelo Español"). Se realizó con 15 expertos (12 enfermeros y 3 médicos). La edad de los expertos varía entre 35 y 65 años así como la experiencia de estos en la ONT, que varía entre 1 año de antigüedad y 24. De los 15 expertos, 13 eran mujeres y 2 hombres.

Esta validación tiene tres pasos que se realizan secuencialmente, el primero se conoce como "Jugando con las simulaciones", el segundo, "Entrevistando a los expertos" y el último el "Test de usabilidad":

1. Los expertos del dominio (expertos de la ONT) juegan con las simulaciones al menos dos veces. Mientras juegan se les graba con una cámara integrada en el ordenador (ver Figura 20), de esta forma se obtienen no solo sus comentarios, sino también posibles expresiones y gestos. Además, como ya se ha mencionado, el entrevistador, apunta, siguiendo una plantilla, todos aquellos comentarios y observaciones que considera necesarios para mejorar el juego, como problemas de usabilidad o errores (la Tabla 1 muestra algunos ejemplo de las notas tomadas durante las entrevistas)
2. Una vez terminada la fase de familiarización de las simulaciones, se les realiza una entrevista semi-estructurada, en la que se les pregunta sobre diferentes aspectos de la simulación: la usabilidad, el interfaz, la complejidad, los casos de uso utilizados etc.
3. Finalmente se les pide que realicen un test de usabilidad (SUS, System Usability Scale)(Brooke, 1996) para obtener un valor único de la usabilidad de la aplicación.

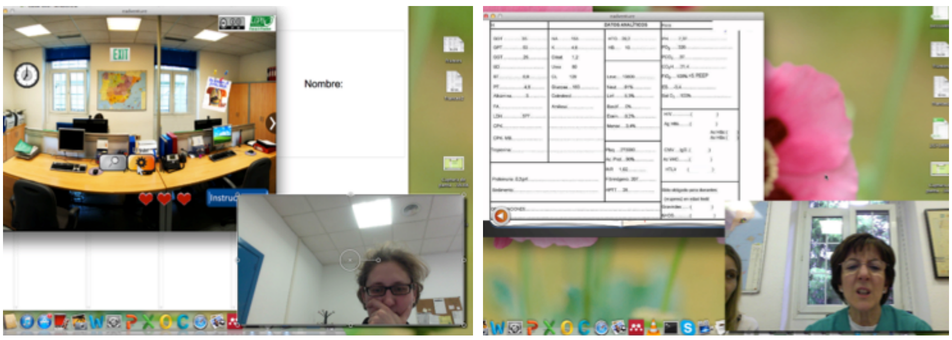


Figura 20 Imágenes de las grabaciones realizadas a los expertos

Para maximizar los resultados de este proceso de validación, después de cada validación con cada experto, y aplicando la metodología ágil de desarrollo, se corrigieron los fallos localizados (sobre todo los de usabilidad). De esta forma de forma rápida la simulación gana en madurez y estabilidad ya que el siguiente experto en jugar ya no tiene los problemas identificados previamente y permite encontrar nuevos fallos.

El último paso a realizar una vez terminadas las entrevistas, fue realizar un análisis cualitativo de los datos obtenidos de la entrevista (Bogdan & Biklen, 1998; J.Rubin & S.Rubin, 2012).

Tabla 1 Ejemplo de algunas de las notas tomadas

Código	Comentario del entrevistador
Error de contenido	Donante 0: Los valores del riñón son confusos. Podrían llevar a una evaluación incorrecta.
Error de contenido	Donante 1: El corazón podría no ser donable por el historial del donante.
Problemas de usabilidad	Con las operación drag and drop (en la distribución de los órganos)
Solicitud de mejora	Piden que se añada la posibilidad de descartar un donante completamente y no solo los órganos.
Solicitud de mejora	Piden incluir el peso y talla del donante en los criterios de distribución de los órganos para acercarse más a la realidad del proceso.

Con toda la información obtenida del experimento completo, se realizaron mejoras en las simulaciones que llevaron a una mejora en la calidad de las simulaciones en cuatro aspectos:

- Fiabilidad: Mientras los expertos jugaban detectaron algunos datos incorrectos o pasos no correctamente representados. Al corregir estos errores, la simulación mejora en fiabilidad.
- Validación del contenido: Se ha confirmado que los expertos consideran que las simulaciones representan correctamente el conocimiento de los tres procesos de coordinación supra-hospitalaria considerados.
- Usabilidad: Se mejora la usabilidad corrigiendo los errores detectados. La usabilidad se mide también en la tercera parte del proceso.
- Implicación: Se ha podido evaluar el nivel de implicación que genera la simulación en los expertos concluyendo que, en general, logra que los usuarios se interesen e impliquen suficientemente (y para lograrlo la simulación debe retar continuamente las habilidades de los jugadores (Chen, 2007)).

4.3 Metodología EGDA

En (Torrente et al., 2014) se presenta la metodología EGDA que es una aproximación al desarrollo de juegos educativos. EGDA se ha optimizado para crear juegos digitales que faciliten el aprendizaje de procedimientos (médicos, tecnológicos etc.) siendo su principal campo de aplicación la medicina aunque es aplicable en otros campos.

La creación de esta metodología ha sido abordada en varias fases:

1. Como paso previo a la definición definitiva de esta metodología, el equipo de investigación de la UCM definió y fue refinando con el desarrollo de varias simulaciones concretas un modo de trabajo para el diseño y desarrollo de simulaciones educativas.
2. Esta metodología se aplicó en varios contextos (p.ej. desarrollo de un juego de primeros auxilios, creación de un juego para la primera visita al quirófano) (Blanco, Fernández-Manjón, Ruiz, & ., 2013; Marchiori, Ferrer, et al., 2012), en este trabajo se describe su aplicación en la Organización Nacional de Trasplantes.
3. A partir de la experiencia adquirida y de los resultados obtenidos de estos desarrollos se definió finalmente la metodología EGDA para el diseño, desarrollo y evaluación de simulaciones educativas.

A pesar de que otros desarrolladores de juegos ya han logrado capturar procedimientos complejos y transformarlos de forma eficaz en juegos y simulaciones educativas (Arnab, Dunwell, & Debattista, 2012; Rosser et al., 2007), el proceso de desarrollo de estos juegos raramente se describe en detalle y normalmente se pone más énfasis en los resultados obtenidos o en la validación de los juegos. Por el contrario, en este trabajo se describe con detalle el proceso de desarrollo y diseño de simulaciones basadas en juegos a partir de estos complejos procedimientos.

Con esta metodología se intenta dar respuesta además a un problema adicional, que suele aparecer cuando se lidia con este tipo de procedimientos, que es la dificultad con la que se encuentran los desarrolladores para comprender procesos ajenos a su especialidad (Friedrich & Poll, 2007; Heiberg Engel, 2008; Kothari et al., 2012), en este caso, desarrolladores de juegos que necesitan entender procedimientos médicos complejos. La metodología presentada en este trabajo potencia la comunicación entre expertos de distintas especialidades. Esto se consigue por medio de comunicación constante entre los distintos actores interesados hasta lograr encontrar un vocabulario común que todos entienden.

Esta contribución propone como novedad la combinación de dos herramientas para crear los juegos: WEEV (Marchiori, del Blanco, Torrente, Martinez-Ortiz, & Fernández-Manjón, 2011; Marchiori, Torrente, et al., 2012) que es una herramienta de modelaje que ayuda a los expertos en juegos y a los expertos del dominio a diseñar el juego, y eAdventure, que es una herramienta de autoría de juegos que permite realizar prototipos de juegos muy fácilmente. Así se intenta facilitar la participación de los expertos del dominio en el proceso de diseño, ya que los diseños realizados por los expertos en juegos con WEEV son fáciles de revisar y pueden ser trasladados a la herramienta eAdventure de forma sencilla y, por tanto, reduciendo el coste.

En la figura 21 se presentan cada una de las tareas y sub-tareas de EGDA:

4.3.1 Análisis

En esta fase, el objetivo principal es conseguir una formalización detallada del procedimiento. Para ello, es fundamental la estrecha colaboración entre todos los participantes del proyecto (desarrolladores de juego y expertos del dominio). En muchas ocasiones, los procedimientos no están completamente formalizados y los desarrolladores de juegos necesitan obtener el conocimiento implícito (basado en la experiencia, sensaciones etc.) a partir de entrevistas formales o informales con los expertos del dominio u otro tipo de métodos como la observación de la ejecución de los procedimientos.

De esta fase también se obtiene un vocabulario común, que permite a todos los miembros del proyecto conocer todos los términos y conceptos utilizados (bien sean en el contexto del procedimiento médico como en el contexto del desarrollo de juego).

La tarea de análisis tiene dos sub-tareas:

- La definición del contexto del juego: Se define el escenario en el cual se desarrollará el procedimiento, los personajes implicados y los elementos a incluir en la escena (tanto los necesarios como los elementos que se utilizarán como distractores).
- La secuencia de pasos a seguir: Necesarios para finalizar el procedimiento, esta secuencia de pasos debe incluir tanto los pasos correctos, como los pasos incorrectos.

4.3.2 Diseño de juego

En esta fase se produce la transformación del procedimiento definido previamente en elementos de juego. Tiene 5 sub-tareas:

- Mundo Juego: A partir del escenario previamente definido se establecen las diferentes escenas que va a tener el juego y se establece la interconexión que tendrá entre ellas, es decir, se establece la navegación del juego.
- Guion: En esta sub-tarea, se obtiene un script de juego a partir de la secuencia de pasos obtenida previamente, es necesario además enriquecer este script para fomentar al jugador correctamente. Para ello, el jugador es *situado* en el juego, el jugador necesita conocer el objetivo del juego, las reglas que tiene que seguir y que rol adquiere, entre otros.
- Lógica: El juego desarrollado necesita fomentar la toma de decisiones del jugador, así, el juego debe: guiar al jugador para que descubra toda la información disponible y proveer al jugador con opciones para ejecutar estas acciones de forma directa y sencilla en el juego.

- Retroalimentación: Es fundamental que el jugador reciba retroalimentación durante el juego, de esta forma aprende mientras juega y retiene la información.
- Ludificación: Hace referencia al concepto de *gamificación,* inclusión de elementos de juego para aumentar la motivación y el grado de inmersión del jugador. Algunos ejemplos de *gamificación* pueden ser la inclusión de vidas, tiempo, bonus o puntuación de juego.
- Ajuste de dificultad: En todas las sub-tareas previamente descritas, es fundamental mantener el equilibrio entre los elementos introducidos en el diseño y la complejidad que este va adquiriendo, asegurando siempre que el juego sigue siendo desarrollable a un coste aceptable.

4.3.3 Implementación

En esta fase se desarrolla finalmente el juego descrito y diseñado previamente. Tiene dos sub-tareas:

- Prototipado: Se desarrollan prototipos de las simulaciones para que puedan ser posteriormente evaluados, estos prototipos tienen que incluir todas las decisiones de diseño previamente tomadas e irán adquiriendo complejidad a medida que se vayan evaluando y validando.
- Recursos gráficos: Es en esta fase donde se incluyen los recursos gráficos a utilizar en el juego. Esta sub-tarea puede resultar muy costosa si es necesario contratar la realización de estos recursos.

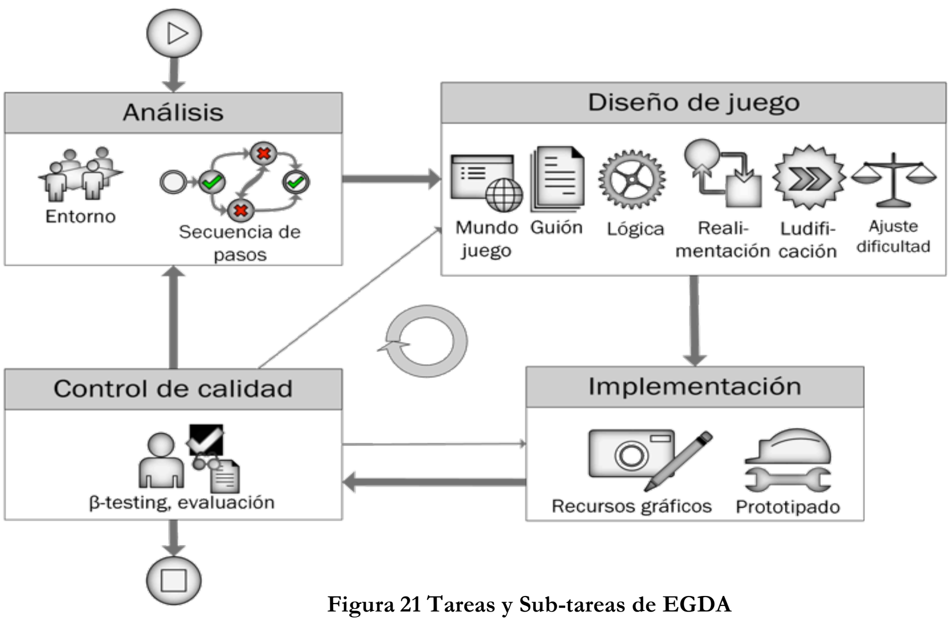


Figura 21 Tareas y Sub-tareas de EGDA

4.3.4 Calidad

En esta fase se comprueba que el juego desarrollado alcanza los umbrales adecuados de fiabilidad, usabilidad, jugabilidad y valor educacional. Para comprobar que estos umbrales se cumplen es necesario realizar evaluaciones a diferentes niveles con todas las personas implicadas: los desarrolladores, los expertos del dominio y los usuarios finales del juego. De esta forma se corrigen entre otros errores de definición de procedimiento, errores de diseño y errores de usabilidad.

4.3.5 Aplicación y resultados

En esta contribución (Torrente et al., 2014) se presentan 7 juegos desarrollados siguiendo la metodología EGDA, entre ellos los que ya se han presentado con anterioridad, sobre la evaluación de los órganos y donantes para la Organización Nacional de Trasplantes. Además, también se incluyen otros juegos en los que se ha colaborado con otras instituciones médicas como el Hospital General de Massachusetts, la facultad de medicina de la Universidad Complutense de Madrid o el Hospital Miguel Servet en Aragón.

Estos juegos educativos se han utilizado para mejorar los procesos educativos y las prácticas clínicas en casos donde el uso y aplicación de procedimientos complejos forma parte de la actividad profesional diaria. Además, permiten a los estudiantes aumentar sus posibilidades de practicar y entrenar procedimientos a los que antes tenían difícil acceso de práctica debido a la falta de recursos o equipamiento. Finalmente, el acceso a estos videojuegos para practicar los procedimientos reduce el estrés en los estudiantes al practicar en un entorno seguro de riesgo y tantas veces como sea necesario.

En este artículo se propone medir la eficacia de EGDA discutiendo el coste estimado de los juegos desarrollados y comparando estos costes con los habituales hoy en día en el desarrollo de videojuegos. Sin embargo, esta tarea es compleja por dos razones, en primer lugar, es muy difícil hacer una estimación precisa de los costes de desarrollo de un juego y, en segundo lugar, es difícil comparar el coste de desarrollo entre juegos. Aun así, y a pesar de lo complejo que es obtener datos sobre el coste de desarrollo de otros juegos, se compara esta información con nuestros juegos para probar que el enfoque es eficiente.

Finalmente, en este artículo se analiza también la efectividad como herramientas educativas de dos de los juegos desarrollados con EGDA: *First Aid* and *HCT* (Marchiori, Ferrer, et al., 2012; Moreno-Ger et al., 2010). En ambos casos el conocimiento adquirido es medido antes y después de la práctica y se comparan los resultados entre los grupos de control y los grupos experimentales..

4.3.6 La evaluación del donante en el nivel hospitalario

En (Borro Escribano, del Blanco, Torrente, Borro Maté, & Fernández-Manjón, 2014) se presenta como la definición de la metodología EGDA unido a la experiencia en el desarrollo de las simulaciones para la ONT y otros contextos médicos, permiten el desarrollo de una nueva simulación mejorada y en la que plantea un uso mas sofisticado de los casos de aplicación. Esta simulación representa otro de los pasos del proceso de donación y trasplante pero dentro del contexto del nivel hospitalario. De hecho es el primer paso en el que el responsable hospitalario realiza la "Evaluación del Donante".

El objetivo a la hora desarrollar esta simulación era aprovechar la experiencia y el conocimiento adquirido por los expertos en juegos del proyecto para desarrollar una simulación útil para mejorar la formación de los coordinadores hospitalarios a la vez que adaptada al público más general (esta simulación está disponible de forma libre en el sitio web del grupo de investigación e-UCM). El conocimiento de la simulación es semejante al de la simulación de "Evaluación del Donante" en la ONT, pero cambiando el punto de vista del jugador quien se convierte en un coordinador hospitalario en una unidad de cuidados intensivos en un hospital.

El problema principal encontrado con las simulaciones desarrolladas para la ONT era que el público objetivo era muy reducido, solamente los coordinadores de trasplante de los cursos de formación y el personal de la ONT. Nuestra idea era aprovechar toda la información obtenida en las encuestas de satisfacción, de usabilidad y en la evaluación de conocimiento realizada con los expertos para realizar una simulación mejorada. Pero además tiene un objetivo más ambicioso que es que cualquier persona pueda jugar y llegar a comprender (al menos básicamente) como funciona el proceso de donación sin necesidad de tener conocimientos médicos. Aun así, hay que matizar que al ser procedimientos médicos muy complejos en los que hay que conocer valores como son los niveles de P02 o la creatinina, el jugador sin conocimientos médicos podrá llegar a conocer el procedimiento de forma muy general.

Una de las mejoras aplicadas a esta simulación fue la definición del conjunto de casos de uso a utilizar, estos casos de uso fueron validados por un experto médico con amplia experiencia hospitalaria en trasplantes y que ha estado directamente involucrado en el proyecto. Para maximizar el número de casos utilizados y mejorar el aprendizaje de la simulación, se ha modificado la forma de emplear los casos de uso en la simulación. Se partió de un caso de uso real y se seleccionó aquella información importante para el aprendizaje, esta información se extrajo de la hoja de donante y se platearon diferentes valores asociados para ese caso. A la hora de cargar el donante al inicio del juego, se cargan todos los campos y se decide pseudoaleatoriamente los valores concretos de esos campos. En la tabla 7 para ver todos los posibles valores asociados a los campos seleccionados. La única condición que se especifico a la hora de combinar todos estos campos fue que tengan sentido desde el punto de vista médico. Por ejemplo, cuando la radiografía de tórax indica una neumonía aspirativa basal, las secreciones siempre van a ser purulentas. Para el resto de valores, que no plantean problemas de validez y plausibilidad médica, las combinaciones son libres lo que da un elevado número total de posibles casos de uso.

A continuación se describen otras de las mejoras añadidas a esta simulación para, entre otros aspectos, ampliar el público objetivo que pueda utilizarla:

- Mejora del sistema de retroalimentación inmediata, permitiendo al estudiante conocer mejor donde ha cometido los errores así como las buenas acciones.
- La posibilidad de jugar a la simulación en multi-idioma (español, inglés y francés).

- La inclusión de un sistema de bonificaciones extra para motivar al alumno.
- La inclusión de un asistente que guía al estudiante a lo largo de la simulación.
- La inclusión de tres niveles de dificultad.
- Se amplía el número de casos de uso utilizados.
- Accesible a un mayor público, gracias a los diferentes niveles de dificultad y el asistente.

Tabla 2 Campos y valores seleccionados para carga de casos de uso

Campo	Valores
Edad	30
	46
	59
Radiografía de tórax	Normal
	Neumonía aspirativa basal
	Neumotórax ayer, hoy normal
	Infiltrados basales bilaterales
Eco Abdominal	Normal
	Enolismo crónico, riñones normal
Ecocardio	Normal
	FE < 40%
Adicciones	No adicciones
	Alcoholismo 15 años
	Tabaquismo 20 paquetes/año
Secreciones	Normal
	Purulentas
Diabetes	No
	Si, mellitus
HTA	No
	Si
Gasometría	PO2 = 300mg
	PO2 = 150mg

Es evidente que el número de casos de uso puede seguir aumentando de forma incremental si se aumentan los valores posibles de las variables o si se añaden nuevas variables. Esto también implica que hay que realizar un esfuerzo extra en garantizar que todos los casos posibles son correctos desde el punto de vista médico.

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 metodología para el desarrollo de simulaciones con estrategia de juegos en el campo médico, llamada EGDA. Esta metodología ha permitido la consecución del objetivo principal de esta tesis que es la sistematización de simulaciones con estrategia de juego en el campo médico.

Para lograr este objetivo, ha sido necesaria la consecución de cada uno de los tres sub-objetivos descritos en el capítulo 3 y consistentes en el desarrollo de simulaciones, su validación y la propuesta de una metodología de desarrollo para este tipo de simulaciones.

La consecución del primer sub-objetivo se ha concretado a través del desarrollo de tres simulaciones educativas con estrategia de juego para la Organización Nacional de Trasplantes para representar los procedimientos que se utilizan en su día a día. Estos procedimientos son conocidos mundialmente por su efectividad y éxito de ejecución en España. Muchos países intentan copiar el modo de trabajar de la ONT. Gracias a estas simulaciones, la ONT puede transmitir sus procedimientos de manera general a los diferentes países sin tener que dedicar un gran número de recursos (personal, tiempo y dinero) en desplazamientos y cursos de formación a lo largo de España. Estas tres simulaciones representan: la evaluación del donante, la distribución de los órganos y la logística de los transportes.

A día de hoy estas simulaciones están siendo utilizadas en dos ámbitos diferentes: como parte del sistema formativo de la ONT para coordinadores de trasplantes en España y como material de ayuda para el nuevo personal de la ONT.

Para la consecución del segundo sub-objetivo, se han realizado dos tipos de validaciones: validación del conocimiento con los expertos de la ONT y validación de la usabilidad y satisfacción entre los asistentes a los cursos de formación de la ONT.

Se ha realizado un procedimiento de validación del conocimiento con los expertos de la ONT que ha permitido verificar que todo el conocimiento incluido en los procedimientos es preciso y correcto.

El hecho de que las simulaciones se utilicen como parte del programa de formación de la ONT nos permitió realizar encuestas de usabilidad y satisfacción entre los asistentes a estos cursos para tener una mejor percepción de su opinión y su grado de satisfacción. Gracias a estas encuestas, se puede afirmar que las simulaciones permiten familiarizarse con el modo de trabajo de la ONT facilitando la adquisición de conocimientos disponibles que son más complejos de aprender sólo a través de la documentación escrita (p.ej. errores comunes). Por tanto, las simulaciones permiten a los jugadores sumergirse en los procedimientos y aprender mientras juegan sin poner en riesgo la eficacia del modelo español de trasplantes y con una menor demanda de personal especializado en la formación.

Finalmente, la consecución del tercer sub-objetivo se logra gracias a la definición de la propia metodología EGDA que como hemos mencionado supone la culminación de este trabajo y su principal aportación. EGDA es una metodología centrada en los procedimientos y especialmente orientada al campo médico aunque consideramos que se puede aplicar también en otros dominios.

Esta metodología mejora la comunicación y el entendimiento de todas las partes implicadas en el desarrollo facilitando así la transferencia de información y mejorando la representación de los procedimientos en las simulaciones. EGDA ha sido evaluada para validar tres aspectos principales: la eficiencia (en términos de coste de desarrollo de las simulaciones), la efectividad del aprendizaje lograda con estas simulaciones y la aceptación del estudiante de las simulaciones como contenidos educativos motivadores.

Los resultados obtenidos nos permiten concluir que los costes de desarrollo de EGDA son mucho más bajos que los juegos educativos actuales. Por tanto, EGDA ayuda a reducir los costes de producción de juegos, que ha sido identificado como un factor bloqueante en la generalización de los juegos y simulaciones educativas (Johnson et al., 2012) y además lo logra sin comprometer en ningún momento su valor educativo. La retención del valor educacional ha sido evaluada y se apoya en datos publicados previamente con algunos de los juegos educativos desarrollados siguiendo EGDA (o versiones previas de esta metodología). En resumen, los datos publicados sugieren que los juegos desarrollados con EGDA mejoran el aprendizaje y los resultados de los estudiantes y además mejoran la retención del conocimiento. Este conocimiento además, es transferido correctamente cuando se aplican los procedimientos aprendidos en el mundo real. De los estudios de satisfacción y usabilidad realizados, se percibe que los estudiantes creen que estos juegos son herramientas educativas útiles. Estas conclusiones se basan solo en 3 de los juegos desarrollados con EGDA que son los únicos que han sido formalmente evaluados a la escritura de esta tesis.

Finalmente, y como prueba final de contraste de la metodología EGDA, se ha aplicado al desarrollo de otra simulación, en la que se aprovecha la experiencia aprendida en la ONT y se está intentando ampliar el público objetivo. Se ha desarrollado la evaluación del donante en el contexto del nivel hospitalario y la idea de esta simulación era llegar no sólo al personal médico que se tiene que formar, sino hacerla disponible a cualquier ciudadano interesado en el proceso. Esta simulación tiene varios niveles de dificultad para adaptarse a estos distintos tipos de públicos y, además, se ha implementado una *"visita guiada"* al juego para permitir a los jugadores conocer mejor el modo de juego y familiarizarse con el entorno antes de comenzar.

5.2 Trabajo futuro

En esta sección se describen algunas de las líneas de trabajo futuro que se han abierto en este trabajo de tesis y en las que consideramos que se debería continuar trabajando:

- El principal problema de EGDA es que se ha definido y se ha estudiado su efectividad en un campo relevante pero muy acotado como es el campo médico. Aunque tenemos la intuición que podría usarse con éxito en otros contextos, este aspecto no puede afirmarse ya que no se han hecho pruebas y experimentos que lo sustenten. Será necesario por lo tanto abrir una línea de investigación que permita evaluar si la metodología EGDA (o una adaptación de ésta) es efectiva para el desarrollo de simulaciones de bajo coste en otras áreas.
- Otra limitación que tiene EGDA es la elección de software para el desarrollo de sus videojuegos, a pesar de que se deja abierta la elección de la herramienta de autoría de videojuegos, en todos nuestros desarrollos se ha utilizado eAdventure, que entre otras cosas no soporta los juegos multi-usuarios (aunque sí que se pueden simular). Dentro del trabajo futuro, existe la posibilidad de utilizar EGDA para enseñar procedimientos en donde la colaboración entre compañeros es esencial lo cual requeriría usar un software un software de creación de juegos diferente (e incluso ampliar la propia metodología para contemplar esos aspectos colaborativos o multiusuario).
- Todos los datos obtenidos en la evaluación de EGDA a día de hoy son cuantitativos. Existen otros datos cualitativos que sería necesario estudiar en profundidad para poder obtener resultados concluyentes, por ejemplo, para evaluar la aceptación de EGDA por otros desarrolladores que tengan menos experiencia en el campo médico.
- A pesar de que uno de los pilares de EGDA es la potenciación de la comunicación entre los distintos profesionales implicados en el proyecto (personal médico, desarrolladores, educadores), todavía es preciso seguir trabajando para mejorar la colaboración y lograr una mayor implicación de estos profesionales en los proyectos. Es necesario estudiar el campo para identificar nuevas formas eficaces de lograr esta implicación con el menor esfuerzo para los expertos.
- Con respecto a la última simulación desarrollada con EGDA que se presenta en este trabajo "Evaluación de donante en el contexto hospitalario", todavía es necesario realizar los estudios formales de fiabilidad, usabilidad y satisfacción de esta simulación así como

validar que el contenido (el mismo que en las simulaciones de la ONT pero aplicado a un contexto diferente) es correcto. Estas validaciones, se ya están en fase de diseño experimental y se harán entre estudiantes de cursos de formación y profesionales de la salud involucrados en el trasplante.

- Aplicación de analíticas de aprendizaje (en inglés, *Learning Analytics*) en la validación de juegos y simulaciones. Esta simulación "Evaluación de donante en el contexto hospitalario", se desarrolló desde un primer momento orientada hacia poder usar analíticas de aprendizaje. De hecho, como la simulación está disponible para todo el público, se están obteniendo datos de las diferentes ejecuciones del juego, para analizar el tiempo de juego, cuanta gente lo finaliza, si cometen muchos errores comunes (de lo cual se podría derivar la necesidad de mejora en algún aspecto del juego). Uno de los objetivos finales de esta recolección de datos es lograr más información sobre la efectividad de los juegos desarrollados con EGDA que al menos complementen y reduzcan la complejidad y el coste de los procesos de evaluación formal (normalmente mediante pre-test y post-test escritos).

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

6.1 Introduction

The excellent deceased donation rates achieved by the Spanish National Transplant Organization (ONT) during the recent years are the result of the so-called Spanish Model on Organ Donation and Transplantation (Matesanz, Dominguez-Gil, Coll et al., 2009; Scandroglio, Dominguez-Gil, Lopez et al., 2011). One of the main elements of this model is the continuous professional training targeted to all professionals directly or indirectly involved in the process of deceased donation through dedicated courses focused on the procedural steps of said process.

This instructional approach was resource consuming, requiring the participation of the most experienced nurses of the ONT who may need to travel and sometimes spend several days abroad during these courses. Having only 14 people as a workforce, it was necessary to find a solution to support and optimize this instruction. In addition to this problem, the students assisting to the course could not practice with the teaching cases or the material used once the course was finished and the only way to retain and refresh the learning was by reading the documentation provided. It was necessary to enable students to practice as many times as possible in a risk-free environment without the presence of the instructor.

To answer the needs detected in the ONT, we developed educational game-like simulations to represent the ONT knowledge. These game-like simulations should include both the explicit and tacit ONT knowledge (i.e., knowledge that is not easily accessible to introspection via any elicitation technique (Blandford & Rugg, 2002)), which is usually very difficult to transmit, especially in healthcare, where highly specialized and complex procedures constitute a considerable part of the domain knowledge and must be executed with precision to prevent patient damage. Capturing this knowledge and representing it through simulations would simplify the transference of knowledge to other countries and institutions, thereby helping the ONT instructional approach. Moreover, it could help to improve the systematization of its procedures.

Developing serious games that are meaningful and effective is not an easy venture, however. One of the key aspects for successful serious game design is to effectively create synergies between domain experts (i.e. healthcare professionals in this case) and serious game experts that enable quick translation of domain experts' knowledge into a working serious games prototypes that can be collaboratively refined by the team and the potential end-users. When this is not achieved, there is a significant risk of ending up with a product that doesn't accomplish the educational objective (Van Eck, 2006). Unfortunately, this scenario is still common nowadays, resulting in many serious games that have not managed to live up to expectations (Hays, 2005).

This PhD arises from a very concrete need, but from all the experience acquired accomplishing this objective and from the experience of seven years of intensive research and development of other serious games, a methodology to systematize this process was born: EGDA (Educational Game Research Approach). EGDA is a methodology for designing and developing serious games that focuses on the effective integration of domain experts in the process (Torrente et al., 2014). EGDA focuses on developing a type of serious games called "low-cost game-like simulations", a formula for maximizing the educational value delivered at a minimum cost, which we have applied mainly in the healthcare domain.

Finally, we have applied EGDA to develop an enhanced simulation, called Donor's Evaluation, including another step of the deceased donation process (belonging to the hospitalary level).

6.2 State of the art

An analysis of the state of the art 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.

Serious games have become a recognized tool for teaching and training in general (Roberts, While, & Fitzpatrick, 1992) and could soon be ready for wide adoption (Hwang & Wu, 2012; Johnson et al., 2013). A serious game is formally defined as an 'interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality' (Graafland et al., 2012). The main objective of a serious game is educational differing from conventional video games. They present an ideal playground to engage players in simulated complex decision-making.

Among other benefits, serious games promote active learning experiences stimulating higher thinking such as analysis, synthesis and evaluation (Boyle, Johnston, MacArthur, & Fernández-Manjón, 2013), learning-by-doing (Akl, Pretorius, et al., 2010; Andersen, 2012; Dror, Schmidt, & O'connor, 2011; Kato, 2010), guarantee intrinsic motivation, promote the acquisition of problem-solving skills and provide situated learning. Also, while playing and learning, the stress and anxiety of the real life experience reduces notably and as a result the level of retention may increase.

Well-designed serious games make learning fun, challenging and rewarding. One of the main characteristics of well-design serious games is that players are so engaged in the game, so focused on achieving goals that they don't realise they are learning while playing. While competing with others they become immerse and master the subject matter without realising it.

Closely related to serious games is the field of Game-Based Learning (GBL), that continues to raise firmly and steadily, producing evidence on its potential (Hwang & Wu, 2012) like significant improvements of academic performance and student motivation (Kanthan & Senger, 2011; Warren, Dondlinger, McLeod, & Bigenho, 2012). As a consequence, the interest in using games in education is quickly increasing among different organizations (McClarty et al., 2012). However, there are still open issues regarding the use of educational games like their high development and production costs or the lack of scalability (Johnson, Adams, & Cummins, 2012).

In this PhD project, we deal with serious games in healthcare. The use of serious games in healthcare is not new. Different kind of medical simulations have been used for more than 40 years to train professionals.

However, the educational healthcare system is facing a shift in its teaching paradigm. The increasing amount of medical information and research makes it hard for medical education to stay up-to-date in its curriculum. Clinical medicine is becoming focused more on patient safety and quality than on bedside teaching and education as patients are becoming increasingly concerned that students and residents are "practicing" on them. Moreover, hospital length of stay is shorter for every disease, there is a new emphasis on outpatient and minimally invasive therapies, which leads to a diminution in the number of hours a resident can practice. In some countries educators have faced these challenges by restructuring curricula, developing small-group sessions, and increasing self-directed learning and independent research. Nevertheless, there is still a connection problem between the classroom and the clinical environment, with the consequence that many students feel that they are inadequately trained in history taking, physical examination, diagnosis, and management. Medical simulation has been proposed as a technique to bridge these educational gaps.

Medical simulations allow students to practice with virtual patients as many times as needed in a risk-free environment. They promote what is known as deliberate practice, that endorses the idea that educational interventions must be strong, consistent, and sustained to promote lasting skill and knowledge attainment (McGaghie, 2008).

Nevertheless, representing medical procedures throughout simulations or serious games is not easy. Tacit knowledge must be extracted from the domain experts and represented accurately to maximize the learning objective. Moreover, usually medical simulations representing complex procedures need a high grade of realism, which usually requires the use of high technology, with the consequent raise of development cost.

In the following lines we will provide a list of some of the scarcities found in this state of art:

- Although there are many research studies, there is still much research work to do in most of the fields to be able to state that serious games are an adequate alternative to traditional education.
- In the current literature there is still need to find and establish proper validation procedures for serious games (Graafland et al., 2012).
- There is a lack of methodologies to design and develop serious games that focus on the development methodology followed, instead, emphasis tends to be placed on the presentation of the results and discussion of the benefits.
- Finally, the development cost of serious games is still a major barrier in this area.

In this PhD work we try to present solutions to some of these necessities.

6.3 Goals

Three sub-objectives have been accomplished in this work, which results in the achievement of a main objective of this PhD: The systematization of the development of game-like simulation in healthcare.

First sub-objective: Development of game-like simulations to capture the know-how of the ONT and systematize the instructional approach.

We have developed three game-like simulations representing some of the procedures used daily in the ONT. These three simulations represent the following steps of the Process of Deceased Donation: the organ and donor evaluation, the organ distribution and the logistics of transportation.

To develop these simulations, we have followed a methodology built on the principles of agile software development that supports the efficient capture of tacit knowledge by empowering communication between domain experts and game designers, who are the main stakeholders. This methodology is iterative and in each loop, domain experts and game designers perform tasks that are related to the following four processes: Specification, Game Design, Simulation Development and Quality Assurance. These four processes are dependent on each other, and depending on the iteration being executed, the workload allocated to each process changes. In the early iterations, the specification and game design activities are more important, and in the last iterations, the implementation and quality assurance become more relevant.

These simulations must allow the students comprehend in general terms the ONT procedures and better understand the pressure and different situations the ONT transplant coordinators face daily.

This methodology and the resulting simulations have accomplished the following results:

- Improvement and systematization of the ONT's procedures.
- Systematization of the ONT's teaching cases used in the instructional approach.
- Improvement of the instructional approach. These simulations are being used as support tool in the ONT's courses. Students can practice these the procedures at any time after the course without risking the real process efficiency.
- Minimization of the resource need, the ONT staffs still needs to go and lead the courses, but they don't need to spend as much time as before.

The development of these three simulations leads to the need of the second sub-objective:

Second sub-objective: Validation of the produced simulations among the ONT staff and by their application in the ONT courses for new personnel and other professionals.

The main objective of this validation was to estimate how accurately the knowledge had been captured and transferred to the game-like simulations. This validation was needed because only one ONT expert had validated the development of the three previous simulations, and as the knowledge represent was very complex and included a certain amount of tacit knowledge, we needed to assure that the knowledge represented was accurate enough. To do so, we followed a process with several steps among the 15 ONT experts to detect usability, content, granularity or quality problems in the simulations.

This process allowed us to improve notably the simulations and to confirm that the knowledge had been correctly acquired.

This objective also presents the usability and satisfaction studies performed among the students attending the ONT courses around Spain where these simulations are used as a support tool. These studies allowed us to conclude that the simulations helped them to establish a better understanding of the donation and transplantation process.

Third sub-objective: Proposal of a methodology to develop game-like simulations to formalize medical procedures.

During the past 10 years, the e-UCM research team has been working with and developing serious games, paying special attention to those related to healthcare.

As a result of all this work, a methodology was defined, the EGDA (Educational Game Development Approach), in order to design, develop and evaluate game-like simulations or serious games in healthcare. EGDA aims at laying the foundations to help other developers and researchers produce educational games and collaborate with domain experts more efficiently.

EGDA is a *procedure-centric* process. First, the procedure and the knowledge associated to it are formalized in order to obtain a detailed specification document and a common vocabulary. This document will have all the information needed by the game developers to make a proper design and development of the simulation. The extraction of a common vocabulary if essential for the success of the project as it assures that every stakeholder understands all the concepts and terms used. This formalized procedure acts as the central communication point for the stakeholders involved along the whole process, including domain experts (e.g. medicine instructors) and game experts. Then, the procedure is used to build an accurate simulation environment. In this step the player is situated in the game, he needs to know the rules of the game, the main objective, the different roles he may have etc. Finally gaming elements are added to transform the simulation into a game-based learning environment.

This objective also presents the application of EGDA to a particular case, the development of a serious game representing the donor's evaluation in an ICU's room from the point of view of a hospital coordinator. To date, eight games have been produced with EGDA in collaboration with different organizations related to health and medicine instruction

In these games we have evaluated three different aspects of EGDA: efficiency in terms of development costs, learning effectiveness and student acceptance:

- The average production cost per minute of game developed is far below current industry standards suggesting that EGDA can help to achieve a significant reduction of the production costs of the games without compromising the educational value.
- The retention of the educational value was evaluated and empirical evidence suggests that these games managed to improve students' performance and knowledge retention, and also transfer the knowledge acquired in the game to the application of procedures in real settings.
- The students also perceived the games as useful learning tools.

6.4 Conclusion and Future work

We have successfully developed three simulations that have been included as part of the National Transplant Organization instructional approach, which confirms that the objective for which they were developed has been accomplished, as this objective was to support the ONT instructional approach and to improve the systematization of its procedures. This was also confirmed with the validation process performed among the ONT experts and in the ONT courses. The procedures represented in these simulations are globally known for their efficiency. Many countries try to imitate the know-how of the ONT and we believe that thanks to these game-like simulations, the ONT will be able to transmit its procedures without having to employ so many resources (time, staff and money).

By developing these simulations, the ONT has also enhanced its training strategy. We believe, based on the feedback reported by ONT experts and on the student's opinions, that students understand better the ONT procedure as they "get into context" from the moment that they start playing.

Additionally, these game-like simulations support effective decision-making. The student must analyze the available information, decide the best action and execute it in the game-like simulation (Gee, 2007). This game-like simulation guides the student in discovering all of the available information that is needed to make decisions and advance in the execution of the procedure.

The main contribution of this PhD project is the proposal of a methodology to develop and design game-like simulations in healthcare, called EGDA. Thanks to this methodology we have accomplished the main objective of this simulation, which is the systematization of game-like simulations in healthcare.

Our future work includes the following lines of work:

- We need to continue evaluating and analyzing the efficiency of serious games developed with EGDA in order to improve the methodology and its games.
- All the results obtained with EGDA are based on quantitative data, qualitative data have been collected through formative and informal evaluations but not analysed, further research would be required to confirm the validity of the results for all the games.
- We plan to apply and include *Learning Analytics* in the game validation process.
- The proposal of EGDA is tailored to a very particular domain, healthcare. Testing EGDA in other fields or domains would clarify whether it is efficient and can be used in different settings.

Capítulo 7 Artículos PRESENTADOS

En este capítulo se incluyen los 6 artículos editados que se aportan como parte de esta tesis doctoral.

7.1 Developing Game-Like Simulations to Formalize Tacit Procedural Knowledge: The ONT Experience

7.1.1 Cita completa

Borro-Escribano, B., Del Blanco, Á., Torrente, J., Alpuente, I. M., & Fernández-Manjón, B. (2013). Developing game-like simulations to formalize tacit procedural knowledge: the ONT experience. Educational Technology Research and Development, 62(2), 227–243. doi:10.1007/s11423-013-9321-6

7.1.2 Resumen original de la publicación

The exceptional success achieved by the Spanish National Transplant Organization (ONT) in recent years has made other countries highly interested in following this organization's methodologies. A good training program is one of the key elements of the ONT. Until 2012, the ONT training program was a paper-based case teaching method, and the small number of ONT experts limited the audience. In an attempt to improve and increase the attendees in this program, a game-like simulation was developed to represent transplant management procedural knowledge. To maximize the educational value, this game-like simulation was based on representative teaching cases to help students practice with different real situations and different levels of complexity in a risk-free environment. This study presents how an iterative game development methodology has been applied to evolve from a paper-based case teaching method to a game-like simulation, with a special focus on the efforts made to include the ONT experts' tacit procedural knowledge in the simulation. Apart from increasing the number of students who can access the ONT training, this game-like simulation also helped to achieve a more detailed formalization of transplant management as well as a more comprehensive systematization of a set of relevant teaching cases.

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DEVELOPMENT ARTICLE

Developing game-like simulations to formalize tacit procedural knowledge: the ONT experience

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Abstract The exceptional success achieved by the Spanish National Transplant Organization (ONT) in recent years has made other countries highly interested in following this organization's methodologies. A good training program is one of the key elements of the ONT. Until 2012, the ONT training program was a paper-based case teaching method, and the small number of ONT experts limited the audience. In an attempt to improve and increase the attendees in this program, a game-like simulation was developed to represent transplant management procedural knowledge. To maximize the educational value, this game-like simulation was based on representative teaching cases to help students practice with different real situations and different levels of complexity in a risk-free environment. This study presents how an iterative game development methodology has been applied to evolve from a paper-based case teaching method to a game-like simulation, with a special focus on the efforts made to include the ONT experts' tacit procedural knowledge in the simulation. Apart from increasing the number of students who can access the ONT training, this game-like simulation also helped to achieve a more detailed formalization of transplant management as well as a more comprehensive systematization of a set of relevant teaching cases.

Keywords Screen-based simulation · Educational games · Tacit knowledge · Medical procedures · Case-based teaching

Abbreviations
ONT Spanish National Transplant Organization

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Introduction

After intense debate, serious games have emerged as a promising technology for education that could soon be ready for wide adoption (Hwang and Wu 2012; Johnson et al. 2013). However, to be deployed mainstream, the scalability of serious games must be improved, because the development of serious games is still a costly and complex process, which limits the situations in which game-based learning (GBL) can be applied (Dede 2009; FAS 2006).

Such a lack of scalability is partly due to the difficulty of capturing, formalizing and adapting the domain knowledge to fit into a video game design. Highly specialized knowledge could be tacit [i.e., knowledge that is not easily accessible to introspection via any elicitation technique (Blandford and Rugg 2002)]. It can be difficult to formalize this type of knowledge, especially in healthcare, where highly specialized and complex procedures constitute a considerable part of the domain knowledge and must be executed with precision to prevent patient damage. Moreover, these procedures are difficult to understand for game developers, who rarely have the medical expertise that is required (Friedrich and Poll 2007; Heiberg Engel 2008; Kothari et al. 2012).

The idea of using serious games, simulations and other content of a similar nature in healthcare education is not new, and several successful case studies are available (Arnab et al. 2012; Rosser et al. 2007). In these experiences, domain experts and game developers must necessarily establish a development methodology that is effective in capturing and transferring (at least partially) the domain knowledge to a simulation. Nevertheless, in these experiences, emphasis tends to be placed on the presentation of the results and discussion of the benefits obtained rather than on the development methodology that is followed.

Here, we attempt to fill this gap by describing the methodology that is followed to design and develop educational game-based content. Therefore, the purpose of this study is not to report on the learning gain or the impact of using the software developed in the learning process, but instead, the goal is to describe a development methodology that could help other developers and researchers produce educational games and collaborate with domain experts more efficiently.

We have applied the methodology to transform part of the Spanish National Transplant Organization (ONT)s technical know-how into game-based educational content. ONT is the institution that is responsible for coordinating organ deceased donation in Spain. The organ deceased donation process refers to all of the tasks that are taken since a hospital transplant coordinator considers a patient to be a potential donor until the suitable organs are transplanted to a recipient. In recent years, ONT has achieved the highest rates of organ deceased donation per country, becoming a world-leading institution (Domínguez-Gil et al. 2011; Matesanz et al. 2009, 2011; Matesanz-Acedos 2009; Scandroglio et al. 2011). As a result, the ONT organizational system (known as the Spanish Model on Organ Donation and Transplantation) is highly appreciated by other international organizations, for whom ONT provides several training courses every year. Having part of this workflow captured into game-based software facilitates dissemination to a wider audience. A second benefit is the improvement of the internal knowledge systematization and standardization processes of the ONT.

We define the software developed as *game-like simulations*: simulation environments that are enhanced with several game elements (Moreno-ger et al. 2008). The software is in the first place a highly interactive, 2-D point-and-click simulation environment that allows students to rehearse a specific procedure in a safe and cost-effective world. These game-like simulations are based on cases that are composed by relevant educational situations and not on a physical simulation model. Then, the process is *gamified*, adding elements that are frequently used in games, such as narrative underpinnings and the use of a score and achievements to foster competition. While the game component is much less important than the simulation component, the simulation helps to deliver a more engaging student experience while preserving the cost efficiency.

The remainder of this study is structured as follows. We first explain the process of organ deceased donation and the ONTs instructional approach. We then provide an overview of the simulation developed and the development methodology followed to develop it. We lastly discuss the strengths and weaknesses of this approach and present conclusions and future work.

Background: the ONT

The process of organ deceased donation

The organ deceased donation process covers multiple tasks that require an extremely efficient interaction among several stakeholders. To maximize a rapid response and efficiency, the process is distributed at two levels: the hospital level and the supra-hospital level. The hospital level covers the identification and maintenance of potential donors: brain-dead patients who could meet the organ donation criteria. A hospital transplant coordinator is appointed for each Spanish hospital to coordinate these tasks. Hospital transplant coordinators interact with the ONT, which is the single entity that is responsible for cross-hospital coordination (at the supra-hospital level). The main steps covered at the supra-hospital level are the organ and donor evaluation and the subsequent organ allocation and transportation processes (including all of the logistical aspects). Figure 1 provides an overview of the whole process.

The process starts with a hospital transplant coordinator notifying to ONT that a potential donor has been identified. Then, ONT nursing personnel ensure that all of the information that is needed to evaluate donor and organ suitability has been provided. Afterward, the ONT determines what individual organs are to be offered to what transplant teams (one or many) across the national territory following complex allocation criteria. ONT contacts the selected teams and provides them with all of the information that is required. Teams then decide on the acceptance or rejection of the organ and the subsequent

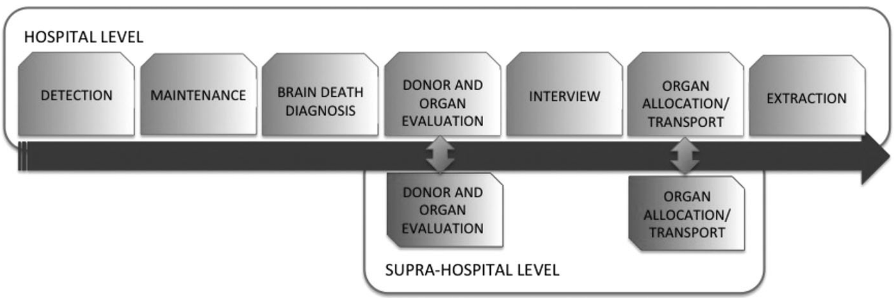

Fig. 1 Process of organ deceased donation

transplantation. Once a team accepts the offer of an organ, ONT organizes the transport and logistics of the organ.

The ONT instructional approach

Since its creation in 1984, ONT has trained over 14,000 health professionals worldwide through several programs. For the sake of simplicity, in this study, we categorize these training programs into two groups: internal programs and external programs. Internal programs target new ONT staff. External programs are open to different professionals who are interested in the areas where ONT is involved.

A typical internal training program lasts 6 months and follows a master-apprentice approach. During these 6 months, the novice nurse works under the supervision of an experienced nurse to learn the procedures and the know-how of the ONT. After this period, the nurse achieves mastery through practice and observation. This process is necessary to acquire the tacit knowledge that is required to address the very diverse cases that could appear in the process of organ deceased donation.

External programs are organized year-round on four different editions in Spain and target the health professionals (e.g., hospital transplant coordinators). The attendees are provided with an in-depth overview of the ONT model on supra-hospital coordination of organ deceased donation. Until 2012, ONT used a traditional case-based teaching methodology (Dolmans and Gijbels 2013). Case-based teaching has already been proved to be an effective method of teaching (Irby 1994; Srinivasan et al. 2007; Strobel and van Barneveld 2009) that promotes critical thinking and decision-making skills (Chan et al. 2008; Kim et al. 2006), which turns students into active agents of their own learning (Barell 2010).

This approach has two significant limitations. First, the approach was instructor-dependent because ONT lacked a standardized set of training cases that were agreed upon by all of the ONT experts involved in the training. As a result, the teaching cases were chosen by the trainers prior to each course based on their own criteria and experience. Second, the instruction was resource consuming, because it always required involving several of the most experienced nurses of the ONT. Having only 14 people as a workforce, it was necessary for ONT to optimize the instruction.

Through the development of a game-like simulation that the ONT aimed to address, there were (at least partially) the two aforementioned limitations plus the known benefits of learning simulations: ubiquity (allow the students to practice anyplace), risk-free learning, and learning by trial-and-error, among others (Aldrich 2004).

Overview of the game-like simulation developed

The game-like simulation that was produced set up a player at the ONT headquarters where the nursing personnel perform all of the supra-hospital tasks of the process of organ deceased donation. The main scenario of the simulation takes place in this central office (Fig. 2a). The player takes on the role of a transplant coordinator (the main character in the game-like simulation). Other characters also participate, for example, the hospital coordinator of a Spanish hospital (Fig. 2b shows the hospital coordinator character calling the ONT). The player must know the goal of the game-like simulation (i.e., to evaluate all of the organs of a potential donor) and what rules to follow, which can be found at any time in the main scene of the simulation.

(a) Main scene corresponding to a real picture of ONT central office **(b)** Character of the game-like simulation **(c)** Action of evaluating the organs

Fig. 2 Different screenshots of the game-like simulation

The player can explore the scene by moving the mouse around to discover the interactive objects. By clicking on any of these objects, the actions that are available for the object appear (in Fig. 2c, the player is performing the organ evaluation action). In this simulation, the player can interact with the phone (to answer or make a phone call), the fax (to obtain faxes from hospital coordinators with different information), the donor information page (to study the information on a potential donor) and the evaluation page (to evaluate the suitability of the organs).

From case-based teaching to game-like simulation

The methodology followed to produce the game-like simulation is built on the principles of agile software development. This methodology is iterative-based, provides a rapid response to changes and fosters communication between heterogeneous working groups (in this context, 'iteration' refers to executing a specific set of instructions or processes a given number of times or until a specified result is obtained). The methodology supports the efficient capture of tacit knowledge by empowering communication between domain experts and game designers, who are the main intervenient roles (in our case, the domain experts are the ONT medical and nursery personnel).

The methodology followed is represented graphically in Fig. 3. In each loop, domain experts and game designers perform tasks that are related to the following four processes: Specification, Game Design, Simulation Development and Quality Assurance. These four processes are dependent on each other, and the workload allocated to each process varies depending on the number of iterations. In the early iterations, the specification and game design activities are more relevant, and in the last iterations, the implementation and quality assurance are more demanding.

In the next subsections, each process is described in detail. Subsections have a common format: first, a general overview of the process is provided. Second, we provide specific details on how the methodology was applied in the development of the ONT simulation.

Specification

The final objective of this process is to obtain a detailed specification document that describes the next aspects: the characteristics of the intended target audience, the know-how related to the medical procedure that the game-like simulation must cover and how it is going to be represented, the environment and settings that the game-like simulation is

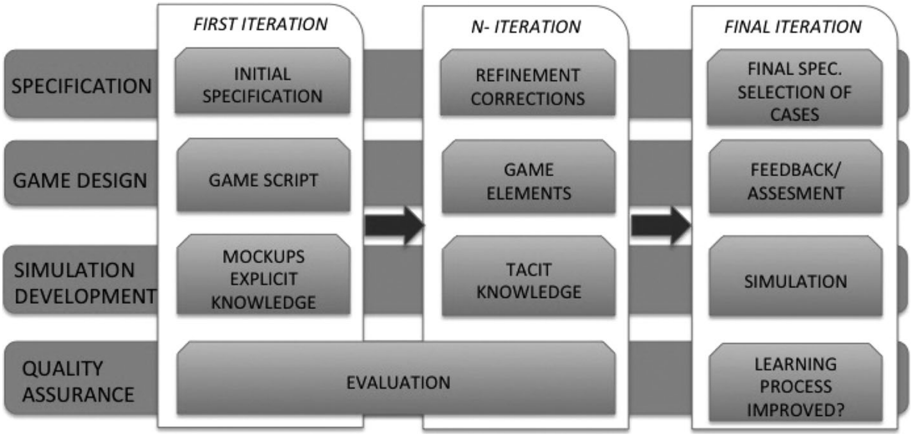

Fig. 3 Iterative methodology

intended to use and any other information that is needed to formalize the medical procedure. This process also facilitates the systematization of the teaching cases.

This detailed description is the result of achieving an agreed-upon project specification among the different experts that take part. Tight collaboration between domain experts and game designers is essential for the success of the simulation.

Another output derived from this activity is the shared vocabulary and knowledge that is related to the project, which are meaningful for every stakeholder. This output facilitates communication among experts with different backgrounds (medical and computer science). Specification tasks must not be overlooked. Any misunderstood or unclear concepts can lead to inaccurate procedure representations with the consequent loss of time and effort.

ONT transplant management specification

Our specification process started with an analysis of the documentation that was provided by the medical experts, which is related to the medical procedure. However, these documents lacked the level of detail that is needed to design a game-like simulation, because these procedures are targeted to staff with medical background. For example, a much more detailed description was needed to define the interactions of the game-like simulation or the common errors or imprecisions that are considered to increase its educational value.

Consequently, we performed several interviews with the domain experts to better understand the process and to capture the necessary level of detail. This communication was difficult, as domain experts tended to overlook information that is not obvious for non-domain experts.

One of the most important aspects of our specification process was the selection of the final teaching cases to include in the game-like simulation, which was conducted following some of the ideas proposed in (Kim et al. 2006). These teaching cases were created from a set of existing potential and actual donors (Gordon et al. 2004) that were relevant.

Domain experts classified, modified and even mixed those cases to meet the educational objectives (Khan 2007). We placed emphasis on selecting cases that were not obvious to analyze or that challenged the student in some special way. The final aim is to assure that a student acquires, after practicing with these selected cases, sufficient knowledge to be able to evaluate the organ suitability of most of the donors.

In a second iteration, the game designers also reviewed the cases that were selected, to ensure that the combination made a good game-like simulation. In this sense, the following were the main criteria that were applied: (1) sequential ordering of cases according to difficulty; (2) adequacy for novice and intermediate players; (3) inclusion of unusual cases; (4) consistency of the data provided, and (5) likeliness with real cases.

As a result, ten significant teaching cases were selected. These cases were further confirmed and were enriched if necessary or filtered out during the quality assurance process. Additionally, to comply with Spanish regulations on personal confidentiality, any personal or sensitive data were deleted or modified from the cases.

Eventually, two outputs of the specification process were obtained, a specification document and an agreed-upon vocabulary. We provide an excerpt of the document in Fig. 4. The shared vocabulary included medical concepts such as hospital level, supra-hospital level or potential donor and game concepts, such as scenario, character or score.

Game design

The final output of this process is a game script that represents the transformation of the specification document to the game design elements. To accomplish this objective, the game designer must understand the procedure, draw the storyboard of the game-like simulation and check that it provides the appropriate entertainment and educational value. The game designer must know how to integrate into the design skills, knowledge and

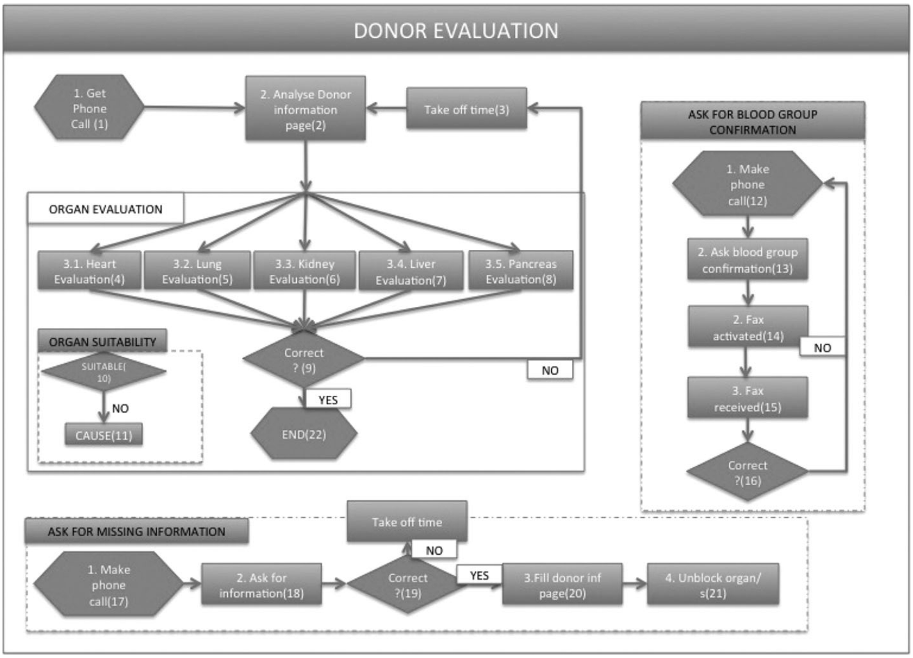

Fig. 4 Storyboard of one of the transplant processes, general overview

values to allow the player to build a way of thinking and problem-solving that is similar to the approach of the field experts (Amory 2006).

The game designer must begin by designing the basic steps that represent the medical procedure (those steps that are usually explicit or easy to elicit). As the design advances, common errors are progressively included as game elements. The goal is to drive students' attention to those aspects that are of the utmost importance (Aldrich 2006). It is also necessary to add traps and to interlace motivational elements to increase the engagement. In this process, the domain experts must also collaborate intensively with the game designers; however, in contrast to the specification process, the initiative here must be led by the game designers, who are responsible for requesting additional information, filtering out aspects that are not compatible with the gameplay and identifying aspects that have not been captured yet.

Instructional design must also be considered in this phase. In this methodology, we place special emphasis on feedback that is provided to both the student and the instructor. We recommend tracking each relevant action (both correct and incorrect) that is taken by the player and use it to generate a report that is either delivered to the student for self-assessment at the end of the game-like simulation or to the instructor for monitoring the students' performance. The report includes detailed feedback about how the student uses the procedure. This information can also be used to identify potential weaknesses in the game-like simulation, correct the formalization of the procedure if necessary and reinforce the learning without requiring teacher intervention.

ONT transplant management game design

Building from the storyboard (shown in Fig. 4, where each of the steps includes multiple actions and decisions that the student must account for while playing), the game designer modeled the different steps and components with game objects. For example, the first step shown in Fig. 4 is answering an incoming call. To implement this step, the game designer used the next game elements: (1) an object to represent the telephone; and (2) the two characters who are involved in the call (the hospital coordinator and the ONT coordinator).

During the game design process, the close interaction between the game designers and the domain experts was a key success factor. The domain experts constantly reviewed for precision checking that the necessary attention was placed on the most risky steps of the procedure. For example, the wrong blood group identification can entail serious damage for the patient, including a high risk of death. Thus, the ONT coordinator must always double check with the hospital coordinator the blood group that is reported onto the donor information page. To emphasize this aspect, one of the donors has a wrong blood group in the information page. If the player does not ask for the blood group confirmation, he will not complete the simulation successfully and will have to start over again to ensure maximum retention.

In contrast, game designers care for engagement and user experience, discarding aspects that could break the engaging atmosphere and proposing the addition of new motivational elements. For example, ONT experts considered that attending random calls from people asking for general information is an important part of their job and therefore the game-like simulation should account for it. However, although this aspect is important for representing the pressure of daily work in the ONT, it is not part of the medical procedure itself. Instead, game designers took a more gamish approach to simulate the pressure of the real job, using the concept of "lives", represented as small heart icons that fade away as time goes on (see Fig. 5 where the player has lost half of one life out of three. The figure also

Fig. 5 Screenshot of the game-like simulation. The figure shows the workplace with several objects to interact with and a live counter

shows the available interactions with the fax). The other game elements that are included are summarized in Table 1.

Game-like simulation development

Starting from the previous output, a game-like simulation is generated. This simulation can be created using a game-authoring tool such as eAdventure (Moreno-ger et al. 2008; Torrente et al. 2010). Game authoring tools reduce the cost and increase the involvement of content experts in the development process. Moreover, using a high-level authoring tool facilitates rapid prototyping, which speeds up content checking processes because the revisions are more productive on working (although incomplete) prototypes rather than on designs or documents. This approach also allows game designers to rapidly test the game mechanics and ideas and to identify major difficulties in the design.

During the first iterations, this task is focused on creating mock-up prototypes (i.e., simulations with provisional art resources), which allows the domain expert to check whether the explicit and tacit knowledge have been properly captured. Intermediate iterations generate prototypes that are oriented toward evaluating the game elements that are included. The final iterations have stable versions, including final art resources to evaluate the engagement with the end users.

ONT transplant management game-like simulation development

Most of the authors of this work are computer scientists and experts in game and simulation development. Therefore, the implementation step was quite straightforward.

We started by developing the complete workflow of the simulation for a single donor case. In this way, we ensured that the common parts of the procedure were correct before developing the specifics of each teaching case. The screenshots used in the game-like simulation, like the incoming phone call at the beginning of the game-like simulation or the action of evaluating the donor organs, are always the same independent of the donor

Table 1 Description of the most relevant game elements included

Type	Game element	Purpose
Object with actions	Fax 	The player receives the fax and learns the importance of verifying the blood group and the serology
	Body 	The player evaluates each of the organs that performs the action "evaluate" on this object
	Telephone 	The player needs to use the telephone to make and receive phone calls
Object	Lives 	Both of the objects emphasize the importance of time in the process
	Clock 	
Hidden information[a]	Serology information 	This element helps the player to better retain that without the serology information the organs cannot be evaluated
	Diabetes information 	This element helps the player to better retain that without the diabetes data, the pancreas cannot be evaluated
	Age of the donor 	This element helps the player to better retain that without the age, the organs cannot be evaluated

Table 1 continued

	Chest X-ray 	This element helps the player to better retain that without it, the lungs cannot be evaluated
Wrong information provided	Wrong blood group 	This game element helps the player learn the importance of paying attention to the blood group
Character	Hospital coordinator 	The player must interact continuously with the hospital coordinator to successfully finish the game-like simulation. The player learns how important the communication is among all of the stakeholders for the success of the process

[a] In each teaching case, the relevant data is missing. The player must make a phone call to obtain the information. Without this information, the player cannot complete the task

chosen. The differences lie in the options that are chosen by the player when answering the phone call or when evaluating each organ. In the following iterations, we gradually included these specifics, such as the hiding of information in each donor information page and the validation of each donor depending on the player's choices.

Nonetheless, some challenges were present. Some were related to the eAdventure tool that was chosen for the implementation of the game-like simulation, which in some cases did not provide the functionality to implement some of the changes demanded by the ONT experts. While these changes were not crucial for the success of the project, we attempted to accommodate them by adding new functionality to the eAdventure tool, because it is free, open-source software.

Quality assurance

The outcome of the quality assurance process is the verification of some or all of the next aspects: (1) *content validity* (i.e., the process has been represented accurately); (2) *reliability* (i.e., the game-like simulation is stable and free of program errors); (3) *usability* (i.e., the game-like simulation is nice and easy to use); (4) *educational value* (i.e., the students can achieve the intended learning goals) and (5) *engagement* (i.e., the game-like simulation is appealing and engaging, accounting for the fact that the game-like simulation must challenge the skills of the player at all times (Chen 2007)).The importance of each aspect varies depending on the specific context.

The validation of the content can only be done by domain experts through a review of the different mock-ups (Kebritchi et al. 2010). A structured approach to the content validation is strongly recommended. Assuming that the target knowledge is organized in the cases, the domain experts can start by evaluating a single teaching case on an early mock-up without considering making errors. If domain experts find any inaccuracy in the game-like simulation representation, then this task would require revising the specification document as well as the storyboard for the next design and implementation iterations. Once inaccuracies have been fixed, domain experts can start reviewing how traps are handled for the selected teaching case. Lastly, the domain experts evaluate the remaining teaching cases by following the same steps, revising each of the specific common errors that are included. Overall, this approach facilitates refining the initial selection of cases performed during the specification process and enables quick replacement of non-representative cases in an early stage of the development.

ONT quality assurance

During the development of the game-like simulation, we opted for a user-centered approach for quality assurance. New versions of the game-like simulation were internally distributed within the ONT to identify any potential flaws regarding the reliability, usability, and engagement. Besides, one expert was especially selected for content review. This evaluation lasted for 4 months and was divided into weekly or biweekly stages.

We have also adopted an approach for post-mortem evaluation of the project (i.e., once the development is complete), which includes pilot testing on real courses of the ONT training program and expert evaluation.

In this pilot testing, 150 students played in groups with the simulation in three different courses. Each group went through a guided execution of the simulation with one donor case, following the instructions of the trainer. Afterward, the students used the simulations freely, this time without guidance and with different donor cases. They played for an hour. After playing, we asked the students to fill out a satisfaction survey. Over 80 % of the students reported the experience to be positive or very positive, stating that it had helped them to improve their knowledge of the processes. This finding suggests that the game-like simulation appears to be reliable, engaging and usable, which are three of the aspects that are evaluated during quality assurance. We could not perform an evaluation of the educational value of the game-like simulation through the experimental research yet because of logistic issues that arose during the courses. However, we plan to do so in the future.

Expert evaluation is being conducted at the present time. Twenty experts have been recruited, and they are reviewing each step of the procedure. We plan to obtain inter-reviewer agreement rates as a heuristic to determine the final efficacy of the methodology in capturing the knowledge.

Discussion

To the best of our knowledge, this study offers a significant contribution in healthcare gaming and simulation for several reasons. First, it provides researchers and developers with a practical development methodology that helps to formalize the knowledge and transform complex procedures into simulations. This overall type of software is not new because it has been extensively explored in the literature. For example, Amory (2006) proposes a very interesting game object model for designing academic adventure games. However, in most of the cases, the authors describe the simulation or game that is developed or reported with respect to the results that are obtained (e.g., the learning gain) rather than the methodology that was followed (Akl et al. 2008, 2013; Moreno-Ger et al. 2010; Roberts and Greene 2011), which is limiting to other researchers by focusing only on reproducing the results that are obtained. Second, there is a lack of analysis on how to integrate game elements in healthcare simulations, because only one document has been found that explicitly discusses how game design principles and techniques can be used to make health games (Brox et al. 2011). Some of the game design elements that were proposed in this study, such as try-and-fail, drag-and-drop to the right position, or choice-making strategies, have been used in our work. We have also contributed to bridging this gap by providing detailed guidelines on how to integrate these game elements into healthcare procedures.

It is not the final aim of this low-cost simulation to substitute the traditional instructional approach of the ONT; instead, we aim to support it and maximize its results without requiring a high investment. The use of the simulation in the ONT training courses has allowed not only the anticipation of the practical part of the course by the students but also the possibility of experimenting in a risk-free environment on the real daily work of the ONT.

Moreover, the development of the game-like simulations also produced a document with a fully formalized procedure, protecting the know-how of the organization and enabling further sharing and reuse. This document has helped us to formalize part of the tacit knowledge that is related to some of the transplant procedures. This formalization has taken place throughout the described methodology, and each iteration has, as a result, not only a better approximation of the simulation to the medical procedure but also its improvement by correcting the errors found in the validation as well as including the tacit knowledge. The teaching cases selected for this simulation were also enriched and systematized thanks to this methodology, because the evaluation process helped to improve some of the cases or to discard other cases that were found to be inadequate.

However, this approach has worked successfully in the ONT case and some other medical procedures (Moreno-Ger et al. 2010; Torrente et al. 2009). There are many medical procedures that require precise hand–eye coordination and for which the manipulation of physical objects (e.g., equipment) is essential. To be able to perform these procedures safely, students must learn the feeling of the real environment. Thus, game-like simulations can help to optimize the instruction by providing students with efficient tools to learn the steps of the procedure before they actually rehearse it on the photo-realistic environment.

Two limitations or drawbacks were found when using the simulation developed for real instruction. The first limitation is related to the behavior that is expected from the nursery staff of the ONT. The staff must be sensitive and understanding as well as always cooperative and diplomatic in the way they address other colleagues and hospital coordinators. Game-like simulations are not the best option for acquiring these elusive soft-skills, because the interactivity with characters is limited; thus, they are still learned with daily practice.

The second limitation affects those experts and students who are not familiar with new technologies. In our experience, there are many of these in the medical field, and these tend to be reticent to change. Extra guidance and support must be provided to these experts. For the students, the problem was that they had several usability problems, having trouble, for example, in understanding the point-and-click actions, drawing out the learning and occasionally not being able to reach an end even with guidance. This issue could be addressed by enhancing the simulation with a built-in tutorial that smoothes the learning curve.

Conclusions and future work

The use of game-like simulations (i.e., screen-based simulations) as a learning tool is a growing tendency in many disciplines (Johnson et al. 2013; Roberts et al. 1992). Those who are willing to maximize the effectiveness of their educational systems move toward this trend once they realize that videogames can be a powerful tool, rather than seeing them as “mere entertainment”.

In this article, we provide a detailed description of the methodology that is followed to design and develop a game-like simulation from a traditional case-based teaching method. In this work, we have explored how the development of game-like simulations can be used to capture and formalize the highly specialized knowledge that many organizations have. We have developed a methodology that facilitates interaction between domain experts and game designers and the rapid development of prototypes, which in turn facilitates a rapid revision of the formalized knowledge. We have applied the methodology in the ONT, a world-leading organization in the field of organ deceased donations.

Currently, we believe that we have achieved our goal of successfully transforming case-based teaching into a game-like simulation approach based on two facts: (1) The preliminary results obtained from the expert evaluation being performed at this moment suggest that the knowledge has been correctly captured. (2) Because the ONT itself has included this material as part of its instructional approach, we can assume that the simulation properly represents the procedure.

By developing this simulation, the ONT has enhanced its training strategy with the ONT simulation. We believe, based on the feedback reported by ONT experts and on the student’s opinions, that students understand better the ONT procedure as they “get into context” from the moment that they start playing. One of our future objectives is to organize an experiment in a controlled environment in which we will be able to analyze and study whether there are learning gains and compare students’ scores in the course with and without the simulation.

Additionally, this game-like simulation supports effective decision-making. The student must analyze the available information, decide the best action and execute it in the game-like simulation. This game-like simulation guides the student in discovering all of the available information that is needed to make decisions and advance in the execution of the procedure.

Other future plans in the project include the development of other game-like simulations to cover the complete ONT supra-hospital processes training course. This arrangement means representing all of the steps of the process of organ deceased donation, including organ allocation to hospitals and the transport and logistics that are involved. Additionally, we aim to analyze how all of these simulations can be effectively distributed to final users [e.g., integrating the simulations into an e-learning environment such as Moodle or LAMS (Blanco et al. 2010)].

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7.2 Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education

7.2.1 Cita completa

Torrente, J., Borro-Escribano, B., Freire, M., Del Blanco, Á., Marchiori, E. J., Martínez-Ortiz, I., … Fernández-Manjón, B. (2014). Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education. IEEE Transactions on Learning Technologies, 7(1). doi:10.1109/TLT.2013.35

7.2.2 Resumen original de la contribución

We present EGDA, an Educational Game Development Approach focused on the teaching of procedural knowledge using a cost-effective approach. EGDA proposes four tasks: analysis, design, implementation and quality assurance that are subdivided in a total of 12 subtasks. One of the benefits of EGDA is that anyone can apply it to develop a game since it keeps development as simple as possible and uses tools for modeling and implementation that do not require a highly technical profile. EGDA has been applied to the creation of seven educational games in healthcare, and has been iteratively refined after each experience. EGDA is evaluated on two aspects. First, the effort and cost needed for creating these games is estimated and compared to current industry standards. Second, impact on knowledge acquisition and a student acceptance are discussed. Results suggest that EGDA can make game development more affordable, which is critical for increased adoption and scalability of Game-Based Learning (GBL), while assuring a high educational value of the resulting games.

Development of Game-Like Simulations for Procedural Knowledge in Healthcare Education

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Abstract—We present EGDA, an educational game development approach focused on the teaching of procedural knowledge using a cost-effective approach. EGDA proposes four tasks: analysis, design, implementation, and quality assurance that are subdivided in a total of 12 subtasks. One of the benefits of EGDA is that anyone can apply it to develop a game since it keeps development as simple as possible and uses tools for modeling and implementation that do not require a highly technical profile. EGDA has been applied to the creation of seven educational games in healthcare, and has been iteratively refined after each experience. EGDA is evaluated on two aspects. First, the effort and cost needed for creating these games is estimated and compared to current industry standards. Second, impact on knowledge acquisition and a student acceptance are discussed. Results suggest that EGDA can make game development more affordable, which is critical for increased adoption and scalability of game-based learning (GBL), while assuring a high educational value of the resulting games.

Index Terms—Computer-assisted instruction, games, gaming, health, software engineering process

1 Introduction

Research in game-based learning (GBL) continues to rise firmly and steadily, producing evidence on the potential of GBL [1] like significant improvements of academic performance and student motivation [2], [3]. As a consequence, the interest in using games in education is quickly increasing among different organizations [4]. However, there are still open issues regarding the use of educational games, their high development costs being one of the most relevant [5]. This limits wider adoption [6] and makes of GBL difficult to scale [7].

GBL can be implemented using different approaches and underlying supporting technologies. For example, there are examples of using IMS Learning Design to create gamified online courses [8], [9]. However, for the scope of this paper we will refer to GBL as the educational approach that uses digital computer games, implemented using purely gaming technology.

In this paper we propose EGDA: an educational game development approach. EGDA is optimized for creating digital games for learning procedural knowledge, which is required in most of science, technology, engineering and health disciplines, among others. Digital games and simulations have been proven effective tools to support learning in healthcare education [10], which is the main application field of EGDA. One of the novelties is that EGDA proposes a combination of two different tools to create the game: WEEV, a modelling tool to help game and domain experts design the game, plus eAdventure, a game authoring tool to assemble game prototypes. This facilitates involving domain experts in the design process, since game experts can make designs with the WEEV tool that are easy to revise and which can be seamlessly translated into running eAdventure games, which reduces the cost.

We first provide context about GBL in Section 2. In Sections 3 and 4 we present EGDA. In Section 5 we provide an evaluation of EGDA. Finally, in Section 6 we summarize the lessons learned and outline future research.

2 Context

Despite the increasing acceptance of GBL, it is still widely considered by most teachers as a promising approach rather than a real alternative. In the last decade GBL has become very popular among educational researchers and innovators, appearing frequently in specialized reports as an interesting instructional paradigm because of its potential benefits [4], [11], and building upon success stories in different case studies and pilots [12], [13], [14]. For example, GBL has appeared in the last three editions of the *Horizon Report* series published by the New Media Consortium as a technology that could be adopted in the midterm [6], [15], [16]. But as time goes on, it seems that we are as far from massive adoption as we were years ago. Actually, many of the barriers and limiting factors identified over the last few years have not been fully addressed yet [17], [18].

One of the reasons preventing the adoption of GBL is that educational game development is hard to scale [7]. Successful approaches are usually fine-tuned for a particular subject, target audience, educational setting and teaching style. These limitations hinder their application in other settings if any of these variables change. In addition, educational game development requires involving domain experts, who have limited time and usually no external incentives (such as being part of a research project) to participate in game design.

This limitation is tightly related to the overall expensiveness of games. The high development cost constrains the

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number of educational games the industry is able to produce, being unable to fulfil current demands of educational games. There is a need to bridge this gap with game development formulas that allow cost reductions. According to [5]: "*Among the most critical development challenges is the need for tools that make it easy to create learning games and simulations quickly, and at low cost*". The challenge lays on how to cut down the cost without constraining the educational value, building upon prior successes [19]. One of the approaches is to bring game development closer to the educator, allowing educational communities to fulfil their own needs for game-based content with a higher level of autonomy [20].

In this work we focus on specific challenges and solutions for teaching procedural knowledge in healthcare environments. Procedural knowledge can be defined as the knowledge that is applied in developing a procedure or a sequence of actions to achieve a goal [21]. This type of knowledge is highly valuable in many professions, especially in disciplines like health, science or engineering, where complex and risky procedures are applied in a daily basis. This is one of the reasons why serious games are increasingly being used in these fields [2], [22].

For many of the procedures related to healthcare or manufacturing there are moral, cost or material constraints that require access to specialized equipment and controlled laboratories where errors can entail severe consequences. This limits the rehearsal possibilities of the students, and sometimes forces an error-reduced instructional approach that can impair learning. In contrast, video games allow learning by trial-and-error [23] in a risk-free environment [24], while keeping a high level of realism. Students make their own decisions and evaluate the consequences, experiencing a situation from multiple perspectives prior to applying the acquired knowledge in the real environment [25]. These are some of the reasons why educational games are considered effective tools for learning complex procedures [26].

3 Overview of EGDA

Over the last few years, we have created different games for teaching procedural knowledge in healthcare. We have used the results and the lessons learned in those experiences to formalize EGDA, a process that covers all the tasks from game design to implementation and evaluation. It is built around four basic principles, which are briefly described in the next subsections.

3.1 Procedure-Centric Approach

Our belief is that an intuitive understanding of the procedure rationale (as opposed to simply memorizing the sequence of steps) promotes situated learning [27], [28], which helps the students to remember and properly follow the procedures. EGDA uses this idea to facilitate the learning of a specific procedure, also emphasizing the potential negative impact on the quality and precision of the outcomes when specific steps of the procedure are ignored. Therefore EGDA is driven by the formalization of the procedure, which constitutes the backbone of the game. More elements are incrementally integrated until an accurate simulation environment is obtained, including gameplay features and teaching strategies. This ensures that the learning content (i.e., the procedure) is embodied within the game design and not merely juxtaposed, an aspect that is essential for any educational game that targets more than pure rote memorization [29].

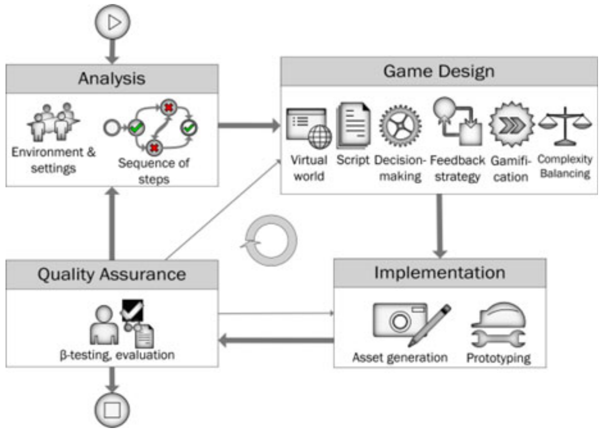

Fig. 1. Tasks and subtasks involved in EGDA.

3.2 Collaboration between Experts

Educational game design is inherently a multidisciplinary process. For this reason, EGDA aims to facilitate the incorporation of domain and game experts, as well as reducing the number of professional profiles needed to create a game. In addition, many educational game development initiatives treat domain experts and educators as external consultants, while we advocate for bringing the process closer to these experts. This also results in higher involvement of the specialists who have the knowledge and, eventually, a higher educational value. Therefore, EGDA requires close collaboration of two profiles: *domain experts* and *game experts*. Domain experts provide their tacit and explicit knowledge about the procedure while game experts contribute to the process with their expertise in game development. Game experts also help domain experts in eliciting their knowledge, which may be difficult to formalize.

3.3 Agile Development with Authoring Tools

EGDA proposes an iterative agile development cycle (Fig. 1) grounded in sound game design principles and methodologies [30], [31] to achieve high educational value with low production cost. The main tasks involved are (1) analysis; (2) game design; (3) implementation; and (4) quality assurance. Each task is also compounded by different subtasks, described in more detail in Section 4.

The main outcome of the **analysis** task is the formalization of the procedure, including an explicit description of all the steps, as well as possible incorrect actions. The formalized procedure is the input for the **design** task, which produces a complete game description document with all the game mechanics, objects, characters, puzzles, etc. that will be used. The **implementation** task utilizes this document to produce working prototypes with one or more easy-to-use high level authoring tools to speed up the process. Game authoring tools are essential in EGDA, as they reduce custom development costs and allow greater domain expert involvement. To facilitate game design, the affordances and expressive resources provided by the tools must be known before the process starts. Finally, the **quality assurance** task produces information to improve the game which is used in all of the other three tasks. The cycle should be repeated until the desired quality is obtained (three to six times in our experience, depending on the complexity of the game). In the first iterations most of the effort is dedicated to analysis and design. In intermediate iterations the focus is on implementation. Quality assurance is always present in different forms, although gets more important towards the end.

3.4 Low-Cost Game Model

EGDA is designed to produce games that are similar to the 2D *point-and-click* conversational adventures that were very popular in the 1990s, such as the *Myst* © saga. In these games, the virtual world is decomposed in multiple pictures (termed *scenes*) that are linked to set a navigational environment (the *game world*). We use virtual worlds to simulate the physical setting where healthcare procedures are performed by capturing 2D photos of the settings to be later populated with the objects needed to complete the procedure.

This type of environment supports reflection and decision making [32], and the approach reduces the development costs, as state-of-the-art graphics (e.g., highly defined 3D models, cinematics, etc.) are not used. In the simplest scenario, only a digital camera and access to the equipment are needed. At the same time, realism is preserved as students see their own work place. Moreover, the simplicity of these games facilitates deployment and use, since the technical requisites are kept to a minimum. On the one hand, the games can be used as standalone desktop applications, which are easier to download, install and run. On the other hand, the games can be directly delivered through the internet, without the need to perform local installations. This is an advantage for educators, who can use games in a versatile manner to better fit their instructional approach. These games are also easier to understand by students who are not savvy game players and may thus feel confused with advanced Game-Based Learning products.

4 Detailed Description of Tasks in EGDA

The next subsections provide details of all subtasks in EGDA outlined in the previous section (Fig. 1). Instead of outlining EGDA (as Section 3), this section provides insight on the tasks that the procedure proposes in a reproducible manner so other researchers can apply it.

4.1 Analysis

As part of the analysis phase, the procedure must be formalized between game and domain experts. This collaborative process is essential to achieve a good educational game design, and it is also one of the most challenging and time consuming [33] because of the disparate vocabularies and culture of game designers and domain experts, who may have completely different backgrounds [34].

Therefore a formalization strategy should be agreed upon, allowing both types of participants to acquire part of the expertise and vocabulary of their counter-parts. Game experts would acquire *domain knowledge* (in this case, procedures and their rationale and pitfalls), while domain experts learn the *affordances* of educational gaming and the chosen implementation platform (the specific game authoring tool and game engine). As a result, a common vocabulary for describing domain knowledge and game changes, understandable by all participants, is obtained. Depending on the complexity of the procedure and the characteristics of the participants, the common vocabulary can be explicitly represented using a formal notation or a visual representation that is used to support communication (e.g., using diagrams, flow charts or even a Domain Specific Visual Language (DSVL)) [35]. It is worth noting that the process of agreeing on (and perhaps formalizing) a common vocabulary is not trivial, and the vocabulary will, with all likelihood, need to be improved and refined in successive iterations. During this process, informal meetings among participants should be arranged to exchange and revise documents. In a typical meeting, domain experts would demonstrate how procedures are performed (if possible, in the physical setting), show videos or any other materials that illustrate the domain knowledge, and provide other background material to the game experts. Game experts would showcase relevant game examples to help the domain experts understand the range of expressive resources that can be used to transform the procedure into a game, and propose particular uses to illustrate parts of the target procedures.

In some cases, procedures are fully described and formally specified, but that is not always the case, especially if the organization does not implement a consistent knowledge management plan. It is common to encounter organizations where specific procedures are only known and applied by a few specialists within the organization, with an insufficiently detailed or inexistent formalization. Moreover, sometimes this knowledge or part of it is tacit [36], as it is usually acquired through experience. Hence it is difficult for the specialists to elicit the knowledge. From a knowledge management perspective, producing an explicit formalization of the procedure is an interesting by-product of the game development process that benefits the whole institution, as it facilitates sharing the know-how between personnel, reduces the time needed to train new personnel, and protects valuable knowledge assets from being lost, by making them less dependent on the availability of specific domain experts [37]. Additionally, the process of formalization frequently results in parts of the procedure itself being refined and improved, as flaws or incomplete parts are identified [38].

The knowledge formalization process must contemplate different aspects, from the scenarios where the procedure is applied to the definition of the outcomes of potentially wrong actions. The main output of this task is a document with the formalized procedure, ready to be used as input for the design of the game. We have distributed these aspects in two different tasks: describing the environment and settings and formalizing the steps of the procedure, which are addressed in more detail in two different subsections.

4.1.1 Describing the Environment and Settings

The initial step of this subtask is to obtain a high-level specification of the physical setting (e.g., a laboratory, an operating room, etc.). The definition of the scenario typically describes the purpose of possible objects (e.g., a microscope in a laboratory exercise) as well as the people or other agents that interact during the execution of the procedure.

The setting should be modelled and described identifying not only all the elements specifically involved in the procedure, but also those not involved but accessible in the physical setting and which may cause distraction or interfere during the process. For example, in a laboratory there may be equipment available that is not required for a particular procedure (the student must know what materials are going to be used). These elements may later be used as potential distracters to enhance the game experience. The experience of the domain experts is critical, as they know how students usually interact with the environment and they can point out elements that usually create confusion among students to be used as "red herrings" during the game.

As a result of this subtask, a detailed description of the environment, the elements and materials used, potential distracters and participants is obtained.

4.1.2 Capturing and Formalizing the Sequence of Steps

The sequence of steps is first described in full detail. This subtask is usually more complicated than describing the environment and settings, and it requires several iterations following a top-down approach where the basic steps are formalized and, in subsequent iterations, split into multiple substeps. Both correct and incorrect actions and decisions are captured. All the steps in the process have a purpose, and different mishaps, either minor or major, may happen if a specific step is not followed, or is followed incorrectly or in an inappropriate moment.

Differentiating between correct and incorrect actions is important. The main difference is that the knowledge that domain experts have of what is the right way to execute a procedure is usually *explicit*, although it may not be previously formalized. In contrast, knowledge related to inaccuracies or wrong actions tends to be *tacit* and it is even more unusual to have it formalized before the game development process starts. This difference is partly a consequence of how procedures are learnt. The right way to do it is learnt first, either through instruction or through observation of other domain experts. Common mistakes and their consequences are learnt progressively through experience until mastery is achieved. Besides, wrong actions are sometimes *operational*, being related to the environment or settings rather than the procedure itself. For example, if students practice a procedure with other peers and must share resources (e.g., a machine), the kind of issues that arise is different from students learning in isolation. For that reason, first iterations should focus on capturing the "right" steps and later iterations will add knowledge related to "wrong" steps.

This subtask requires the most interaction between game experts and domain experts, due to the inherent difficulty of making the experts' *tacit* knowledge *explicit*. To support this process we have developed a Domain Specific Visual Language [39]. This visual representation of the procedure facilitates its understanding as the flow can be easily followed (Fig. 2). Another advantage of the DSVL is the support for the aforementioned top-down formalization of the procedure. The WEEV tool [40] is a reference implementation of this DSVL, and allows the resulting design to be used to produce a game skeleton that can be edited further with the eAdventure tool. Although WEEV is particularly well-suited to formalization support, its use is optional, and does not preclude that of alternative visual instruments such as graphs or flowcharts which may contribute to the subtask's outcome: an agreed upon formalization of the expert's knowledge, understandable by all participants.

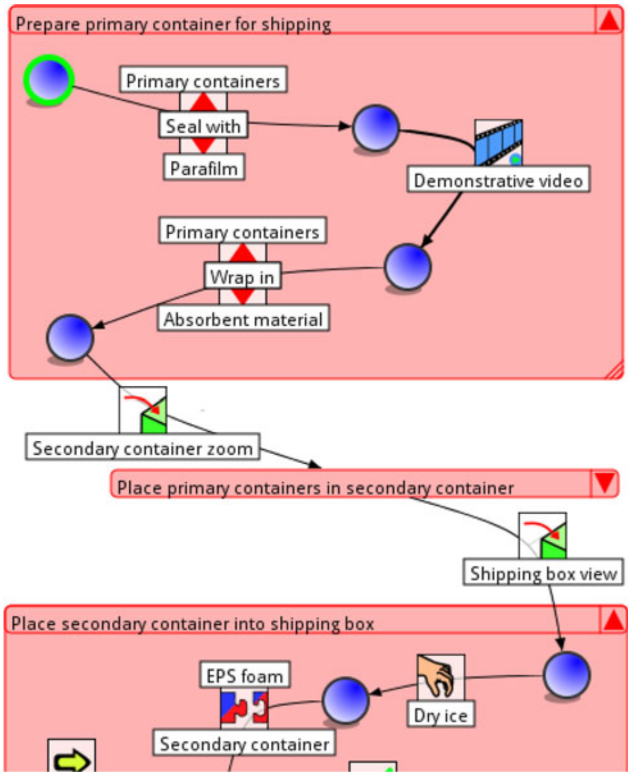

Fig. 2. Diagram excerpt produced with the WEEV modeling tool during the formalization and game design phases of the *HazMat* game. It shows the steps to ship hazardous materials (e.g., virus sample) in the WEEV Domain-Specific Visual Language.

4.2 Game Design

Transforming the procedure into a game design requires a change of the language and terms used to formalize the procedure. Even though the vocabulary used to describe the environment, elements and steps of the procedure must be neutral and platform-independent, it must also be compatible with the affordances and requirements of the game authoring tool used to implement the game. In this sense, certain aspects of the game platform's technology and its expressive affordances must be known by all participants before the game development process starts, to avoid designs that include non-implementable characteristics.

The game design can be subdivided into five subtasks, described in detail in the following subsections. The first subtasks are the creation of a *virtual world*, the writing of a

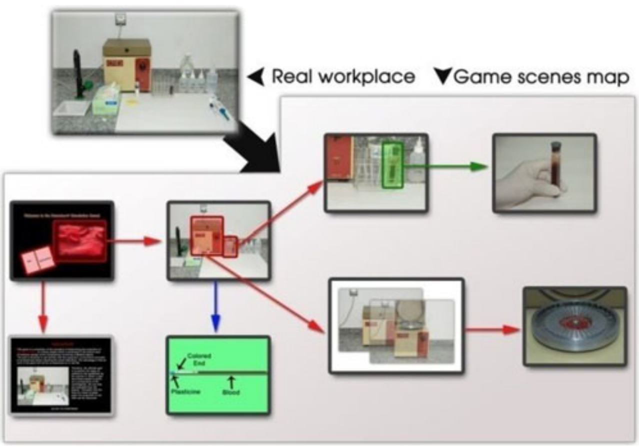

Fig. 3. Example of translation of the real environment into game scenes for a procedure where a blood microsample is centrifuged to measure the proportion of red cells.

game script, and the design of the *decision-making* structure. Together, these first subtasks result in the basic skeleton of a working simulation. The fourth subtask addresses the *feedback strategy*. Finally, the last subtask involves *gamification*, a process where additional game elements are introduced with the goal of increasing player engagement.

The main output of the game design task is a document with sufficient information to start the implementation of different prototypes.

4.2.1 Designing the Virtual World

The high-level description of the environment is translated into game elements. In the case of a 2D game, this involves the design of a series of interconnected game scenes. The 2D scenes in this map, and the way that they are linked together, will constitute the student's navigation environment. In the EGDA game model, each screen is composed by a single picture and provides a specific view of a part of the environment, materials or participants of the procedure. Multiple views of a specific part can be used to allow students explore the situation from different perspectives or angles, or to provide more details if necessary. Fig. 3 provides an example of how a typical laboratory workstation in a School of Medicine was decomposed into multiple game scenes for a training game. Notice how some scenes are essentially close-up views of others, providing additional details on instruments; while other scenes contain abstract representations of machine controls or descriptions of the procedure. The game environment model can be produced also with the WEEV tool or using any other graph representation.

4.2.2 From Procedure to Game Script

In this subtask, the description of the procedure is iteratively extended until it can be used to specify the flow of the game. Through this process, a game script is eventually obtained. But a script is not only a sequence of steps; it is necessary to enhance it to provide the student with an experience that fosters immersion.

When the game starts, students need to be *situated*. The lack of appropriate contextualization can seriously damage the gameplay experience, making the students feel lost, and diminishing the educational yield of playing the game. First, the students need to have a clear understanding of the main goal of the game (i.e., how to succeed) and the general rules (what you should and should not do in order to succeed). Clear rules and goals are elements present in all good video games [32], [41]. Second, students need to know what the initial conditions of the game are. For example, if the player adopts a specific role in the game (e.g., a medicine student who attends a clinical surgery intervention for the first time) this has to be clearly specified. Students also need to know any initial conditions regarding the in-game materials, settings or instruments that affect how the procedure must be executed (e.g., a pre-screening of the patient is available and a coronary problem has been identified). This can be addressed in a cost-effective manner by the use of cut-scenes, which are non-interactive, expositive scenes where the player is consuming content rather than playing. Cut-scenes can be videoclips or slides.

The game script can be created by an aggregation of smaller subprocedures that are applied in different situations. The concept of aggregation is interesting because it facilitates maintenance of the game by making it more modular and therefore subject to piecewise improvement. Modularity also facilitates extending the game to cover new situations or parts of the procedure. During gameplay, the student will be confronted with different situations or problems that must be solved. Each of these situations can be focused on a different part of the procedure. For example, consider a game for conducting medical sample analysis: the game can set the player in the lab, ready to analyze samples. From time to time the player receives requests from doctors to carry out different types of laboratory analysis on incoming samples. Each test would require the application of a different procedure. This design strategy can also be randomized: having to deal with exceptional situations allows students to rehearse procedures that are used only under rare circumstances or experience abnormal situations, enhancing replayability and immersion.

4.2.3 Decision-Making Support

In the context of a procedure simulation game, effective decision-making support by the game mechanics is one of the most important requisites. Providing an adequate sense of agency and control is a critical component for any game [42]. When making decisions to advance in the procedure (and therefore in the game), students analyze the information that is available at the moment, reflect on the best available option (with an amount of implied risk assessment) and then execute it in the game. The pattern is repeated recurrently throughout the whole game. The game must: (1) guide the user in discovering available information related to the decision and the different available options; and (2) provide the student with a straightforward way to execute those actions in the game.

There are many ways to provide alternatives in games and support decision-making, with varying degrees of in-game subtleness and development costs. An effective cost-balanced approach is to combine highly exploratory scenes with others where options are presented more explicitly. The simplest way to present options is the use of multiple-choice questions presented in text, although options can also be presented visually using animations (at a slightly greater production cost).

The game must also provide mechanisms to execute decisions. Interactions available in the EGDA game model are inspired from the conversational adventure genre, including unary and binary actions. Unary actions are performed on a single element (e.g., *grab* a *key*) while binary require two elements (e.g., *use* a *key* in a *lock*). Interactions can be *point-and-click* as well as *drag-and-drop*.

4.2.4 Feedback

The way that feedback is naturally conveyed in video games is a powerful enhancer of the learning process [43], and therefore feedback delivery should be carefully designed and planned. Most video games combine several sources of feedback to serve different purposes. From a usability perspective, feedback is needed to indicate that a desired user interaction was actually executed. Feedback should also support and facilitate reflection on the events that occurred in the game, and especially highlight the effects on procedures of wrong decisions. This type of feedback has been shown to contribute strongly to learning [44]. Feedback also contributes to create a continuous perception of progress, an inherent feature of good games which prevents frustration and encourages the player to go on, among other benefits [45].

The goal of this subtask is the adoption of a general feedback strategy. This strategy should be consistent throughout the game, and coherent with the chosen game mechanics. For instance, frequent and time-consuming feedback cutscenes break the sense of immersion in a time-constrained simulation. In most cases, feedback should be simple (limited to simple audio or visual clues), short and non-intrusive in order to avoid breaking the pace of the game.

Feedback should be more explicit and extensive in parts of the procedure that are especially complex or where precision must be maximised. Debriefing screens providing reasoned explanations of the internal processes taking place should be included from time to time. This helps students reflect on the underlying concepts in more depth, and transfer the acquired knowledge to real world situations. Various types of materials can be used for this purpose. While cutscenes with large pieces of text may be useful, they should be used carefully and only when necessary. A short video showcasing a particular aspect of a procedure can be more useful and engaging.

When dealing with feedback for incorrect actions, the timing can be adjusted to reflect the consequences of valid and invalid manipulations, both in the procedure itself and in its possible by-products. Feedback can be provided immediately, but deferred feedback may have significant advantages when the consequences of incorrect manipulations are not immediately observable. For example, the consequences of a mistake during the preparation of a blood sample might not be evident until it is analyzed, several steps later. This is a common aspect of complex procedures and it is important to ensure that the game reflects these situations, making students "pay a price" for mistakes (e.g., having to start over) and helping them avoid the same mistake next time. Negative consequences of mistakes can be overly exaggerated to increase the impact on the student.

When the game is completed, the student can be presented with deferred feedback for self-assessment purposes, including a list of all mistakes and incorrect actions performed. This information can be used to identify potential weaknesses in the game, tweak the formalization of the procedure and reinforce learning without requiring teacher intervention [46].

4.2.5 Gamification of the Design

Once the procedure has been accurately captured and virtualized, *gamification* techniques can be applied to increase student engagement and motivation [41]. *Gamification*, which is a very active research topic, is usually described as the application of game mechanics and elements in non-gaming contexts [47], for example to improve customer fidelity for an online purchasing company. In EGDA *Gamification* is inspired by current research but applied in a different manner, as it concerns the application of game elements to a simulation environment to make it more engaging.

Gamification strategies should be cost effective and avoid conflicts with the correct representation of the procedure and the environment. Players enjoy intrigue and curiosity, opportunities for challenge, strategy and problem solving [48], competition (self-directed or with peers) or humour [49], which can be implemented in a cost-effective manner. Very advanced technology or state-of-the-art 3D graphics are attractive and can contribute to create an immersive environment, but they are comparatively much more expensive. Fortunately, these features are not strictly necessary to engage students in a learning activity, and very simple strategies can yield amazing results. For example, the use of quantifiable heuristics to display students' progress and achievements in the form of a visible score can provide an effective form of challenge. These heuristics can be complemented with badges [50] or other visual elements that can display status or skills acquired by the student. Other potential sources of challenge include the total number of objectives fulfilled, the time required to complete each procedure, or the total number of mistakes.

Quantifiable heuristics are comparable and can be used to foster competition between peers and tap into the student's desire for self-improvement. When displayed prominently or when aggregated in a public ranking, heuristics can drive students to improve their results, increase replayability by encouraging students to explore all possible situations and endings, and reinforcing the learning process.

4.2.6 Complexity Balance

During game design, it is necessary to regularly revise the overall complexity to ensure that the game will be implementable with the available resources and within the expected time-frame. The complexity of designs increases progressively, as alternative paths and endings are added. Designs start with a simple representation of the main steps of the procedure, expanding as the procedure is defined in greater detail, and reaching full complexity as game elements are added in an incremental fashion. At a certain point it may be necessary to trim some paths or limit parts of the game, resulting in a smaller and potentially less engaging game-world. Finding a correct balance between breadth and depth (with consequences in educational value and user engagement) while keeping development costs in check is a critical component of any game development project.

4.3 Implementation

The implementation phase is compounded by two subtasks: *asset generation* and *prototyping*. It is driven by the use of a simple, high-level authoring tool, which simplifies the process of generating working prototypes of the game. However, the time required to capture the resources (images, photos, etc.) is still considerable. The implementation task receives as input the design document produced in the previous task, and its main outcome is a set of working prototypes to be used for different purposes.

4.3.1 Rapid Prototyping

Iterative prototyping is critical in game development [51]: it allows the use of a staged and stepwise evaluation and testing plan [52], and facilitates analysis and design tasks. On the one hand, it is easier for domain experts to find inaccuracies or overlooked aspects in the formalized procedure by reviewing a working (though incomplete) prototype rather than looking at designs or documents, as prototypes can provide explicit context which may have been overlooked in other formalizations. On the other hand, prototypes allow game experts to rapidly test game mechanics and identify major pitfalls in the design.

EGDA proposes the use of one or more authoring tools for rapid prototyping and game implementation. Game authoring tools have proliferated in the last years, making development more agile, less expensive and more accessible to people without solid programming skills. There are tools of every kind, ranging from complex semi-professional software (e.g., Unity) to simpler, high level authoring tools meant to be used in amateur productions or even by students, such as Game Maker [53] or Scratch [54]. The development of EGDA has always relied on eAdventure for implementation [55] and WEEV for modelling, open source free software packages focused on conversational adventures and simulations, although similar tools could be used (e.g. Adventure Maker or Storyline) to achieve comparable results.

Different prototypes can be created for different purposes (Fig. 4):

- *Mock-up prototypes* allows rapid evaluation of the accuracy of the formalized procedure.
- *Intermediate prototypes* mainly used to elicit comments on the game design for the next iterations.
- *Beta/Final prototypes* stable prototypes that are used for end-user evaluation.

4.3.2 Gathering the Art Resources

Game resources may include workplace pictures, animations or other visual assets, sounds, videos, etc. Gathering

Fig. 4. Different prototypes created for one of the games produced, which is set up in a visit to the operating theatre in hospital. Left: Mock-up prototype. Middle: Intermediate prototype. Right: Final version.

the final version of a game's resources is one of the most expensive parts of the process. On the one hand, generating "in-house" art resources is a very time-consuming task. On the other hand, hiring a professional artist can have a significant impact on the budget. In order to plan for the projected cost of resource acquisition, a list of all necessary resources has to be prepared and kept updated during game design and development. Mock-up prototypes can use placeholders while the design stabilizes and until better versions become available (Fig. 4). Intermediate prototypes can combine sketches and temporary art resources. Final prototypes should always include final versions of all art resources.

Careful planning of recording and resource capturing sessions allows for significant cost reduction and shortens the development cycle. The final version of the resources is only necessary once the design is stable and has been validated with mock-up and intermediate prototypes. All relevant equipment and materials should by then be identified, and the exact views and recordings thoroughly planned. The scheduling process may be not trivial if access to specialized, dangerous or expensive materials is needed. Additionally, a clear understanding of the technical formats expected by the game authoring tools is critical to ensure the production of high-quality resources.

4.4 Quality Assurance

As commonly argued in the literature, using games for education does not always entail an improvement of the learning process. Ak [56] identifies four aspects for which actions to ensure quality assurance must be taken. These aspects also appear in other game evaluation studies [57]:

- *Reliability*. The game should be stable and free of programming errors. While this is not so important in the beginning, it is crucial to ensure the reliability of the game once it is deployed.
- *Playful/Engaging experience.* The game should be appealing, motivating and engaging for the students it is targeted to.
- *Usability.* Interaction with the game should be pleasant and prevent frustration.
- *Educational value.* The game should be accurate and precise, and provide valuable insight about the procedure to the student.

Elaborating on these four aspects, we propose the evaluation questions shown in Table 1, based on those proposed by Youngblood that were especially designed for medical simulation and gaming [58]: To answer these questions we propose combining three types of evaluation sessions:

TABLE 1
Evaluation Questions for Quality Assurance, Based on Proposal by Youngblood (2006)

Question	Who answers?	Related to
Are there any bugs or unexpected behaviours in the game?	Beta-testers	Reliability
Does the game work in all the target platforms (e.g. Windows and Mac)?	Beta-testers	Reliability
Does the game simulate the procedure and environment faithfully?	Domain experts	Educational value
Is the content embedded in the game (e.g. reference materials, dialogues, text) accurate and appropriate for the target audience?	Domain experts	Educational value
Are game goals and rules clear for the novice user?	Students, Domain experts, Game experts	Playful/Engaging experience, Educational value
Is the game appealing for the target audience?	Students, Game experts	Playful/Engaging experience
Are the context and preconditions clear for the novice user?	Students, Domain expert, Game experts	Playful/Engaging experience, Educational value
Is it easy to learn to use the game?	Beta-testers, Students, Game experts	Usability
Is it easy to use the game?	Beta-testers, Students, Game experts	Usability
Are the learning goals covered?	Domain experts	Educational value
How well do the students achieve the learning goals?	Students	Educational value
Do the students learn anything else? (incorrect or correct knowledge)	Students	Educational value

- *User-centred evaluation*. This is the most important type of evaluation to ensure quality. Introducing formal evaluations throughout the whole design and development process will unnecessarily extend the production of the game and increase the cost. It is more efficient to conduct frequent informal, user-centred evaluations that could be arranged with colleagues and students in short sessions without requiring formal evaluation instruments, which allows identifying major pitfalls and design flaws more easily [59].
- *Beta-testing*. Members of the development team, colleagues, or students, can be recruited to perform beta-testing of the prototypes. Beta-testing evaluations differ from user-centred evaluations in that attention is only paid to the reliability and perhaps usability of the game. Beta-testers will explore the game, trying out all possible actions and options, seeking hidden bugs, technical errors or major usability flaws. No feedback about the educational value or playful experience is expected.
- *Formal evaluation*. In final iterations a more formal approach is encouraged, where research questions are formally formulated for quality assurance. Formal evaluation is the most time-consuming type of evaluation and therefore only one or two experiments towards the end of the process are recommended, oriented to evaluate the educational gain compared to traditional instruction.

The outcome is a set of proposed modifications to any of the sub-products of the other tasks (analysis and design documents or prototypes).

5 EGDA in Practice: Case Studies

In this section we describe the case studies where EGDA has been applied (Section 5.1). Through these experiences, we have been able to evaluate the effectiveness of EGDA from the perspective of development costs and return on investment (Section 5.2). Based on previous publications and also new data collected, we discuss in Sections 5.3 and 5.4 two parameters that we measured to evaluate the quality of two of the games produced: the effectiveness of the games as learning tools (Section 5.3) and the student acceptance and perceived usefulness (Section 5.4). Although other games were also evaluated, data collected does not support a quantitative analysis and have therefore been omitted from this section.

5.1 Overview

The seven games produced with EGDA have been developed in collaboration with different organizations related to health and medicine instruction, like the Massachusetts General Hospital (MGH, Boston, US), the School of Medicine of the Complutense University of Madrid (Spain), the Spanish National Transplant Organization (ONT), or the Miguel Servet Hospital (Aragon, Spain).

Three of these games have been already deployed to end users while four more are currently undergoing further evaluation cycles (see Table 2 and Fig. 5).

These games have been used to improve learning processes and clinical practice when the application of complex procedures is an essential part of the professional activity. The games increase the rehearsal opportunities for students in situations where access to equipment or resources was limited. They have also been used to reduce the stress of students and trainees.

5.2 Development Costs and Return on Investment

In this section the efficacy of EGDA is discussed by estimating the cost of the games developed, which is compared to current industry standards. This task poses two challenges. First, game development cost is complex, almost impossible to calculate with precision. Therefore we will only try to make a rough estimate of the order of magnitude of the game development cost based on the work hours spent. Second, difficult to compare the cost with other games, partly because in few cases the overall cost of a game project is reported, and partly because the inherent singularity of each title makes a fair comparison almost impossible. We have just gathered together some of the data we were able

TABLE 2
Summary of Games Developed

Institution(s) and Target audience	Topic and Motivation	Status
CVC		
Mass General Hospital, Boston Resident physicians	98-steps CVC protocol Increase rehearsal opportunities, reduce trainee/student anxiety & stress	Prototype [60]
HazMat		
Mass General Hospital, Boston (MGH) Hospital staff	Hazardous materials packaging & shipment Reduce training costs, simplify certification process	Deployed since 2009
Operating theatre		
Complutense School of Medicine, Madrid Medicine students (surgery)	Introduction to the surgery room Reduce trainee/student anxiety & stress	Under evaluation (ETA 2013) [61]
Checklist		
San Carlos Hospital, Madrid; Mass General Hospital (MGH) Clinical surgery staff (nurse, surgeon, anaesthesiologist)	Application and use of the safety checklist in clinical surgery Improve current usage of the checklist	Under development (ETA Q3 2013)
Donations		
Spanish National Transplant Organization Healthcare personnel related to the transplantation processes	Management of the supra-hospital transplant coordination (donor evaluation and organ allocation) Improve training of new personnel	Under evaluation [38]
HCT		
Complutense School of Medicine, Madrid 2nd year medicine students	Measurement of the level of Hematocrit in a blood sample Increase rehearsal opportunities	Deployed and evaluated since 2009
First Aid		
Miguel Servet Hospital; Schools of the region of Aragon, Spain 14-year-old high school students	Instruction in basic cardiopulmonary resuscitation techniques Produce alternative instruction content for cases when experts are not available	Evaluated in 2011 [62]

to find on game development costs and will compare the order of magnitude to our games.

A coarse estimation of the work hours dedicated to game development is provided in Table 3, ranging from 66 hours for the simplest game to 410 hours for the most complex. The resulting total is then compared with the estimated completion time of each game, which is a rough measure of the complexity of the games. However, this yields an estimated development cost for each minute of gameplay that can be used to understand the return on investment. To develop one minute of gameplay around 10 hours of work are needed.

The total estimated development cost, in US dollar, is obtained by multiplying hours invested by an estimated hourly wage of $50 per hour.

Fig. 5. Screenshots of four games developed according to the EGDA.

TABLE 3
Estimation of Hours Invested for Creating the Games

Game	PT	PH	PH/PT	Cost ($)	$/PT
	Avg. play time in min	Total labor hours	Labor hours per min of game play	Total estimated cost $=PH x $/h	Estimated Cost per min of game play
CVC	30.00	410	13.67	$20,500	$683
HazMat	20.00	140	7.00	$7,000	$350
Operating theatre	21.30	141	6.62	$7,050	$331
Checklist	48.00	225	4.69	$11,250	$234
Donations	40.00	180	4.50	$9,000	$225
HCT	8.00	66	8.25	$3,300	$413
First Aid	20.00	122	6.10	$6,100	$305
Order of magnitude		10^3	10^1	10^4	10^2-10^3
* Estimated cost per hour: 50 $/h					

This number is used to estimate the development cost in dollars and cost per minute of gameplay.

In all cases development was carried out by teachers and home staff of the institutions where the games were going to be used, including computer scientists and medicine instructors. There was no need to hire external staff, which is an argument to support that EGDA makes game development more affordable for teachers and other low-tech profiles.

On average, each minute of game play has had a cost of order 2 or 3 (greater than \$100 and lower than \$1,000). Approximately the total cost of the games has an order of magnitude of 4, ranging from \$3,000 to \$20,000.

These numbers may seem too high for educational materials, but they are actually very low compared to standard development costs for games, even those tagged as ‘serious’ or educational. For example, consider *Immune Attack*, one of the best educational games developed in the recent past [63]. The development of *Immune Attack* was funded by a \$999,865 NSF grant [64], and it took approximately 4 years to develop. Considering an estimated length of 120 minutes, the estimated cost per minute of game is around \$8,000. *Science Pirates* is another great educational game whose evaluation results and development cost are known [65]. It was funded by a \$450,000 USDA’s (US Department of Agriculture) National Institute of Food and Agriculture grant [66]. It takes around 2 hours to complete the game, resulting in around \$3,000 per min. And these costs are relatively low compared to AAA games being developed at the moment, with budgets on par with Hollywood films, ranging from \$3 to \$100 million [67]. While it is very difficult to compute specific average gameplay lengths for commercial games as a whole, any game requiring over 30 hours to complete is generally considered “a long game” (a 20 hour game with a development cost of \$3M costs \$2,500 per minute). Compared to these costs, EGDA games are at least one order of magnitude cheaper to produce.

It is true that the comparison above is not truly fair since EGDA games do not use 3D technology as *Immune Attack* or *Science Pirates*, which is more expensive than 2D. In 2008 the eLearning Guild carried out a survey among its members (eLearning professionals and developers) to understand current trends on serious games and simulations development (called Immersive Learning Simulations in the report, which did not distinguish between them) [68], which was completed by 1,100 of its members. The games and simulations considered in this report are similar to EGDA games, being 2D content of similar duration developed in Flash or with other high level authoring tools equivalent to eAdventure. From data provided on the report ([68, p. 13, Fig. 10]),the average development cost can be estimated around \$200,000 on average and \$58,000 on median. EGDA games are still far from these numbers.

5.3 Educational Impact

The effectiveness of the *First Aid* and *HCT* games as learning tools has been analysed in two randomized trials where the use of the game is compared to the classic instructional approach. In both cases the knowledge acquired is measured before and after the intervention (i.e., the application of the selected instructional approach) and results from control and experimental groups are compared. In the case of the HCT game also results in the final test are compared to the previous year to analyse educational gain.

Fig. 6. Screenshot of the First Aid game. Student is presented with alternatives to support decision making. Note: The game was originally developed in Spanish and translated to English after validation.

In Section 5.3.1 we briefly discuss evidence collected from the evaluation of the First Aid game, which has already been published in the Journal of the Spanish Society of Emergency Medicine [62]. The results from the HCT game are divided in two sections: Section 5.3.2, where we summarize findings published in the International Journal of Medical Informatics (IJMI), and Section 5.3.3, where we enhance the discussion with new, unpublished data.

5.3.1 First Aid Game: Educational Gain from Unattended Gameplay

The *First Aid* game (Fig. 6) was developed to teach cardiopulmonary resuscitation (CPR) manoeuvres to high school students in the Spanish region of Aragon. Traditionally, two doctors expert in emergency medicine and CPR training provide this kind of instruction. However, the number of experts that can dedicate time to student instruction is limited, so not all the students in the region can receive training every year. Having a game available will help to provide similar instruction to all students in the region. The game could be used also in any Spanish or English speaking country, as it is now publicly available for download in both languages.

344 students were divided into control and experimental groups (CG and EG) [62]. Both groups were instructed in CPR for 50 minutes. The CG devoted these 50 minutes to attend a practical session driven by the two experts in emergency medicine, while the EG played the game without further tutoring. Pre and post tests were conducted to measure knowledge acquisition. Students in EG improved from an average score of 5.41 to 7.48 while CG improved from 4.95 to 8.56. The improvements were considered statistically significant in both groups after a paired Student’s t-test ($p < 0.001$ in both cases). While improvements of students in the CG were higher, being the difference statistically significant ($p < 0.001$ unpaired Student’s t-test), the game was also effective as a learning tool and represents an inexpensive and reusable solution, as opposed to the practical sessions with experts.

Fig. 7. Screenshot of the HCT game.

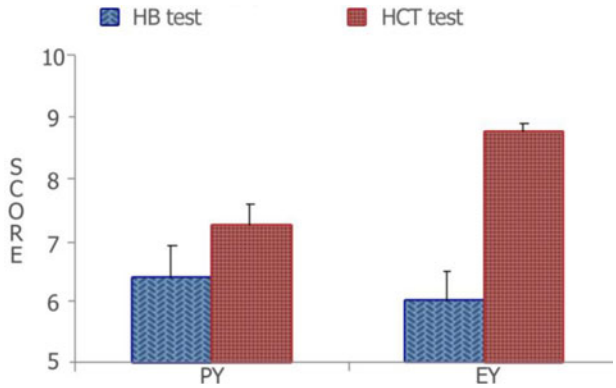

Fig. 8. Comparative of the score obtained by the students in the HB and HCT tests in the experimental year (EY) and the previous year (PY). Results of the HCT test improved significantly while the HB remained almost unchanged.

5.3.2 HCT Game: Impact on Student Performance

The HCT game (Fig. 7) was developed for a Physiology course in the School of Medicine at the Complutense University of Madrid to instruct students in the application of the Hematocrit (HCT) blood test. This test calculates the level of red cells (Hematocrit) in blood with a classical laboratory test approach based on the centrifugation of a blood microsample, which separates the plasma and cellular components in two layers. It is freely available for download, in English and Spanish.

The HCT Blood test is practiced a few weeks after the academic year begins, during the second session of the course. The HCT practical session also covers the Haemoglobin (HB) test which is not covered by the game. During the year a total of 14 practical sessions are conducted. For several reasons, like the high number of students—around 400—and sessions, this course has complex logistics. Therefore the time and resources for rehearsing the procedures in the actual laboratory are limited. In the case of the HCT test this is especially cumbersome as resources for practicing are only available at the beginning of the course, nine months before the final practical exam. There are also ethical issues, as blood samples are obtained from laboratory rats that must be sacrificed.

Results from a preliminary evaluation of the HCT game are available on previous publications [69]. Sixty-six students were randomly selected for the Experimental Group, who played the HCT game in a controlled environment for 30 minutes two weeks before the laboratory session where they practiced the HCT test. Students in the Control Group did not have any contact with the game, and proceeded to the laboratory sessions as usual in all previous editions of the course. After completing the game, the results of the HCT test were compared for both groups. Measures reported by students in the experimental group presented a higher reliability, considered as the deviation of the value obtained from the HCT correct value (3.10 versus 26.94, SD; variances significantly different after a Mann–Whitney U-test, $p < 0.001$). These findings suggested that students in the experimental group were able to learn the procedure by playing the game, and they were also able to transfer knowledge acquired to the real world as their measurements of the Hematocrit were more accurate in EG than in CG.

5.3.3 HCT Game: Educational Gain

After that experiment, the HCT game was made available through the e-learning system of the Complutense University of Madrid three weeks before the final exam of the module (seven months after the practical session) for all the students (making it available to the EG only could have been an unfair disadvantage for students in the CG taking the same exam).

To further measure the impact on the learning outcomes, student performance in the final exam was compared to the previous year, when the game was not available. In the final test students are requested to perform the procedures instructed in one of the 14 practical sessions of the course, randomly chosen. If the second session is selected, students must perform the HCT and HB tests. Results from both tests were also compared.

Both tests (HCT and HB) have similar complexity. As a result, student performance is usually similar in both procedures. For example, in the previous year to the experiment (PY), the average score obtained by the students was 7.2 for the HCT test and 6.4 for the HB test, being this difference not statistically significant ($p = 0.12$ after a paired Student's t-test) (Fig. 8).

However, in the experimental year (EY) the average score obtained was 8.8 for the HCT test and 6.0 for the HB test, being this difference statistically significant ($p < 0.0001$ after a paired Student's t-test). Comparing results across years, the HCT score increased from 7.2 to 8.8, being the difference statistically significant ($p = 0.0002$ after an unpaired Student's t-test), while the HB score decreased slightly from 6.4 to 6.0, being this difference not statistically significant ($p = 0.32$). These data suggest that the score of the HCT increased significantly, while the HB scored remained invariant, and thus the game seems to have had a significant impact in improving students' performance.

5.4 Student Acceptance and Perceived Usefulness

For both the First Aid and HCT games the student perceived usefulness of the games was measured through subjective questionnaires but also by tracking voluntary access to the content (after the trials they were able to play the games for self-studying and practicing without teacher guidance). In this section we discuss results obtained, which have not been published elsewhere.

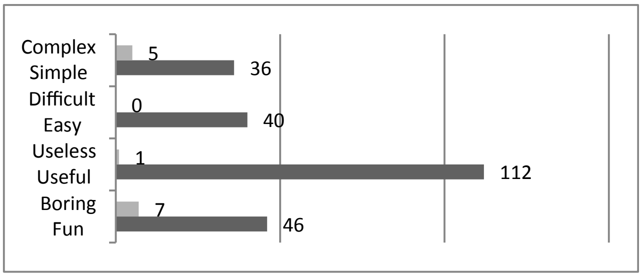

Fig. 9. Students' opinions collected about the First Aid game.

5.4.1 First Aid Game

Students in the control group were surveyed on their impressions about the First Aid game. They were presented with a tag cloud with the following adjectives to describe the game: "fun", "boring", "useful", "useless", "easy", "difficult", "simple", and "complex". There were no restrictions on the number of tags that could be marked. Although this way of evaluation may be deceptive, results shown in Fig. 9 suggest a high acceptance and perceived usefulness from the students, as most of them marked the option "useful" (112 out of 187 students) and only one the option "useless".

5.4.2 HCT Game

Students in the EG were asked to fill in a questionnaire about the perceived usefulness of the game just the first play. Results were mostly positive. Most of the students reported that using the game was a positive experience (81 percent) and agreed that the simulation had helped them to identify and use the equipment in the lab (65 percent) and to complete the practical exercise more easily (61 percent).

During the three weeks that the game was available to all students, they had no pressure or incentives to use the game, nor did instructors motivate students to use the game in any way. The number of accesses to the game were measured and compared to other materials.

From the 406 students enrolled in the course, 177 (43.6 percent of the students) accessed the game at least once. The average access time to the game (6:45 minutes) was the second highest among all the contents available to the students. Only one static document had a higher time/access ratio (10:01 minutes), but its reading was compulsory as opposite to the HCT game.

In addition, the game was one of the most accessed contents (497 times). Only seven pages had more accesses than the HCT simulation game (from a total of 38 pages), but they were published for a considerably longer period of time (four to seven months) and their use was compulsory.

Given that the use of the game was completely voluntary these data suggest that in general students found the game useful to practice for the final exam.

6 Conclusions and Future Work

Ongoing research on Game-Based Learning demonstrates that it can be a very useful educational paradigm. While good examples of educational games populate the literature [19], the approaches used are still hard to scale [7], in part because of their high development costs [5].

In this work we have formalized our educational game development approach for teaching procedural knowledge in healthcare environments, with special focus on reducing the development costs.

EGDA is a *procedure-centric* process. First, the procedure and the knowledge associated to it are formalized. The formalized procedure acts as the central communication point for the stakeholders involved along the whole process, including domain experts (e.g., medicine instructors) and game experts. Second, the procedure is used to build an accurate simulation environment. Finally gaming elements are added to achieve a GBL environment.

EGDA and its products have been evaluated, focusing on three aspects: efficiency (in terms of development costs), learning effectiveness and student acceptance. Regarding the evaluation of the EGDA itself, the average production cost per minute of game developed is far below current industry standards. This suggests that EGDA can help to achieve a significant reduction of the production costs of the games, which has been identified as an important requirement for educational games to go mainstream [6] without compromising the educational value.

This retention of the educational value was evaluated and it is supported by previously published experimental data, as well as new evidence. In summary, findings suggests that these games improve students' performance and knowledge retention, and also transfer the knowledge acquired in the game to the application of procedures in real settings. The students also perceived the games as useful learning tools. These conclusions are drawn from data collected for two of the seven games developed, as in those cases a quantitative evaluation was conducted. Although qualitative data collected through formative and informal evaluations of the other games are consistent with these findings, further research would be required to confirm the validity of the results.

Several limitations should be addressed with future research. EGDA is tailored to a very particular domain and it is unclear how it could be used in different settings. Moreover it does not contemplate strong interaction mechanisms between peers. While it is possible to simulate interaction via multiple-choice conversations, all the responses and outcomes must be implemented in advance, and the real player is a single student, a severe limitation of the software of choice (eAdventure) which does not support multi-user games. Future research should look into how EGDA could be used to teach procedures where the collaboration of different colleagues is essential, but this would require using different software. It would also be interesting to explore how more complex technologies, like 3D graphical engines or haptic devices could be integrated into the EGDA approach without resulting in a significant cost increment.

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7.3 Expert User Validation of Transplant Management Procedure Simulations

7.3.1 Cita completa

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7.3.2 Resumen original de la contribución

The Spanish National Transplant Organization (ONT) in collaboration with the e-UCM research group of the Complutense University of Madrid has developed three screen-based simulations representing the ONT supra-hospital deceased donation management processes. As the ONT is using these game-like simulations as a support tool for its instructional approach, it was necessary to perform a validation of these simulations to assure the knowledge had been correctly represented. This paper describes the methodology followed to validate and estimate how accurately this ONT complex knowledge has been captured (including some tacit knowledge used by the transplant coordination experts) and transferred into these screen-based simulations. We present the results obtained from the validation done with 15 ONT experts and how their feedback was used to improve the simulations.

Expert User Validation of Transplant Management Procedure Simulations

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Abstract— The Spanish National Transplant Organization (ONT) in collaboration with the e-UCM research group of the Complutense University of Madrid has developed three screen-based simulations representing the ONT supra-hospital deceased donation management processes. As the ONT is using these game-like simulations as a support tool for its instructional approach, it was necessary to perform a validation of these simulations to assure the knowledge had been correctly represented. This paper describes the methodology followed to validate and estimate how accurately this ONT complex knowledge has been captured (including some tacit knowledge used by the transplant coordination experts) and transferred into these screen-based simulations. We present the results obtained from the validation done with 15 ONT experts and how their feedback was used to improve the simulations.

Keywords— knowledge validation; screen-based simulation; transplant procedure

I. Introduction

The Spanish National Transplant Organization (ONT), in collaboration with the e-UCM research group of the Complutense University of Madrid developed a set of simulations (the ONT simulations) to represent the ONT procedures and some of the tacit knowledge implied in their procedures. The ONT simulations were developed with the aim of providing students at ONT training courses (both face-to-face and online courses) with a hands-on activity where they can apply in a free risk environment the theoretical knowledge acquired. These simulations consist on three screen-based simulations representing the ONT supra-hospital deceased donation management process [1]–[5]. These simulations represent three of the stages of the process of deceased donation: a) the donor and organ evaluation (Fig. 1); b) the allocation of organs applying the corresponding geographical and clinical criteria; and c) the logistics of transportation.

The ONT knowledge is a very complex one and to master it requires not only to learn the documented procedures, but also to acquire the team tacit knowledge used in everyday practice [6], [7]. This tacit team knowledge is hard to transmit from experts to novices and even harder to represent it throughout documents or simulations. To design and develop the ONT simulations, the engineering team (e-UCM) followed an educational game development approach (EDGA) [4] where an interdisciplinary team of professionals (i.e. game designers, game developers, art designers, doctors, nurses, etc.) worked together with the aim of capturing the knowledge from the ONT experts and effectively including it into the simulations [8], [9].

Once the simulations have been produced, it is needed to perform a proper validation of the simulations to assure the ONT knowledge had been correctly represented. The main objective of this validation was to estimate how accurately the knowledge had been captured and transferred to the game-like simulations.

In this work, we present the process followed to validate whether the simulations developed include all the knowledge expected and if this knowledge is correctly represented. Other aspects such as the usability of the simulations or the level of understanding of the communicative metaphors are also validated. Moreover, how this process has helped us to improve the quality of the simulations is also described.

The paper is structured as follows: section II describes the development process followed to develop the simulations. Section III describes the three ONT simulations. Methods, participants and settings of the study are described in section IV following by a presentation of the results and its analysis (sections V and VI respectively), to conclude with a brief summary of conclusions extracted.

II. Description of the Development Process

The methodology followed to produce the game-like simulations is built on the principles of agile software development that provides a rapid response to changes. This methodology is iterative-based and fosters communication between heterogeneous working groups. It also supports the efficient capture of tacit knowledge by empowering communication between domain experts (in our case, the ONT medical and nursery personnel) and game designers.

In each of the iterative loops, domain experts and game designers perform tasks that are related to the following four processes: Specification, Game Design, Simulation Development and Quality Assurance. In this paper we will focus on the Quality Assurance process and more specifically in the final product evaluation.

Fig. 1. Screenshot of the donor evaluation simulation.

Because of the complex nature of the ONT procedures, the Quality Assurance Process is of great importance, medical experts validate that the simulations developed include all the implied knowledge and that it has been represented correctly throughout the simulations, providing feedback accordingly to the game developers to solve the issues found during the game design and development. After the medical experts validation, they were be tested by final users (in our case, students or trainees at ONT training courses).

The initial design decision taken by the development team was what kind of simulation to develop (i.e. action games, puzzles games, platform games, etc.) and what game development platform was adequate to develop this kind of games.

III. Description of the Simulations Developed

Simulation and game-like simulations promote active learning [10] and learning-by-doing, which make them an adequate learning tool in medical education [11]–[14]. Games also offer a risk-free authentic practice environments[15], [16].

In the simulations developed we used 2D real photos of the ONT headquarters to simulate the physical setting and preserve the realism. These photos are populated with objects the player has to interact with in order to advance throughout the game.

As the process of deceased donation includes three clearly identified stages, the development team agreed to follow the same structure in the ONT simulations: develop one simulation per stage. This design decision provides the benefit of decomposing the whole problem in three phases and reducing the complexity during the design and development tasks and during the experts' validation process. As main content for the simulations 10 representative teaching cases were selected from ONT real cases, covering a large percentage of the most common cases arriving in the ONT. To avoid ethical issues and possible tracking of the real cases, these teaching cases selected were fully anonymized.

In the first simulation the player learns how to evaluate a potential donor. It starts with a hospital transplant coordinator notifying to ONT that a potential donor has been identified. The player needs to ensure that all of the information that is needed to evaluate donor and organ suitability is provided. He needs to analyze a donor case and determine if the organs are suitable for transplantation.

In the second simulation the student learns how to allocate the liver, heart, and lungs to the corresponding hospital taking into account the complex national allocation criteria. The player must demonstrate that he can oversee this allocation process by identifying the information that needs to be verified and then offering the organs to the proper hospital.

The third represents the logistics of organ transportation. The player starts by making all the necessary calls between the transplant coordinator of each recipient hospital and the donor's hospital to agree a common extraction time. Depending on whether the organ or transplant team needs to be transported by plane or only by car, the player will also need to call the airline to be sure that there are planes available and to know at what time they will be ready to pick up the team. After synchronizing the extraction time, the player has to wait until the donor coordinator calls to inform him/her of the beginning of the extraction. The player is then responsible for calling every transplant coordinator involved to inform about the beginning of the extraction.

We have included game mechanics in the simulations to keep the attention of the students as well as to help them retain some of the key aspects of the process. For example, in each teaching case we have hidden some information of the donor clinical data that blocks the evaluation of one or more organs (for example, if the donor's age is not provided all organs will be blocked). The player needs to discover how to retrieve this missing information. As time is a very important factor in the whole process, to emphasize it, the game element of player lives has been included. Each life lasts 6 minutes, and each simulation has 3 lives, so the player will have 18 minutes to complete the full simulation properly. Lives can also decrease if the player makes critical mistake.

IV. Methods, Participants and Settings

A. Objective

In this work we describe the methodology followed to validate and estimate how accurately the knowledge has been captured and transferred into ONT game-like simulations.

B. Participants

The validation was performed among ONT experts: 15 experts (12 out of the 13 ONT nurses and 3 out of the 8 ONT doctors) participated voluntarily in this validation. ONT expert's age vary from 35 years old to 65 years old and there are 13 women and 2 men. The years of experience in the field of the ONT experts varies from 1 year to 24.

C. Methods and Settings

The methodology has three steps; first each ONT expert plays with the simulations and gains familiarity with them. Second, they answer to a semi-structured interview to obtain their opinions, sensations and suggestions on the simulations. Finally, they fill a Usability Test System (SUS).

In this first step the ONT expert plays with the simulations twice consecutively with two donors previously selected by the interviewer. A “thinking aloud” procedure is used and experts were asked to play with the simulations verbalizing whatever crosses their mind during the task performance.

Several things are done while the ONT expert is playing:

- We record his face and his voice.
- We record all the movements he performs with the mouse.
- While the expert plays, the interviewer, based on a detailed storyboard analysis of each of the simulations (Fig. 2 represents one of the storyboards), points down the observations from the player's comments and from its own feelings. We defined codes for the different types of notes: the ones related to the level of detail, the ones referring to discrepancies in the content and the ones referring to usability problems. Table 1 shows how the comments were codified.

TABLE I. CODIFICATION OF THE NOTES

Code	Description
1	Granularity mistake: Detail missing, some of the steps need more detail to be correctly represented or understood.
2	Granularity mistake: Knowledge unnecessary, some of the steps have too much detail not useful that leads to misunderstanding.
3	Content mistake: Knowledge or facts are not represented in the adequate order.
4	Content mistake: Information needs to be improved in order to have a learning outcome.
5	Usability problems found.
6	User Requests

These are some examples of the notes taken by the interviewer:

- Code 4: Donor 0: Kidney values are confusing. It could lead to an incorrect evaluation.
- Code 4: Donor 1: The heart would also be not suitable due to the donor medical record.
- Code 5: Usability problems with the drag and drop interaction.
- Code 6: Improvement suggested. Add to the simulation the possibility of discarding a donor completely and not only one specific organ.
- Code 6: Improvement suggested. Include the size and the weight of the donor in the allocation criteria simulation to better approach the reality.

The interviewer first writes the code to identify the type of error found (for example Code 4 is a content mistake) and then a description of the error or difference found. If relevant, he will also write down the donor were the mistake was found.

The second part of the experiment consisted on a semi-structured interview. This interview was also recorded.

In order to maximize the outcome of this interview, before performing it with the ONT experts, we performed it among some other ONT staff in order to discard those questions that were confusing or not useful.

Finally, we asked experts to fill a Usability Test System [17], [18] for measuring the perceptions of usability, Table 2 shows the questions.

The qualitative analysis of the data [19]–[21] of this experiment has several steps:

- Organizing the information: We put all the information regarding each expert together (Expert profile, recorded play, recorded interview, tracking log, usability test).
- Coding: We defined categories for each question depending on the different answers obtained. Then, each answer was classified in one of those categories..
- Filtering: In this step, we discarded those questions from the interview that turned out to be not useful for the experiment (e.g. not relevant information provided).
- Integrating the information: Finally, we collected the categories obtained in the previous step and analyzed them; we tried to find the relations between them and the reasons of some of the answers/categories.

TABLE II. USABILITY TEST SYSTEM

Code	Question
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very awkward to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system

V. RESULTS

A. *Improving the simulations to get a better approximation of reality*

In the first step of the methodology described, “Playing with simulations”, we were able to improve the simulations from the comments and suggestions of the ONT experts as well as from the notes taken by the expert that was supervising it.

We corrected several minor errors either about content such as some data that could be misleading, or either about interaction (for example adding point-and-click actions to all the objects representing phones appearing in the scene).

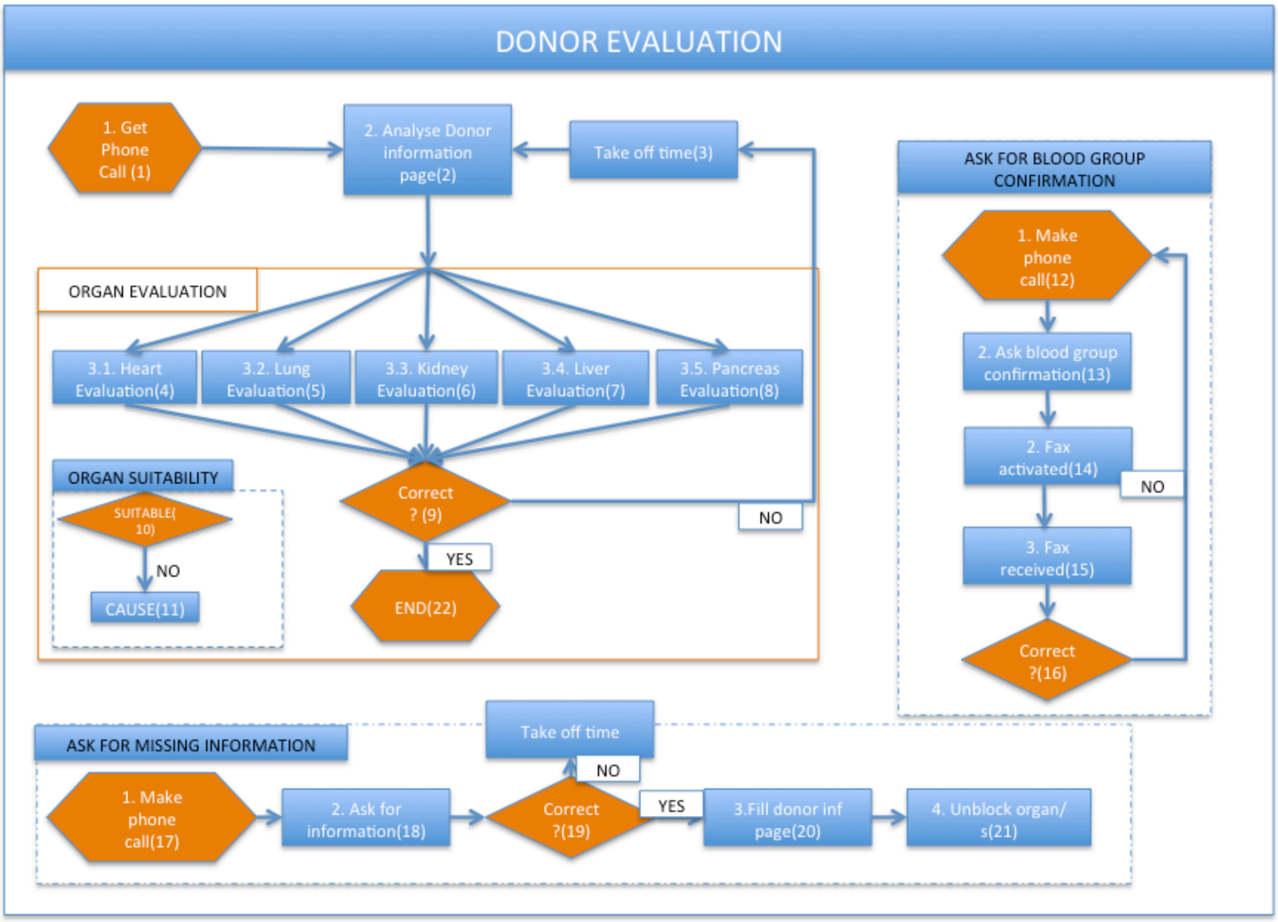

Fig. 2. Storyboard of the donor and organ game-like simulation.

Therefore we also fixed some usability errors detected by the users.

There were not comments codified with codes 1 or 2 (granularity mistakes), which means that the number of steps included in the simulation were adequate, this conclusion was also confirmed later in the semi structured interview. For those comments codified with 3 or 4 (content mistakes), we had to analyze what was the issue:

- The content was wrong.
- The content was correct but not provided at the right moment/position of the workflow.
- The content needed to be improved by changing the way it has been represented to meet the requirements of the software simulation.

For those steps where the content was different but the context was correct, the expert analyzed whether to modify the simulation to decrease the differences with the real procedure or whether not to modify the simulation if the discrepancy didn't affect the understanding of the procedure.

B. *Results obtained from the interview*

- In your opinion, what are the main benefits of using simulations like this in the training courses of the ONT (if any)?

All of the experts claimed that the main benefit of using simulations in the instructional approach of the ONT was that it allowed the students to immerse themselves into the ONT's world and learn in a free-risk environment how to make important decisions that are their daily routine.

- And what are the main disadvantages (if any)?

40 % of the experts (agreeing with those that had already used the simulations as a support tool in the ONT courses) said that the main drawback was the lack of resources (i.e. computers). To profit these simulations to the maximum the places where the courses take place should provide enough resources to allow each student practice with a simulation on their own. Another 13% claimed that the biggest drawback was the lack of flexibility, as they didn't fully represent the capacity of improvisation that a transplant coordinator needs to have. The rest of the experts didn't find drawbacks.

- Would you say that the introduction of this type of contents in the training process was necessary?

Only 1 expert (0.6%) claimed that not only it was not necessary but also it did not add any improvement to the previous method. The rest of the experts said that although they were happy with the previous method the simulations had allowed them to update their instructional approach as well as to systematize the teaching cases to use in the courses.

- Do you think that its use can modify the role of the ONT tutor? How? (It facilitates or it can raise difficulties?) (Although we asked this question to every expert, we only considered the answer of those who had already used them in the ONT courses)

Only 1 expert (0.6%) said it had modified the ONT instructor role making it more complex. He claimed that he didn't know enough all the details of the simulations and that there were few computers in the course making it more difficult for her to teach. 33% of the experts agreed that the simulations improved and complemented their teaching. They said that students were more attentive. All these experts had used the simulations in real ONT courses.

- Specify the things you would change to improve how the simulation reflects the way of working of the ONT (e.g., would you include the brain death diagnosis?) [What else could be missing?]

All of the experts said that in order to transmit the pressure the ONT staff encounters every day, external asynchronous calls not related to the task should be included. That way, while playing, the student would be interrupted several times by an incoming call of somebody asking for the steps to follow in order to obtain the donor card or from another transplant coordinator that want to contrast some doubts regarding another possible donor, etc.

For next versions of the simulations a 33% of the experts asked for the pancreas distribution to be included. Only 26.6% of the experts said that we could include the possibility of having to cope with the evaluation of two donors at the same time, but just as a possibility for advanced students.

- Completeness: Do you think the set of cases that includes the simulation is representative enough? (i.e., 10 cases ...) What do you think it would be enough? Would you expand or reduce the number of donors? [If yes, how many cases would you include on it?]

100% of the experts also agreed that the number of donors included in the simulation was adequate, representative and relevant.

- Relevance: I want you to give me your opinion on the selected cases. Do you think they are relevant for learning? What do you think of the cases that were selected? (Are they too difficult or too easy? They represent real cases or are the extremely generalist?)

86.6% of the experts suggested that donors should be older, to better represent the average donor type arriving nowadays. The ONT is changing and will change even more in the days to come and now donors are usually older and when the donor is young, the cause of death has changed, now they usually die of asystole and not so much in traffic accidents.

- In general, would you have used different donor cases? (e.g., a donor with tattoos ...)

73.3% also suggested that the inclusion of a child donor would improve the learning outcome, as it also would help the student to understand this distribution process, which is slightly different. This new donor is going to be included in the following ONT courses.

- Granularity. Do you consider the number of steps to be performed in the simulation to complete tasks relating to the management of transplant is the right one?

All the experts agree that the number of steps the student has to follow to finish the process is valid and the tricks and distractions included were adequate.

- Do you think that the aesthetic of the game is appropriate?

1 expert said that he didn't like the aesthetic of the simulation at all and that he found it childish and ugly. 53.3% said that they liked it but that they would improve it as the goal of this simulation was very serious and including too many game-like elements could make the students take less seriously the learning objective. 40% said they liked it.

- What do you think of the images used to represent organs and internal documentation of the ONT? What do you thing of the inclusion of real images used as the actual main scene of transplant coordination?

All the experts agreed that it was adequate.

- Do you think that adding game elements to simulations is positive or negative? Do you think the number of game elements included is adequate? Would you increase or reduce it?

All the experts agreed that using game elements is always positive and that they could help the student realize those points of special importance of the process. They all said that the number of game elements included was adequate and that they would not include any more unless the target of the simulations changed to a profile of a higher initial knowledge.

- What do you think about the final score? Does it help the player to improve himself and continue playing?

2 experts (13%) did not like the idea of using a final score. They both believed that evaluating students in courses like the ONT ones is not useful and does not contribute to the learning at all. The rest of the experts claimed that it was positive.

C. User satisfaction survey

As we know, a SUS score under 68 is considered above average and anything under 68 is obviously below average. In our tests we obtained 1 grade A, 11 grades B, 2 grades C and just one D (see Fig. 3). Notice that the results below average as well as the two Cs came from the first experts being interviewed (when more errors were present in the simulations; score under 68 is from the experts that didn't feel comfortable with new technologies and computers).

We decomposed the Overall SUS Score into its Usability and Learnability components as suggested by [22]. Items 4 and

10 provide the learnability dimension and the other 8 items provide the usability dimension.

The x-axis represents the experts interviewed, the numbering given to the experts is temporary, being the 1st expert interviewed the first and the last would be the 15th expert.

The y-axis on the left represents the SUS score (blue) and it is divided in usability (red) and learnability (green) that can vary between 0 and 100, however we have only values from 40 to 100 to perceive better the values since there are not values inferior to 45. The grades are represented in the y-axis to the right.

VI. DISCUSSION

A. *Playing with the simulations*

In this first part of the interview we achieved the following objectives:

- The expert gains familiarity with the project and learns the aim of the simulation.
- With the recordings, we obtained spontaneous opinions, surprise or disgusting faces that allowed us to know what aspects of the simulation needed to be improved or corrected. Also, sometimes the ONT expert mentioned minor mistakes or usability problems that were not previously detected (for example, one of the objects to use during the simulation is a phone, one expert noticed and commented that there were two telephones in the scene, but just one could be used).
- By registering all the interactions performed by the experts, we detected usability problems and concept errors (for example, some ONT experts clicked first on the object they wanted to use –selecting it- and then clicked anywhere else in the screen de-selecting unconsciously the object and preventing the completion of the action)
- And finally, the notes taken by the interviewer allowed us to improve the simulations notably.

From the results of this first part we know that the granularity of the simulation is satisfactory, contains the sufficient level of detail and the number of steps involved to complete the tasks is adequate.

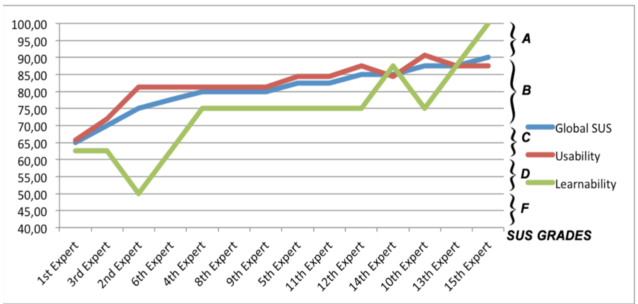

Fig 3. SUS Score, Usability and Learnability

Regarding the content metric, we detected that some objects of the simulations lead to confusion and we also detected some erroneous data, that although did not harm the game logic of the simulation, it would risk its consistency. All those aspects were corrected to increase reliability as well as all those other usability problems previously identified.

B. *Attitude towards the ONT simulations*

All of the experts claimed that the main benefit of using simulations in the instructional approach of the ONT was that they allowed the students to immerse themselves actively into the ONT's world. The main result is that 93% of the experts believed that the introduction of the simulation was positive.

Regarding the drawbacks reported, unfortunately we could not solve the first reported problems, as we are not responsible of the resources provided in the courses (i.e. not enough computers in some of the training facilities). Regarding the lack of flexibility of the simulations, we think we solved part of this problem by including random calls in the simulation, this way, the student needs to decide whether to answer the call or to go on to complete the task. If he answers he will need to decide whether to maintain a conversation or just take the phone number and call the person back.

The use of this simulation in the ONT courses can be hard at the beginning, especially for those experts that had been using the other method for many years and for those experts that don't feel comfortable with computers. But once they have practiced with the simulations enough they can help notably the instructor role.

C. *Analysis of the simulation and the teaching cases included.*

We can conclude that the cases selected are representative enough. As previously described, to better represent the ONT way of working random calls have been added to the simulations. We are also working in the inclusion of the pancreas distribution. At this moment we cannot afford for the inclusion of two donors at a time as it would imply too many changes in the logic of the game.

Increasing the age of the donors would not improve the learning outcome of the students, but reduce it as the casuistic of donors and of validity of organs would be notably reduced. We have, nevertheless, changed the cause of death of the youngest donors. We are planning to include a child donor that can be chosen once finished the simulation in order to improve coverage.

D. *Content evaluation (Aesthetics / interface)*

We solved the problem presented by some experts by changing those objects that could look childish by photos of real objects.

E. *Game elements section*

From the questions of this section, we can conclude that all the experts find that the inclusions of the elements of the game are positive and adequate. There were two game elements that cause some disagreement, one that was considered childish, which has been modified, and the final score, that some claim that is not positive for the learning outcome. We have decided to keep the final score as we believe that it doesn't make any harm, and that it can motivate students to try and play again to improve their marks.

F. *Usability System Test*

The last part of the experiment consisted on a Usability System Test, we already know that the distinguished benefits of using SUS are:

- It is a very easy scale to administer to participants.
- It can be used on small sample sizes, which is our case, with reliable results.
- It is valid and it can effectively differentiate between usable and unusable systems.

With the results obtained, only 1 result below average, and 80% were classified in grades A or B according to [17], we can conclude that the simulations are usable. Moreover, as we have increased the quality of the simulation after each experiment, which is represented by the improvement of the SUS scores, we can conclude that the usability has increased notably since the beginning of the experiment.

With all the information obtained from the complete experiment (including the three parts) we performed several improvements of the simulations. These improvements lead to an enhancement of the quality of the simulations in four aspects:

Reliability: while the experts were playing they detected when some data were incorrect or some step was not correctly represented, by correcting these errors, the reliability of the simulation improves every time an expert played.

Content validity: in this step and in the structured interview, we assure that the process has been represented accurately.

Usability: is improved as we have already mentioned, usability is also measured in third step.

Engagement: And finally, by watching the experts playing, we can evaluate whether the simulation is engaging enough (taking into account that the simulation must challenge the skills of the player/expert at all times [23]).

VII. CONCLUSSION

Literature about how to validate the knowledge acquisition of complex medical procedures is scarce. When the authors were analyzing how to measure whether the knowledge had been correctly acquired and that the process has been precisely represented [24], [25] [26] were of great usefulness as it is the only research found by the authors where it is explained how to compare different procedures by using specific metrics such as granularity or content. This information was used in our experiment to analyze the differences between the real process, “the process of deceased donation”, and the process being represented throughout game-like simulations. The granularity metric was used to see if the simulation had all the steps of the real procedure, and the content metric to confirm whether these steps were correctly represented.

We have validated the knowledge acquisition of three simulations. These simulations represent three complex transplant procedures where there is some quantity of tacit knowledge. In order to validate whether the knowledge had been correctly acquired we used different strategies. First we observed how the experts of these procedures used the simulations in order to find content and usability errors. Second we interviewed them in order to obtain their opinions and their suggestions regarding different aspects of the simulations. Third we asked the experts to fill a Usability System Test in order to obtain a concrete value of Usability and Learnability.

From all this data we have been able to improve notably the simulations and not only that but also we are sure that the content that the ONT is using in their instructional approach is correct and it represents properly their procedures.

We have also incorporated some of the improvements requested by the ONT experts and our future plans are to keep incorporating their requests in order to minimize the differences with the real procedure and to maximize the learning objective of the simulations.

These game-like simulations are being used as a ONT support tool in their instructional approach as a way for students to actively acquire a basic understanding of the ONT process.

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7.4 Application of game-like simulations in the Spanish Transplant National Organization

7.4.1 Cita completa

Borro-Escribano, B., Martínez-Alpuente, I., Blanco, A. Del, Torrente, J., Fernández-Manjón, B., & Matesanz, R. (2013). Application of Game-like Simulations in the Spanish Transplant National Organization. Transplantation Proceedings, 45(10), 3564–5. doi:10.1016/j.transproceed.2013.09.017

7.4.2 Resumen original de la contribución

Application of game-like simulations in the Spanish Transplant National Organization. 20 years ago, ONT started a management and organizational system, known as the Spanish Model, that has allowed ONT to occupy a privileged world position regarding deceased donation rates, 33–35 donors pmp in recent years.

One of the key elements of this model is its instructional approach. Two years ago, ONT started the project "educ@nt" in close collaboration with the e-UCM research group of the University Complutense of Madrid, to support and maximize its successful professional training system. As a result, three game-like simulations have been developed representing the different procedural steps of the supra-hospital level transplantation process.

These simulations represent the donor and organ evaluation, the allocation of organs applying the corresponding geographical and clinical criteria and the logistics of transportation. Simulations are based on 10 representative teaching cases that will help students to get familiar with the most common cases arriving in the ONT. For the second consecutive year, these simulations have been used in different courses around Spain.

ELSEVIER

Application of Game-like Simulations in the Spanish Transplant National Organization

B. Borro-Escribano, I. Martínez-Alpuente, Á. del Blanco, J. Torrente, B. Fernández-Manjón, and R. Matesanz

ABSTRACT

Twenty years ago, the Spanish National Transplant Organization (NTO) started a management and organizational system, known as the Spanish Model, that has allowed the NTO to occupy a privileged world position regarding deceased donation rates, which have been 33–35 donors per million population in recent years. One of the key elements of this model is its instructional approach. Two years ago, the NTO started the project "educ@nt" in close collaboration with the e-UCM research group of the University Complutense of Madrid to support and maximize its successful professional training system. As a result, 3 game-like simulations have been developed representing the different procedural steps of the suprahospital level of the transplantation process. These simulations represent the donor and organ evaluation, the allocation of organs applying the corresponding geographic and clinical criteria, and the logistics of transportation. Simulations are based on 10 representative teaching cases that help students become familiar with the most common cases arriving in the NTO. For the 2nd consecutive year, these simulations have been used in different courses around Spain.

THE EXCELLENT deceased donation rates achieved by the Spanish National Transplant Organization (NTO) during recent years are the result of the so-called Spanish Model of Organ Donation and Transplantation.[1,2] One of the key elements of that model is the continuous professional training targeted to all professionals directly or indirectly involved in the process of deceased donation through dedicated courses focused on the procedural steps of the aforementioned process. These necessarily include those steps mainly dependent on the NTO as the suprahospital agency in Spain.

The NTO, in close collaboration with the Complutense University of Madrid, has been working for 2 years on the "educ@nt" project. The results of this project are 3 low-cost educational game-like software simulations representing these suprahospital processes, to give support to and maximize the NTO instructional approach.

MATERIALS AND METHODS

These game-like simulations were developed with the use of the e-Adventure game platform that facilitates game development and integration of the games produced into the learning processes while at the same time reducing technical and cost constraints.[3,4] The methodology to develop these simulations followed the idea of achieving a more detailed and fine-grained formalization of the NTO processes. First, we investigated and acquired as much knowledge as possible about the NTO procedures to be simulated. Because common errors and other tacit knowledge[5] are not usually formalized in the procedures documentation, we obtained this information by interviewing NTO experts. This kind of information was then represented by using, among others, game elements. Also, with NTO expert help, we selected a set of 10 actual donors as representative teaching cases to use. Game mock-ups were then developed and formatively evaluated by NTO experts to ensure that the information had been properly acquired and that the procedures were being represented as expected. If any mistakes were detected in the representation, the specification of the procedure as well as the simulations were modified and validated again. This phase tried to avoid what can be referred to as software failure, where a software developer does not grasp the domain and its

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intricacies correctly and thus develops software that is not useful for the medical user. This methodology continued following a cyclical process where each loop included a new version, which was finished, evaluated, and improved by fixing the mistakes found. These simulations are aimed at any health staff who want to practice and improve their knowledge of the suprahospital transplantation process.

RESULTS

Three simulations were developed as a result of this project. The first simulation represents the process of organ and donor evaluation. The student is asked to analyze an incoming donor case and determine whether or not each organ is suitable for transplantation. To do so, the student has to identify which information is relevant for the evaluation of donor and organ suitability. During the simulation, any missing data can block the evaluation of one or more organs. The second simulation represents the phase of organ allocation. The student is asked to allocate the liver, heart, and lungs to the corresponding hospital, taking into account the national allocation criteria. The student must demonstrate that he/she can oversee this allocation process by identifying the information that needs to be verified and then offering the organs to the proper hospital. And the third simulation represents the logistics of transportation. The first thing the player has to do when starting this simulation is the synchronization of the extraction time of every organ and transplant team involved. To achieve this, the player needs to make several calls to the transplant coordinator of each recipient hospital and to the donor's hospital. Depending on whether the organ or transplant team needs to be transported by plane, the player has to call the airline to be sure that there are planes available and to know at what time they will be ready to pick up the team.

After synchronizing the extraction time, the player has to wait until the donor coordinator calls to inform him/her of the beginning of the extraction and then he/she needs to call every transplant coordinator involved. This process is repeated for the suitability of organs and the rest of the steps until the transplantation is completed. Because time is a very important factor in the whole process, the game element of player lives has been included to emphasize it. Each life lasts 6 minutes, and each simulation has 3 lives, so the player will have 18 minutes to complete the full simulation properly. Lives can also decrease if the player makes critical mistakes.

These 3 game-like simulations have already been used twice as part of the educational program for transplant coordinators in Spain.

DISCUSSION

Educational simulations in the medical arena have been proven to be effective. They provide students with the opportunity to enhance knowledge and skill acquisition in a safe environment. By using screen-based simulations, the NTO will profit from the benefits of the case-based teaching system combined with the benefits of simulations and games.[6]

We already know that in these kinds of games we learn from practicing, with direct feedback in an entertaining and low-risk environment.[7,8] Also, it is said that by allowing active learning experiences, educational games stimulate higher thinking such as analysis, synthesis, and evaluation. We can also say that while playing and learning, the stress and anxiety of the real-life experience is notably reduced and as a result the level of retention may increase.

These 3 game-like simulations have already been used in 2 NTO courses in 2013. With the feedback given by NTO trainers and students, our next step is to improve these simulations. These improvements include the simulation of random calls to better represent the pressure NTO nursing personnel experience every day. NTO experts also requested the inclusion of pancreas allocation and transportation in the second and third simulation. To make the set of teaching cases more representative, a child case will be included to help students better understand this specific distribution process. Finally, we will enrich 2 of the educational cases, modifying the donor's hospital information to include a hospital in Catalonia and another hospital in Andalusia to improve the coverage of organ distribution, because these 2 Spanish regions have slightly different distribution processes.

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7.5 Using Low-cost computer-based simulations in the Spanish National Transplant Procedures

7.5.1 Cita completa

Borro-Escribano, B., del Blanco, A., Fernandez Manjon, B., Martinez-Alpuente, I., Dominguez-Gil, B., & Matesanz, R. (2013). Using Low-cost computer-based simulations in the Spanish National Transplant Procedures. In 2013 IEEE 15th International Conference on e-Health Networking, Applications and Services (Healthcom 2013) (pp. 90–94). doi:10.1109/HealthCom.2013.6720645

7.5.2 Resumen original de la contribución

Spain holds a worldwide privileged position with extraordinary rates of organ deceased donation resulting from an organizational approach known as the “Spanish Model”. The Spanish National Transplant Organization (ONT) is making a continuous effort to improve its teaching methods and to share its knowledge with other countries.

This study describes the use of low-cost computer-based simulations covering two key procedures of the organ deceased donation process managed by the ONT central office. The goal of these simulations is to increase the awareness of other health care professionals involved in the process and to support the ONT instructional approach.

After ONT experts’ validation, these simulations were used by 90 trainees for practicing after a short theoretical presentation of the procedures. Students gave their opinions in a short survey where they confirmed that the simulations helped them establish a better comprehension of the processes. These simulations are now part of the ONT instructional material.

Using Low-cost computer-based simulations in the Spanish National Transplant Procedures

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Abstract—Spain holds a worldwide privileged position with extraordinary rates of organ deceased donation resulting from an organizational approach known as the "Spanish Model". The Spanish National Transplant Organization (ONT) is making a continuous effort to improve its teaching methods and to share its knowledge with other countries.

This study describes the use of low-cost computer-based simulations covering two key procedures of the organ deceased donation process managed by the ONT central office. The goal of these simulations is to increase the awareness of other health care professionals involved in the process and to support the ONT instructional approach.

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Keywords—Computer-based software simulation; transplant procedures; training; learning by doing

I. INTRODUCTION

Spain has reached the highest rate of organ deceased donation in the world on a nation-state basis, namely 33–35 donors per million population (pmp) during recent years. The excellent deceased donation rates achieved are the result of the so-called Spanish Model on Organ Donation and Transplantation[1]. This is an organizational approach to guarantee that opportunities for organ deceased donation are properly identified and that potential organ donors are converted into actual donors. One of the key elements of this model is its continuous professional training targeted to all professionals involved directly or indirectly in the process of organ donation through dedicated courses focused on the procedural steps of the said process. These necessarily include steps mainly dependent on the Spanish National Transplant Organization (ONT). As a worldwide leader, ONT is making an effort to share this knowledge with other countries and institutions around the world, which further increases the training demand on the limited number of ONT staff.

Computer-based simulations are becoming recognized as an adequate medium for teaching and training in general [2]. The use of computer-based simulations yields multiple benefits [3–5]: a) Simulation and game-like simulations promote active learning [6] and learning-by-doing, which make them an adequate learning tool in medical education [7–10]; b) Because this training is computer-simulated, it is risk-free in terms of human life [11], [12]; c) It addresses the need to minimize costs [13]; d) It is less constrained by the availability of medical facilities and reduces the pressure on the expert trainers; and e) It provides the learner with an objective assessment and immediate feedback [14]. The effectiveness of computer simulations in the area of medical teaching and learning has been demonstrated in different areas [15–18].

In an attempt to reinforce and systematize its instructional approach, ONT developed two computer-based simulations on the management of organ deceased donation. The aim of this paper is to describe the development of these computer-based simulations. Additionally, to analyze users' perception of these simulations, they were tested on a group of 90 trainees who then gave their opinions on the contribution of these simulations, their interaction while playing, and the kind of improvements that could be made.

II. MATERIAL AND METHODS

Simulations were developed using the eAdventure platform [19], a trainer-oriented game development platform that facilitates game and simulation development and their integration into the learning process while at the same time reducing technical and cost constraints [20, 21]. This platform is an authoring tool for creating point-and-click adventure games or game-like simulations, where the player has to

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interact with different objects within the scenes to make progress while playing. A content centric development process [22] was followed as the development methodology. The eAdventure platform and the proposed development process have been previously used successfully to create game-like simulations in the medical domain [23].

A. Creating the simulations

Using as a baseline the documents describing ONT procedures, an initial simulation script to drive the game-like simulation development was created. Two different stakeholders took part in the creation of this script: the domain experts, corresponding to ONT nursing personnel; and the programmers of the simulations, corresponding to developers of the Department of Software Engineering and Artificial Intelligence of the Complutense University of Madrid.

Simulations were based on teaching cases selected by ONT nurses among all potential donors notified to ONT, so as to select the most representative ones [24]. Ten teaching cases were selected from real potential donor cases, covering what ONT expert nurses considered to be more than 70% of the most common situations. In order to keep anonymity as defined by law, personal data was anonymized and some additional information modified to avoid traceability, but without altering the logic of the case and that of the process.

After the creation of this script, an early prototype of the simulations was produced. First versions were simply executable mockups to ensure that the information had been properly acquired and that these educational games represented what was expected. Hence, ONT's expert nurses played the simulations. They were then modified based on the mistakes detected and validated again until they were believed to closely replicate real life cases [25].

Game elements like timers and other types of distractions that indeed are commonplace in the daily work life of the ONT were also included in an effort to make the simulation as true to real life as possible. At the end of each simulation, the player obtains a self-evaluation report showing player performance (including details about the errors made) and a final mark. This evaluation report can also be sent to the trainers for review.

B. Analyzing user opinion

To analyze user opinion, simulations were used by ONT in a dedicated workshop at a training course for transplant coordinators, the Transplant Procurement Management Course in Barcelona, in February 2013, with trainees divided into several small groups.

Each group went through a complete simulation with one predetermined donor case following the instructions of the trainer. Each group simultaneously received the theoretical explanation of the processes for the first time while performing the simulations.

Afterwards, the students used the simulations again, this time without guidance and with different donor cases, in order to assess whether they had properly understood the processes.

Trainees completed a short survey after the workshop with three open questions.

III. RESULTS

A. Simulations

The first simulation represents the process of organ and donor evaluation. The student is asked to analyze an incoming donor case and determine whether or not each organ is suitable for transplantation. To do so, the student has to identify which information is relevant for the evaluation of donor and organ suitability. During the simulation, any missing data can block the evaluation of one or more organs. Fig 1 shows how the user would evaluate each organ in the simulation.

Fig 2In this screenshot, for this specific donor the heart has already been evaluated as suitable, the pancreas as not suitable and the rest of the organs are still pending evaluation.

The second simulation represents the phase of organ allocation. The trainee is asked to allocate the liver, heart and lungs to the corresponding hospital, taking into account the complex national allocation criteria. The student must demonstrate that he/she can oversee this allocation process by identifying the information that needs to be verified and then offering the organs to the proper hospital. Fig 2 corresponds to the organ allocation simulation.

Fig 1 This screenshot corresponds to the organ allocation simulation. In this case, the student is allocating a liver.

B. *Testing the simulations*

Simulations were tested at the Procurement Management Course in Barcelona in February 2013 with a group of 90 trainees, 33 men and 57 women, including 73MDs and 17 nurses. Although all trainees were health-care professionals, they were novice in the donation and transplantation processes. Therefore, playing with these simulations while receiving the proper explanation of the logic of the process is how they were intended to learn (learning by doing) [26]. As a way to promote reflection and group discussion, simulations were played in groups of 5 persons that needed to agree on the decision and actions to be carried out in the simulation.

After playing with the simulations, trainees were expected to understand properly the following concepts:

1. What information on the donor case reported to ONT is essential and cannot be missing?
2. What information on the donor case reported to ONT is relevant, but not essential?
3. What kind of errors can lead to an incorrect evaluation of an organ?
4. What are the possible causes of unsuitability of an organ?
5. What information needs to be checked in order to properly allocate an organ?
6. How does one properly select the criteria when allocating an organ?
7. How do time constraints affect these processes?

An evaluation was carried out in this workshop. Trainees completed an evaluation form with three open text questions:

1. Give your opinion on the contribution of the simulations to the learning of the organ deceased donation process.
   - 67% of the participants agreed that the simulations had contributed to helping students learn and better understand the donation and transplantation processes.
   - Among the rest of the answers, it is important to note that 3% of participants stated that simulations had helped them in the systematization of their concepts.

2. Tell us what would you change or improve to make the simulations more useful or engaging.
   - 42% of the trainees requested more visual and remarkable game elements; for example, they asked for a louder sound when the phone rings or for the warnings of the simulation to be more colorful.
   - 14% of the trainees requested a third simulation representing the logistics of transportation.
   - 9% of the participants said that they would like to have more levels of difficulty and another 9% suggested that they needed more time to learn or to be able to finish the simulation properly.
   - Among the rest of the answers, each one representing 2%, the most remarkable were the request of the translation of this game so it can be exportable to other countries and also the request of the inclusion of random calls at the middle of the game to add more stress.

3. Describe your interaction with the simulations. How did you make the decisions? Did you need any guidance?
   - 76% of the trainees said that they made the decisions with full consensus from the rest of the group playing.
   - 90% of the trainees needed help to finish the simulation while playing without supervision, most of them because they got lost and did not know how to advance.

IV. DISCUSSION

These simulations have given the ONT the opportunity to represent its procedures with low-cost computer-based simulations as a way to reinforce and systematize its instructional approach.

Developing healthcare simulations is always a challenge because it is necessary to involve different domain experts (medical personnel, developers) and communication is usually problematic. However, involving these different experts in the simulation development process ensures the educational value and the validity of the content.

Learning some of the steps of the complex process of deceased donation with game-like simulations allows trainees to practice as many times as they want without risking the lives of the recipients and without interrupting the effectiveness and transparency of the process [27], [28]. Moreover, the feedback provided automatically to the trainees by these simulations allows them to learn from their own mistakes and to increase gradually their level of knowledge.

To understand the importance of these simulations, we now focus on the particular case of a new nurse in the ONT Central Office working a typical day. Imagine that he or she makes a clinical mistake when analyzing the donor information page or an allocation mistake and offers a heart to a hospital when there is a high priority recipient compatible in another hospital. Immediately after realizing the error, he or she will experience strong feelings of regret that will probably be very instructive for the next instance. He or she will likely remember this mistake forever, but in that exact moment there will quite certainly be feelings of anxiety and frustration, as well as some other negative consequences. These simulations replicate some of these common errors in a risk-free environment, allowing this nurse to experience the consequences of this kind of mistake without risking efficacy and the lives of the recipients.

With reference to user opinion, we can conclude that most of the participants in the course agreed that the simulation helped them to establish a better understanding of the donation and transplantation process. We need to focus on improving the simulations to make them easier to follow and finish, as most of the students needed guidance while playing on their own. In reference to the improvements suggested by the trainees, we must work to make game elements easier to find and more noteworthy, as this what requested and will help users avoid getting lost while playing. More levels of difficulty may be included in future versions. The amount of time provided, however, will not be increased, though it was requested, as one of the objectives of the simulations is to show how pressing time is in these kind of processes. In fact, the fact that users requested more time demonstrates that they felt the pressure of time while playing.

Finally, the resulting simulations are editable by using the eAdventure platform, not only by the programmers but also by the medical experts, as no programming is needed. So, if simulations were to be exported other countries, it could be done with some modifications such as replacing the screenshots of the ONT central office or modifying the logic of the allocation criteria simulation if needed.

V. CONCLUSION

ONT has created two simulations to support and improve its educational program. They provide an educational environment in which learning occurs while doing. These interactive simulations have allowed students to learn the demanding process of donation and transplantation while interacting with a simulation of the real environment based on real pictures and videos. This way, players understand complex concepts not easily acquired by simply studying textual procedure descriptions. These simulations provide an active, realistic environment where learning can advance from simple knowledge acquisition towards skill development to evaluate a potential donor and allocate organs [29].

These simulations represent two of the steps in the donation and transplantation process and open the door to more simulations depending on the success of the ones already developed. After internal ONT evaluation and validation by ONT expert nurses, these simulations were used in a workshop in February 2013 in Barcelona for the first time. Trainees used these simulations and subsequently completed an evaluation form expressing their opinions. The results indicate that the simulations helped them to better understand how the ONT works. In addition, several trainees requested the creation of an additional simulation comprising the logistics of organ transportation in order to get a more complete picture of ONT processes.

Subsequent steps in the project include the development of a transport logistics simulation, the aforementioned improvements, and the analysis of how these simulations can be effectively distributed to final users (e.g., integrating the simulations into an e-learning environment such as Moodle or LAMS [30]). In addition, a larger study is being planned that will examine the use of simulations in other courses offered by the ONT in Spain. It is hoped that this study will provide additional data regarding the use and benefits of simulations in actual training settings.

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7.6 Applying Egda To A Particular Case: The Donor 'S Evaluation

7.6.1 Cita completa

Borro Escribano, B., del Blanco, Á., Torrente, J., Borro Maté, J. M., & Fernández-Manjón, B. (2014). Applying Egda to a particular case: The donor's evaluation. Transplantation Proceedings.

7.6.2 Resumen original de la contribución

Serious games are a current trend nowadays. Almost every sector has used serious games in the latest years for different educational purposes.

The e-UCM research team main focus of research is the development of low-cost serious games. During the past 10 years we have been working with and developing serious games, paying special attention to those related with healthcare.

From all these studies, a methodology was defined, the EGDA (Educational Game Development Approach), in order to design, develop and evaluate game-like simulations or serious games in healthcare.

In this article we present the application of EGDA to a particular case, the development of a serious game representing the donor's evaluation in a ICU's room from the point of view of a hospital coordinator following the EGDA methodology. In this simulation we have changed the strategy of selection of teaching cases by increasing exponentially the number of teaching cases.

This kind of educational content provides several benefits to students as they learn while playing without noticing it; they receive immediate feedback of mistakes and correct moves and an objective assessment. These simulations allow the students to practise in a risk-free environment. Moreover, the addition of game elements increases the engagement and promotes the retention of important information.

A game-like simulation has been developed following this methodology. This simulation represents a complex medical procedure.

Applying Egda To A Particular Case: The Donor 'S Evaluation

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Abstract

Serious games are a current trend nowadays. Almost every sector has used serious games in the latest years for different educational purposes.

The e-UCM research team main focus of research is the development of low-cost serious games. During the past 10 years we have been working with and developing serious games, paying special attention to those related with healthcare.

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A game-like simulation has been developed following this methodology. This simulation represents a complex medical procedure.

The growing prominence of serious games (digital games applied to education) in the latest years has consolidated them as a learning approach with great potential to enhance students' motivation and learning outcomes, thus being reinforced in the military, business, industry and education fields as a training and motivation tool (Johnson et al., 2013).

Serious games have especially gained acceptance in the medical field, where they have been used to improve patients' healthcare and health professionals' education alike (Arnab, Dunwell, & Debattista, 2012; Rosser et al., 2007).

But developing serious games that are meaningful and effective is not an easy venture. One of the key aspects for successful serious game design is to effectively create synergies between domain experts (i.e. healthcare professionals in this case) and serious games experts that enable quick translation of domain experts' knowledge into a working serious game prototype that can be collaboratively refined by the team and the potential end-users. When this is not achieved, there is a significant risk of ending up with a product that doesn't accomplish the educational objective (Van Eck, 2006). Unfortunately this scenario is still common nowadays, resulting also in many serious games that never managed to live up to expectations (Hays, 2005).

At the e-UCM research group of the Complutense University of Madrid we have proposed EGDA (Educational Game Development Approach), a methodology for designing and developing serious games that focuses on the effective integration of domain experts in the process (Torrente et al., 2014). EGDA is the result of an intensive research and development of serious games for the last seven years (Blanca Borro-Escribano et al., 2014; Blanca Borro-Escribano, Blanco, Torrente, Alpuente, & Fernández-Manjón, 2013; Moreno-Ger, Martínez-Ortiz, Sierra, & Fernández-Manjón, 2008; Torrente, Blanco, Marchiori, Moreno-ger, & Fernández-manjón, 2010; Torrente, Moreno-Ger, Fernández-Manjón, & Del Blanco, 2009). We have specialized in developing a type of serious games that we call "low-cost game-like simulations", a formula for maximizing the educational value delivered at a minimum cost, which we have applied mainly in the healthcare domain.

Among the simulations developed over the last years, the most relevant ones for this article are those developed for the Spanish National Transplant Organization (B Borro-Escribano et al., 2013; Blanca Borro-Escribano, del Blanco, et al., 2013) which include some of the steps of the supra-hospitalary level of the process of deseased donation (Matesanz, Domínguez-Gil, Coll, Rosa, & Marazuela, 2011). These simulations are used nowadays as a support tool in the ONT instructional approach.

The good acceptance of these game-like simulations among both students attending ONT courses and other professionals, has enhanced the development of a new simulation, called *Donor's Evaluation*, that includes another step of the deceased donation process (belonging to the hospitalary level). In this work we will describe the application of the EGDA methodology to the design and development and of *Donor's Evaluation*, hoping that this case study could help other programmers and designers in the development of cost-effective serious games or simulations in healthcare. Also this new case study proves the effectiveness of EGDA for eliciting complex procedural knowledge from domain experts in such a complex and risky field as deceased donor transplant evaluation.

MATERIAL AND METHODS

The development of this game-like simulation was led by an expert in serious game development, working in close collaboration with a doctor specialized in the transplantation process, who has acted as a domain expert during the whole development process.

We applied the EGDA (Educational Game Development Approach) methodology (Torrente et al., 2014), which is built around these four basic principles:

- Procedure-focused Approach: EGDA gives most importance to capturing the procedural knowledge of the domain, a kind of knowledge that is very difficult to elicit since it is acquired by years of practice in doing the same highly specialized tasks. In the case of the deceased donation process, this type of knowledge is of vital importance. So/Therefore, once this procedure has been correctly formalized in the simulation, we improve it with game elements in order to increase engagement and learning value. This way, we try to help students understand the procedures intuitively.

- Collaboration between Experts: EGDA encourages communication between the different stakeholders (in our case, game developers and the transplantation specialist) to take advantage of both profiles and to maximize the learning outcome.
- Agile Development with agile tools: EGDA is based on the principles of agile software development. It provides rapid response to changes and it is iterativebased. We achieve a highly educational value with a low production cost. The main tasks involved are (1) Analysis; (2) Game Design; (3) Implementation and (4) Quality Assurance.
- Low-cost game model: EGDA is designed to produce low-cost 2D point-and-click conversational adventures. In our case, we have developed the simulation by using the eAdventure game platform.

In order to expand the audience of our previous healthcare simulations, we have tried to open this simulation to anyone interested in learning the know-how of the process in general terms.

The next subsections are an explanation of the application of the EGDA methodology to our particular case:

Analysis

The aim of this task is to find a common strategy between the stakeholders of the project to formalize the procedure. In our case the stakeholders were composed of game developers and one expert, a medical assessor involved in the transplantation process.

Although game developers had already got some knowledge of the deceased donor process from the previous studies of the transplant procedures, the domain expert was involved in complementing that knowledge and fully validating how the procedure was transferred into the game. We have learnt that the best way to acquire all the knowledge is by observing the experts perform their daily taks and the procedures. For this reason, we performed several observations for those situations where we needed to assure knowledge.

In this task, we also defined a set of teaching cases (representative set of potential donor cases), along with the domain expert. In order to maximize the number of possible teaching cases and to improve the learning outcome of the simulation, we decided to use data from a real potential donor and to vary some of the data included to generate different teaching cases. The domain expert selected the data to be modified and defined the different values this data could have (for example the Chest X-Ray would have 4 possible values: "Normal", "Pneumothorax yesterday but today ok", "Basal aspirative pneumonia", "Bilateral infiltrates"). Then, we decided that all these values would be loaded dynamically and randomly at the beginning of the game, which enlarged substantially the number of possible teaching cases. By combining all the possibilities, we reached a number of 576 possible teaching cases, varying among very simple cases and very complex ones. Moreover, we could increase exponentially this number easily by adding new values to any of the data selected (Chest XRay, Age, Diabetes, Hytertension etc). At this stage, we also defined which the scenarios to use in the game are; we decided to set the simulation in an intensive care unit (ICU) room where the potential donors are evaluated in the real process. The definition of the scenario also describes the purpose of possible objects, such as the telephone, the fax or the trash, used to launch bonus questions, or the use of the donor's page or the blood type page to provide the player with the donor information. The people or other agents that interact during the execution of the procedure are also defined in the analysis stage. In our case, the hospital coordinator and a nurse have been the only characters involved.

Game design

Multiple scenes were designed based on pictures of the real environment (ICU room as the main scene, the donor page scene, the evaluation scene, etc.) linked to set a navigational environment (from the ICU room you can access to the donor page scene and to the blood group page scene; from the evaluation scene you can go back to the main scene and you can consult the donor page scene, etc.). This way, the physical setting where the procedures are performed is accurately represented.

In this the game design task it is very important to situate the player in order to provide him with an experience that fosters immersion. In the simulation, the player acquires the role of a hospital coordinator that needs to evaluate correctly a potential donor and decide which organs are suitable or not (this defines the main goal for the game).

Another character also appears in the scene, a nurse, whose role in the game is to guide the player throughout the simulation, to help the player when he needs helps or is lost, and to provide the player with information of the donor when needed.

In this simulation we needed to reinforce the immediate feedback, so that the player would learn from his own mistakes while playing, and he would receive an objective assessment (Burrows, 1989; Hays, 2005). To do so, a score system was included and the player's mistakes were shown while he was playing. The correct actions were also shown to motivate the student.

Finally, in order to improve the game engagement, game elements were included. To achieve so , we analized what aspects of the simulation we wanted to highlight so that the player could retain them easily. These aspects were represented through different game elements, such as scoring, lives and bonus stars. This is called gamification of the design.

Implementation

In this task, the development began and all the design decisions were placed in the simulation. As in other implementations, we first developed a very simple case and showed it to the expert, which is the easiest way to rapidly validate the knowledge representation, as the expert is seeing and playing with the exact case he usually deals with in his daily job. Game elements, complexity and more teaching cases will be added once this first mock-up prototype has been validated.

Game resources were included in order to make the game appealing. We hired a professional to design a workplace animation of the main scene and of the cover. In contrast with other simulations developed, we have not used authentic photos of the environment, which could lead to loss of realism, but instead we gained versatility and we avoided hurting players' feelings, as, in this occasion, including authentic photos would mean including a photo of a real potential donor in a hospital.

Quality assurance

We tried to assure the resulting simulation has the following characteristics:

- Reliability: We assured that the game was stable and free of programming errors. This was achieved by performing tests at different levels: by the developers, the experts and users not related with the project. Validation of the teaching cases was necessary, as the amount had increased dramatically, the domain expert revised the cases to perform such validation. First he analyzed the combinations that could never happen or that he thought unlikely to happen (for example, it was decided that if the abdominal ultrasound value charged dynamically is: “Signes of chronic enolism”, then the addictions results must show a history of alcoholism, so other combinations were excluded) and then he discarded those cases that were too similar.
- Playful/Engaging experience: It was checked that playing the game was enjoyable and immersive as well after adding game elements and attractive art resources
- Usability: Interaction with the simulation has to be pleasant. If playing the game is frustrating, then the player will not repeat the experience. Most of the usability problems are found when testing with users/players not related to the project as they usually click everywhere with no awareness of what they are doing. Usability problems were quicky identified and fixed.
- Educational value: Last but not least, having a clear learning outcome is essential for an educational simulation. The player needs to know what he is learning and what he needs to achieve.

RESULTS

Organ and Donor evaluation in the ICU room simulation has been developed as a result of this project, following the EGDA methodology and taking advantage of the previous experience in developing game-like simulations.

We have added three levels of difficulty and language options have been included as well. When starting the game, the player will be able to choose between English, French or Spanish as well as between beginner, medium or expert level. In order to help players understand the simulation we have included a tutorial to guide them throughout the game on the first time. The tutorial also helps claryfing what the players are supposed to do to complete the simulation.

In Figure 1.a we can see the main scene of the simulation, which is common at every level and language selected. Some game elements have been included in this scene:

- Time is represented by the use of lives that decrease when the player makes critical mistakes or after a certain period of time (one life lasts 6 minutes for the beginner, 4 and a half minutes for the intermediate level and 3 minutes for the expert level) (in Figure 1.a you can see the heart on the top left corner)
- A set of 5 rewards (stars) has been included. The player will earn them throughout the game by performing some extra-actions (see Figure 1.a to see the rewards obtained on the top left corner), like using the trash or the phone (see Figure 1.d to see one of the bonus questions appearing when clicking on the trash or the phone). These rewards are also earned when the player performs an action considered as proficient, such as the checking of the blood group and sending it by fax to the corresponding organization.
- We have made special emphasis in providing immediate feedback (Charlier & De Fraine, 2013; Ericsson, 2008; Moreno-ger, Blesius, Currier, Sierra, & Fernández-manjón, 2008; Okuda et al., 2009) by enabling players to learn from their mistakes and also reinforce their correct moves. This is a common feature in games and it is very convenient in eduacational contexts.

In order to promote the decision-making support and provide the student with an adequate sense of control, the player needs to study the donor information page and decide whether each of the organs is suitable or not, in Figure 1.b you can see the evaluation scene. In this scene the player will find different objects, the different organ options where he will decide the suitability of the organs. If he is not sure about the suitability of one of the organs, he can always search for help by clicking on the question mark button (see Figure 1b). Once he has finished, he will navigate to the validation scene where the simulation will let him know which options were correct and which ones were not, and then the simulation will explain to him why (immediate feedback). Finally the player will obtain a score explained (see Figure 1.c).

The beginner level is targeted to those students who are novice in the process; this means that when studying the donor information page, they will be able to detect some of the wrong information and decide whether one organ is suitable or not, but not always (for example, maybe they can determine that a donor in his 50's will not donate the pancreas but they won't be able to determine whether a pneumothorax or an enolism's history determine the unsuitability of certain organs). This is the reason why at this level they don't need to justify) the reasons why an organ is not suitable on the donor information page, they just need to decide whether an organ is suitable or not. The immediate feedback at this level will then explain to the player each of the reasons by marking them on the donor information page (see Figure 2.a).

On the other hand, at the intermediate and expert level, the player is expected to know why each of the organs is suitable or not, so he will need to justify these facts on the donor information page (for example, if the age is over 55 the pancreas will not be suitable, the player will need to click over the age to justify it correctly), the immediate feedback will indicate the mistakes and score the correct answers (see Figure 2.b). In Figure 2.b you can see that this level has three different types of immediate feedback, the first one marks the correct justifications with a green check. In this case, the player has selected the abdominal ultrasound result as one of the reasons why the liver is not suitable. Second type corresponds to those justifications that are incorrect. In the figure, you can see the player has selected the chest X-Ray result as the reason why the lungs are not suitable. However, this is not the correct justification so the simulation marks it with a red cross. In the third type the player has not even justified the unsuitability. In the figure, you can see several examples of this type of error, one of them is that the player has not justify that the heart and pancreas are not suitable due to the age of the donor.

Expert level includes the hiding of some of the data in the donor information page, for example the age or the serology results, forcing the player to ask for it to the nurse in order to be able to evaluate the organs.

DISCUSSION

The use of serious games produces multiple benefits (McCallum, 2007; Mcclarty, Frey, & Dolan, 2012; Okuda et al., 2009). Some of the outstanding benefits are the promotion of active learning and learning-by-doing (Boyle, Johnston, MacArthur, & Fernández-Manjón, 2013), thus making them an adequate learning tool in education (Akl et al., 2010; Andersen, 2012; Dror, Schmidt, & O'connor, 2011; Kato, 2010). Serious games have also been shown to be beneficial in training scenarios where the key is to have a rapid execution of the process based knowledge. (Knight et al., 2010). However, the development of serious games is a complex activity, especially because of the need of getting domain experts and developers working in close collaboration. This is essential for capturing and transferring domain-specific knowledge into the game or simulation, ensuring that the content produced has the uttermost educational value. We have developed a methodology for serious game development called EGDA which, among other features, propose strategies for effectively involving domain experts in game or simulation development.

In this paper we present *Donor's Evaluation*, a game-like simulation developed to capture the hospital transplant procedure where the EGDA methodology has been applied. This is the first time EGDA is applied in such a complex setting. The procedure for donor evaluation is very complex, since a lot of cauistic must be considered with little time for reaction and its mastery requires lot of experience. This proves the effectiveness of EGDA for capturing and transferring highly specialiced knowledge from domain experts to working game-like simulations, even when the knowledge is particularlycomplex.

Donor's Evaluation is also a contribution as an innovative learning material. In literature we can find an old case of the development of a simulation to craft a transplant policy policy(Pritsker, Daily, & Pritsker, 1996). Since then, this work and our previous studies represent the first approach to the representation of a transplant procedure throughout simulations, helping in the systematization of the procedures. We hope the content produced help spread this highly valuable knowledge, in order to improve deceased donor evaluation protocols around the world.

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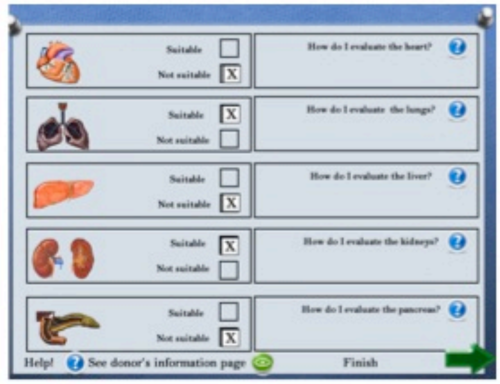
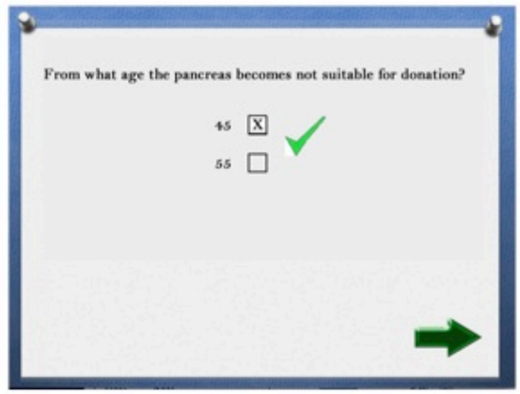
a) Main scene of the simulation

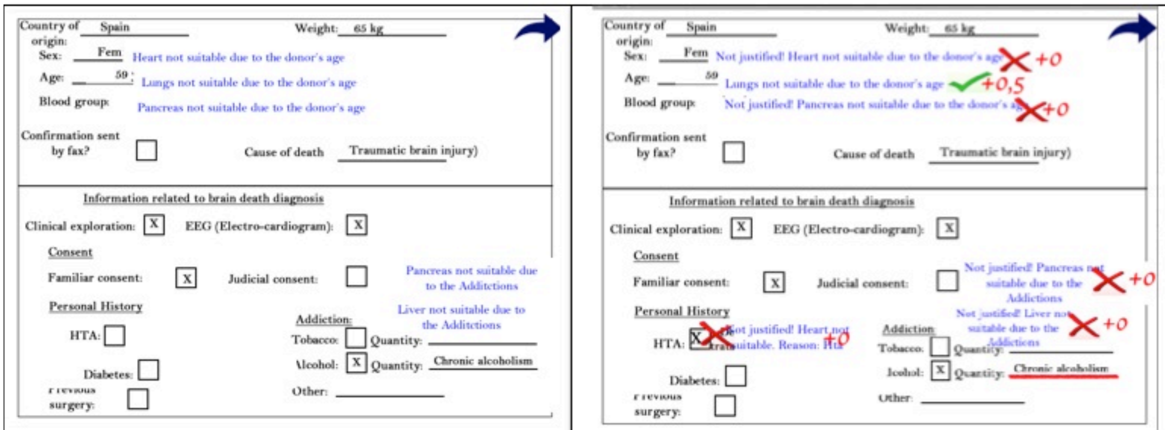


b) Organ evaluation scene

c) Final punctuation scene



d) Random question to earn rewards



a) Immediate feedback beginner's level

b) Immediate feedback intermediate level

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