Interactive simulations for health education: a case study on the cardiovascular disease in Portugal

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ABSTRACT

Many of the top causes of the death in the world are directly related to risk factors that can be avoided with changes in lifestyle behaviors. In Portugal, cardiovascular diseases are responsible for about 39% of the lost lives. It is clear that the current health education media is not enough.

Computers with internet access are now widely available and their multimedia capabilities show great potential for e-learning applications. Furthermore, most of the frequent internet users already use their computer to look for health related information.

This project aims to capitalize on this interest, building an interactive simulator that educates people on how to mitigate the risk of cardiovascular diseases. The application was named SimBody and is available for the web. It allows users to control the behaviors of an avatar in a simulation that starts from a custom profile. Besides showing the influence of each parameter in the risk, SimBody offers contextualized lifestyle advices and depicts the progression of atherosclerosis.

After successful usability tests, two sample groups participated in knowledge transmission tests. One tested SimBody and the other a text-based website with roughly the same content. The users who tried the simulator outperformed the ones who read the website. The majority of the participants stated that after using SimBody they are more aware of the dangers and will be introducing changes to their lifestyle. These results, combined with the opinions collected during the development, constitute a strong indicator that interactive simulators can be an effective tool for health education.

KEYWORDS

Interactive simulator, Multimedia learning, Health education, Cardiovascular diseases prevention

1. INTRODUCTION

The World Health Organization (WHO) states that, currently, 60% of the deaths in the world are caused by chronic diseases like cardiovascular complications, cancer or diabetes (1). Many of these diseases are connected to obesity, another serious threat to global health. Most of them have one thing in common: risk factors directly related to habits and behaviors, such as smoking or having an unbalanced diet. People need to be educated to be able to understand the actual risks in which they incur by keeping their dangerous habits. The information is available in different forms, from pamphlets to TV ads, but, judging by the numbers, the health education process needs to be reinvented, in order to become more effective and efficient.

Currently, society has absorbed information technologies into the quotidian life. The global access to computers and the Internet presents a great opportunity to reach citizens across the world. The internet has emerged as one of the main sources of information (2), related to virtually any area of knowledge. Health is not an exception. According to data from the 2007 European survey on eHealth consumer trends (3), a WHO project supported by the European Commission, 44% of the European citizens have used the internet to search for health related information. That number corresponds to 71% of the frequent internet users. Looking at the United States of America, those numbers are even higher: 56% and 79%, respectively. In Portugal, 30% of the population (62% of the internet users) has looked for health content online (4). These numbers show that people are interested and confirm the potential opportunity of using information technologies to educate society, promoting those much needed changes in life habits.

From another perspective, personal computers and smartphones have rapidly evolved in the last two decades and, today, even an entry level device has great multimedia capabilities that can be explored to build powerful learning tools. These possibilities have sparked the Multimedia Learning research field, which dedicates itself to explore new ways to combine different media to provide more effective learning experiences. This project aims to explore the promise of learning through interactive multimedia applications (5), applying them to one of humanity’s educational priorities: health.
In Portugal, cardiovascular diseases are the leading cause of death, accounting for 39% of the total deaths between 2003 and 2009 (6). Thus, it becomes imperative, from a public health point of view, to raise awareness for this problem. The risk of having these diseases is directly connected to the diet, physical exercise and smoking habits, factors that can be voluntarily changed, as long as people realize the dangers in which they incur. These characteristics enlighten cardiovascular diseases as a very suitable candidate subject for educational software.

The project intends to build an application that depicts what goes wrong in the human body in the advent of a heart attack and what can one do to mitigate the risk and prevent cardiovascular diseases. Therefore, the target audience is the general public, without any kind of medical degree. The information should be presented in a way that potentiates the apprehension of the inherent concepts and the relations between them and the everyday activities of the user. To achieve that objective, we propose a simulation in which users directly control the life habits of their avatar and are rewarded with constant feedback of what is happening inside the cardiovascular system, what they did right and wrong, and what can be done to reduce the risk of a fatal incident.

This article describes the development of that 3D interactive simulator destined to educate the Portuguese population for the dangers and preventive measures related to cardiovascular diseases.

2. RELATED WORK

Specifically in the field of health education, there are few well succeeded attempts to use widely available interactive multimedia applications. Nevertheless, a lot of useful and relevant information can be gathered from the projects presented in the following paragraphs. From each one of them there was a drawn inspiration or lesson learned and ultimately built into this project.

2.1 Interactive medical training

2.1.1 3D Viewers

To be able to visualize and precisely understand what is inside the human body is an ability that can be applied to a wide range of purposes. Be it diagnostic medicine, medical student study support or simply to satisfy the curiosity of avid citizens, there are 3D human body viewers based on many distinct technologies.

One example is Visible Body, a web 3D viewer that effectively functions as an interactive listing of the main components of human anatomy. They are catalogued by system (respiratory, digestive, cardiovascular, etc.) and each part can be hidden or made transparent, allowing the inner objects to be seen. Besides the hierarchical list of elements, the user can rotate the model and zoom freely. The controls are simple enough and work well with few systems selected. However, when one wants to take a more vertical look at the human anatomy, every system is visible and there is no easy way to hide them sequentially.

The content provided by Visible Body is really complete. Each system of the human body is composed by hundreds of individual models, accompanied by their respective name tag. In spite of this large database, Visible Body does not present any more textual information besides the name of each element. This lack of more detailed information compromises the effective use of the application by members of the general public, eager to learn more about our body. Therefore, the target audience of Visible Body is composed of medical professionals and students.

An alternative to Visible Body is Google Body, launched in December 2010 as a WebGL, plugin-free, tech demo. In terms of content, this new product presents itself like an evolution over Visible Body. It shares its basic functions of searching and selecting each element of the human body. There are better looking textures, but the main advantage over Visible Body is the presence of a level switch slider that provides a continuous transition between levels, making it very easy to understand the connection between all the presented layers. The UI takes advantage of user experience with geographical applications, mimicking Google Earth’s controls.

2.1.2 Interactive medical cases

One of the types of content most appreciated by doctors is medical cases (7). They consist of the description of real cases, with real patients, including treatment and result analysis by the doctors involved in the case. As an evolution from this concept, a new content format as emerged: the interactive medical cases, popularized by top medical publications like The New England Journal of Medicine. Their purpose is to present doctors with the challenge of correctly diagnosing the disease of a given patient. These applications are usually built in Flash and offer very limited interactivity, mostly based on a sequence of static images with a textual description. Seizing this opportunity, BioDigital, a North American company, dedicated to apply computer graphics to medicine, has identified the limitations of the usual approaches and launched a line of 3D products. In some cases, the third dimension allows the user to examine the patient directly, potentially making a better evaluation on which is the best course of action. These applications only need to represent the relevant specifics for each case. Therefore, the 3D models and animations don’t need to be as accurate and complete as, for instance, in a surgery simulator.
2.2 Interactive medical training

2.2.1 Traditional health education media

Naturally, health education has evolved with technology and, today, it is not centered on the visits to the doctor’s office (8). Media advertisements take the center stage, often integrated in wide campaigns that include street check-up points, where people can easily get more information and perform screening tests.

With the worldwide adoption of the Web, these campaigns are usually supported by a website that contains more information on how to prevent the disease. Unfortunately, in many cases, these written materials are long and not very appealing, which results in the user skipping most of the content and thus in a poor knowledge transmission. The textual information is sometimes accompanied by didactical videos that explain how a given disease affects the human body. Video constitutes a quick and effective mean to identify and explain concepts. Besides being able to represent computer graphics with more detail than a real time application can, it has one other main advantage over interactive applications: videos can easily guarantee that the user is focused on what is important. Therefore, one of the main design concerns in an interactive application with learning purposes must be to mitigate this problem, looking to keep the user focused by presenting him with the relevant information.

2.2.2 Interactive applications

The use of videogames for physical therapy and other healthcare purposes has been researched and applied, with considerable success (9) (10). This, in conjunction with research experiments in the field of multimedia learning, has, in the last few years, led to an increase of interest in applying interactive applications to health education. Unfortunately, there still are not that many successful and widely publicized attempts. The evolution of health education material has taken the next step into interactivity, but there still is a lot of uncharted territory that needs to be explored. Nevertheless, in the context of the project proposed for this dissertation, two particularly relevant applications were identified. These were able to distinguish themselves and are analyzed in the following paragraphs.

Re-Mission is a serious game developed by HopeLab, a non-profit organization from the United States. Its target audience is children and teenagers with cancer. The game aims to demystify cancer and influence positive behavioral changes on its players. The gameplay is centered on a nano robot, controlled by the player that is in charge of killing all cancer cells, while monitoring the patient’s health. HopeLab conducted extended user testing, with 375 young cancer patients from the United States, Canada and Australia. The results published (11) in 2008 and were clear, stating that a carefully designed videogame can have significant positive impact on health behavior of patients with chronic diseases. These results provide empirical evidence that there is a lot of potential to be explored, regarding the use 3D interactive applications to health education.

Naturally, interactive applications are not necessarily games or in 3D. The X-Plain product line was developed by the Patient Education Institute. The typical X-Plain application is a multimedia slide presentation focused on one disease, surgery or exam. Besides the texts, each slide has an image or animation that illustrates the. The presentations follow a common structure that begins by introducing the relevant concepts and continues presenting the symptoms, causes and available diagnostic methods. This sequence concludes with the enumeration of the available treatments and the changes in everyday life that can prevent the problem. In spite of all this information, X-Plain looks and feels like an online class. That fact may influence some users and lead them to avoid the application. The variety of topics in an X-Plain presentation is in line with the objectives of the application proposed in this project. The challenge is to present them in a more appealing way, that can motivate more users to take some minutes and learn, by themselves, about a given health problem.

2.3 Multimedia learning in general

Broadening the scope outside of health and medicine, it is crucial to acknowledge that there is a lot of research related to pedagogical applications (12), in a field known as e-learning. One of the main foundations for e-learning is Multimedia Learning, another area of knowledge which is defined by Richard Mayer (5) as the use of “coordinated verbal and pictorial messages" to transfer knowledge. In his book, he summarizes several studies that his team has made over the years, testing multimedia presentations in several formats, from slides to interactive simulations. The overall results are clear, as he provides consistent evidence that the learning process is more effective and efficient when using a multimedia explanation, rather than a simple textual approach. E-learning takes this multimedia learning approach and uses a combination of technological solutions to deliver knowledge acquisition experiences. Naturally, to take advantage of their inherent potential, multimedia e-learning applications have to be carefully designed. Ruth Clark and Richard Mayer (13) compiled the extensive work done over the years and extracted proven guidelines to design multimedia learning applications:

- Use words and graphics rather than words alone.
- Align words to corresponding graphics.
- Present words as narration, rather than on-screen text.
3. DESIGN

3.1 Requirement definition

The 2007 European survey on eHealth consumer trends report (3) stated that 71% of the European frequent internet users have used the internet to search for health related information. In Portugal, that number was set at 62% (4). In order to get the sense of how things have evolved in the last four years, a survey disseminated through online channels was promoted. From the 151 Portuguese residents that answered, 90% indicated that they have used their computer to get health related information. This overwhelming number is a clear indicator that, indeed, there is interest and that it is likely increasing with the expansion of internet access. Only 28% of the enquired individuals used offline health education software, while the large majority of 90% have used the Web for health education purposes. Therefore, Web availability emerges as one of the key requirements of our interactive simulator.

The results of the survey also reflect that users show very significant interest in the following health education topics:

- Connection between symptoms and diseases (88%).
- Preventive recommendations (87%).
- Treatments and therapeutics (81%).
- Diagnose alternatives (70%).
- Biological process associated to the disease (63%).

These indications constitute a strong guideline on which content should be included in the application. Focusing on the chosen subject for this project, cardiovascular diseases have very clear risk factors with direct impact on the risk of suffering a cardiovascular accident. Some factors are immutable, like family history of cardiovascular diseases. Others, like the lack of physical exercise, can be willingly corrected by anyone. The simulator should be able to clearly identify all of these factors and somehow represent their influence in the risk of cardiovascular diseases. Furthermore, the diet is a factor which encompasses multiple variables, like carbohydrates or meat. The user must be able to understand what actual changes to the diet can help to reduce the risk.

While delivering this preventive information, the application must convey the steps of how a typical cardiovascular accident occurs, connecting the symptoms with the actual biological process inside the human body. At each step, the main applicable treatments should be identified and explained.

Finally, considering that the target audience is the general public with internet access, the application should be easy to use and not require any kind of prior medical knowledge to successfully achieve its main goal: alert people for the concrete dangers of cardiovascular diseases and show them how they can change their lifestyle to prevent future complications.

3.2 Solution overview

In order to fulfill the specified requirements, the proposed simulator invites the user to create a profile, filling in their relevant clinical history, diet habits and physical exercise behaviors. The profile is then associated to an avatar and used as the starting point of the simulation, which spans through the whole life of the avatar and ends with the event of a heart attack.

At any point during the simulation, the user can change the value of the parameters and perceive the impact that they have on the risk of suffering a cardiovascular accident. The influence that each choice has on the risk can be checked on a risk meter or through the lifestyle advices that are updated according to the user choices.

The risk calculation is based on a set of relevant and relatable parameters, identified with the help of medical consultant. Each parameter has a list of quantity options and the user is asked to select one of those quantity options. The contribution of a given parameter to the risk calculation is based on the distance (number of options in between) from the chosen option to the optimal value. This way, the simulation is able to influence the risk value as the behaviors are deviated from the pre-defined healthier choices. Note that not every parameter has the same amount of influence. For instance, smoking has a much bigger impact on cardiovascular disease risk than not eating enough vegetables. To address this constraint, each parameter has a weight value, used to calculate a weighted average, which is used to qualify the risk as “moderate” or “higher”. Every time the user changes a parameter, there is visual feedback, informing if the risk is going up or down.

It is possible to go back in time, reverting the simulation, in order to assume other choices and understand what different consequences they might bring. Concurrently, the application represents the progression of atherosclerosis that leads to the eventual heart attack. This is done using cinematic events which occur sooner or later in the life of the avatar, depending on the risk level. When a treatment
option becomes available, the user is prompted with a description of the procedure and the option to apply it.

Throughout the simulation, the user can visualize their avatar through three levels: the macroscopic view with an external look at the body, an intermediate internal view that shows the skeleton and the beating heart, and a microscopic view that depicts the inside of an artery.

4. DEVELOPMENT

4.1 User Interface

With a well-defined scope and a solid concept, the development was ready to start, under the name of SimBody. The user interface is probably the most important element of an e-learning application. For all intents and purposes, from the point of view of the user, the UI is the application. With this in mind, the interface design was a priority in the development process.

As this application targets the web and aims to reach as much people as possible, the user interface was designed to work at a minimum resolution of 1024x768 and scale gracefully to higher resolutions, maintaining or improving the user experience. The interface was built following guidelines resultant of multimedia learning (5) and human-computer interaction (14) research. It was positively evaluated in usability tests described in Chapter 5.

At any time during the simulation, the user can access any of the three visualization levels. Maintaining the principles of consistency, the level switching operations work the same way in every level. One of the crucial missions of this user interface is to convey the simulation state, that is, let the user know how far he has progressed and what his choices caused, in terms of cardiovascular disease risk. This information is contiguously located in a bottom bar (Figure 2), which serves as both the simulation state monitor and the simulation control. The simulation can be paused or resumed through a button that mimics the control of a video player, hoping to explore existent user experience with other applications. In the same way, the simulation can be reverted by dragging back the age slider.

Figure 2: The simulation control and monitor bar.

The risk of cardiovascular disease indicator (Figure 3) is located in the bottom right corner and serves as one of the main feedback points of the simulator. The textual indication varies between “moderate” and “higher risk”. The background color is gradually changed to red, as the risk goes up. As it is critical to provide feedback on what happens when a simulation parameter is changed, the risk indicator shows an arrow, pointing up or down, whenever the risk is increasing or decreasing, respectively.

Figure 3: The risk indicator in three different states.

Changing parameter values constitutes the most important interaction between the user and the simulation. This is accomplished by a bar on the right side of the screen. Each parameter is assigned to a slider bar (Figure 4) that allows choosing from one of the available quantity options. Most quantities are expressed in “portions”, to accommodate multiple food types in the same category. However, many users might not know by heart what a portion of a given type of food actually corresponds to. To mitigate this problem, more detailed information about quantities is available in a tooltip, that is, when the user passes the mouse cursor over the selected quantity indicator. To maintain consistency, the same type of slider controls is used in the profile creation screen.

Figure 4: An example of a parameter slider bar.

The lifestyle advices presented by the application are contextualized within the current choice of values for the simulation parameters. Therefore, it is important that the users can immediately perceive the impact of their latest action. To achieve this goal, a collapsible advices panel (Figure 5) was introduced on the left side of the main simulation interface. It presents the first two advices of each type, regarding good and bad behaviors. In an effort to save for space for smaller resolutions, only the title and a short summary of the advice are shown. The full list of complete advices is available in a dedicated screen, accessible through a tab button on the top of the screen.

Figure 5: The simulation state monitor and the simulation control.
4.2 Architecture

The architecture for SimBody was built starting up from the requirements and taking into account a planned expansion of the simulator, specifically to allow for the comparison of concurrent simulation sessions and supporting multiple pathologies. Additionally, there was a special concern in separating the viewer functionalities from the actual simulator implementation. With this decision it will be possible to reuse the simulator with an entirely different visualization architecture or technology. The main modules of SimBody are represented in Figure 6.

Taking into account the goal of making the simulator viewer-independent, there is only one point of contact between viewer modules and simulator modules. This interface is managed by the Body Simulator Module, which provides indirect access to risk values, parameter values and advices, and raises events anytime there is a significant change in any pathology.

These are the modules that compose the Body Simulator:
- **Body Profile**: a repository for the simulation parameters. It allows any of the other simulator modules to be notified when the value of a given parameter is changed.
- **Risk Calculator**: responsible for calculating the risk value, based on the values of the simulation parameters, obtained through the Body Profile.
- **Pathologies**: the logic components the Body Simulator that observe the evolution of the simulation parameters and reflect it on the progression of a given medical condition, materialized by publishing events to the Body Simulator, which will distribute them to any other interested parties.
- **Advisor**: analyzes the Body Profile parameters and chooses, from the database of advices, which ones are valid at a given moment.

All of the higher-level, user-facing functionalities are split between three modules:
- **GUI**: responsible for collecting user input and controlling all of the visualization process while the simulation is running, that is, choosing and configuring the appropriate view level and presenting the state of the simulation to the user.
- **View Levels**: controls the actual visualization of the microscopic, intermediate and microscopic levels. It is responsible for maintaining an accurate representation of the simulation, per instruction of the GUI module, as well as executing the transitions between visualization levels.
- **Cinematics**: listens to pathology events and is responsible for their visual representation, hereby called cinematic. Whenever a cinematic event takes place, the GUI module steps back and cedes control to the cinematic which is about to be played.

In this system, logging poses as a cross-cutting concern that is necessary to support the feature of going back in time and revert the simulation. The logger module serves as a repository of actions that will be rolled back to a requested point in the simulation time. This module is generic and used by both Viewer and Simulation modules, to store any actions that will need to be reverted.

4.3 Implementation

4.3.1 Tools

The decision of developing a 3D simulator for the web was the main constraint while surveying for the right technology to implement this project. Unfortunately, there still is not a technology that allows hardware accelerated 3D applications to run natively, without any plugin, in all of the major browsers. WebGL is a Javascript binding to OpenGL ES and aims to achieve this goal, but it only runs on some browsers. With this scenario, a no-plugin solution was out of the question.

When talking about visualization plugins for the web, Flash immediately comes to mind. According to
Adobe, their plugin is installed in about 99% of the browsers. Unfortunately, despite a few 3D tools that Flash Player 10 brought, there still is not true 3D support in Flash, therefore, it is also not an option and, for the same reasons, neither is Microsoft’s Silverlight.

Looking at the market, there are a few 3D game engines with web plugins, such as Unity and Shiva. They offer a similar set of features and both have lightweight plugins, which can be installed in a matter of seconds. Either one of these tools could have been used to successfully implement this project. Unity emerged as the best choice because of its powerful and easy to use scene editor and web-specific optimization capabilities.

4.3.2 Simulator

The simulator implementation doesn’t bear any strong dependency from the Unity engine. Therefore, it could be easily separated, powering a totally different visualization tool or technology. The communication between the simulator and the viewer is implemented through a single class, BodySimulator, which provides assessor methods to the body profile parameters and to the list of advices.

The parameter simulation is centered on two classes: the BodyProfile and the BodyProfileParameter. BodyProfile aggregates all of the simulation parameters and serves as a repository for the immutable attributes, such as the family history of cardiovascular diseases. In addition, BodyProfile stores the most important parameter of the simulation: age. Age serves as the effective measure of time in simulation-space, which means that all simulation parameters are updated when age changes.

Each simulation parameter is represented by an instance of BodyProfileParameter. When a user modifies the value of a given parameter, the method SetParameter on BodyProfile is called and the corresponding targetValue is set to the new value. Each quantity option has the value of its order number. From this point on, each time the simulation is updated, the Update method on the BodyProfileParameter instance is called and the currentValue attribute is gradually incremented to eventually match the targetValue. The speed of increment is determined by the updateRate variable. This behavior aims to mimic the influence of certain types of lifestyle behaviors in the human body. For instance, when someone starts smoking, the drastic effect on health is not immediate, after the first cigarette. It is an ongoing gradual process that progressively affects health.

In order to use the simulation parameters for the risk calculation, their normalized value is a floating-point number between zero and one, calculated from the module of the difference between the currentValue and the bestValue. The bestValue attribute represents the healthiest choice between the available quantity options for a given parameter. On the other hand, the maxValue attribute is the total number of quantity options available for that parameter. Additionally, the parameters feature an OnValueChanged event, which can be subscribed by any entity that wants to be notified when the value has changed, like the risk calculator, for instance.

The risk calculation is based on one central class that must implement the RiskCalculator interface. This abstraction allows to easily deal with different risk values, obtained with different risk models. Each time that a relevant parameter is updated, the risk calculator is notified by the OnValueChanged event of the BodyProfileParameter and recalculates the current risk value. The risk is a value between zero and one, which is calculated from the weighted values of the simulation parameters combined with the values of the relevant immutable parameters like the existence of established cardiovascular diseases and the body mass index. The weighted value of a parameter results from the aforementioned normalized value multiplied by a weight constant that is used to distinguish the influence of each parameter in the subsequent risk calculation.

Pathologies are instantiated by the BodySimulator class and are responsible for processing the evolution of the conditions that are being simulated by the program. There is one interface - BodyPathology - that all pathologies must implement. Pathologies should deliberate and raise events through the RaisePathologyEvent method in the BodySimulator, which maintains a queue of pending events, in order to only publish one per update cycle. When published, these events should be used by the visualization components to kick off the representation of the current stage of the disease. In this project, the only existent pathology is the heart attack, which manages the progression of atherosclerosis until the critical cardiovascular accident. Every time the age is updated, the HeartAttackPathology deliberates whether or not to raise the next event.

Lifestyle advises are a fundamental part of SimBody. In its essence, these advice are paragraphs of text that clearly need to be produced outside of the application’s source code. With this in mind, a XML schema was defined, in which advices are qualified as pertaining to good or bad behaviors and structured in three fields: title, summary and text. This XML is loaded when the Advisor is initialized and is translated into an in-memory object structure. Each Advice has one or more PreConditions, which represent an alternative to validate the advice. For the advice to be valid, one of its pre-conditions must be valid. A PreCondition is valid when all of its ParamValueConditions are valid. ParamValueCondition is an abstract class to be
extended by specific parameter value comparison classes, like ValueEqualsCondition, which simply checks if the value of the specified parameter is equal to the specified value.

4.3.3 Viewer

The visualization components are implemented on top of the Unity engine architecture, taking advantage of its superclass for scripts, MonoBehavior, which provides automatic invocation of initialization and update methods. The Graphical User Interface was built using a direct abstraction over the Unity GUI functions and visually configured with their skin support.

The visualization levels control the actual 3D representation of the action. As was already specified, there are three visualization levels that correspond to the outside avatar view, the intermediate view of the skeleton and heart and the inside view of an artery. The content for each view is built and configured in a separate Unity scene. In Unity, scenes are composed of a list of game objects. Game objects are entities that are placed in the scene and have a set of transformations (translation, rotation and scale) and a list of components. A component can be, for instance, a mesh renderer, which draws a 3D model on screen or a custom script that inherits from the MonoBehavior class.

In SimBody, there is a main scene which stores the GUI game objects and the singletons that are necessary to bootstrap the simulator. The remaining scenes are loaded through the LevelManager class. Each level is represented by a concrete implementation of the Level abstract class, which provides methods to activate and deactivate the levels (that execute tasks such as switch the cameras and lights on or off), to play an animation and to choose the transition between that level and a specified target level, identified by its proxy. An instance of LevelProxy is associated to every 3D object that serves as an entry-point to another level. When the GUI needs to change to another level, it calls the SwitchTo method on LevelManager, specifying a proxy to the target level. The level transitions are classes that implement the LevelTransition interface. The most used transition is fade, which progressively transitions from the image rendered by the camera of the current level to the image of the target level's camera.

The representation of the pathology events was implemented with cinematic events, which are a
combination of real-time animations with pre-rendered videos. These videos are the result of extensive research and other pre-production work to identify the details which should be included. The reproduction of the cinematic events is managed by a singleton instance of CinematicManager. It listens to pathology events raised by the simulator and plays the appropriate cinematic. A cinematic is composed of several shots. A cinematic shot can be any given visual action, like a video or a level transition, that executes and then reports back to the Cinematic object, through the OnShotEnded event handler method. The Cinematic class is responsible for sequentially playing all of the CinematicShots until the cinematic concludes.

4.3.4 Logger

At any point in the simulation, SimBody allows the user to go back in time, undoing everything that occurred after the selected age. To accomplish this task, the application needs to roll-back actions that were performed both on the simulator and the viewer, which makes this a cross-cutting concern for the system. Each time any entity wants to log a relevant action, it uses the LogManager singleton to add an instance of any concrete implementation of LoggedAction, which will have an Undo method that is subsequently called by LogManager, when the age is reverted through the RevertTo method.

Besides supporting the reversion of the simulation, the LogManager offers one other functionality: storing milestones throughout the simulation. These milestones are produced when a user changes a parameter or when a relevant pathology event has occurred. The list of LoggedEvents is used by the Graphical User Interface to get the content to be displayed on the History screen, accessible through the top menu bar.

4.3.5 Optimizations

By default, when building for the web, Unity packages all assets in a single file that must be completely downloaded by the client before the application can start. Adding all assets including models, 720p HD videos and sounds, the complete SimBody build has roughly 103MB. Naturally, this size poses a serious problem and would render the application inapt for web distribution. To address this problem, an asynchronous pre-loading and streaming system was implemented. It takes advantage of Unity’s ability to play partially downloaded video and audio contents. The goal is to delay the download process of those media files that are not necessary until the first cinematic. This was achieved by using the asynchronous download class of the Unity Engine, in conjunction with a custom structure inside the Cinematics module.

After the initial loading, as soon as the CinematicManager is initialized, it starts downloading the first video clip and the first audio clip in parallel. Once the first video is done, the second video starts transferring, and so on. The same process is followed for the sound. This way, the application is taking advantage of the fact that the cinematics are sequential, which means that one video will only be necessary after the previous one was completely played and hence downloaded. Furthermore, the video is streamed, meaning it can start playing even before the download is over. As the application starts with the profile creation and the first cinematic does not start for a few minutes, in most cases, with a good server and an average internet connection at the client, the user will never have to wait after the simulation starts. Without the weight of the videos and sounds, the initial download of SimBody was reduced to 15MB, a value that is more acceptable for a web application, given today’s broadband internet access speeds.

5. EVALUATION

5.1 Usability

The usability tests were based on the methodologies proposed by Alan Dix et al (14). The tests consisted of three tasks of increasing difficulty that were performed by a sample of ten users. For each task, the completion time and the number of errors were recorded. Each testing session was closely observed, looking for signs of interaction difficulties. Afterwards, each user answered a satisfaction questionnaire and was interviewed for a few minutes.

Almost all of the users were able to complete the three tasks within the accepted time, without making a significant amount of errors. The answers to the two general satisfaction questions also indicated that the users were satisfied with the user interface of SimBody. When asked to grade, from one to ten, the ease of use of the application, the users gave an average of 8.2 points. The satisfaction of the user experience with SimBody was marked at an average of 8.7 points. These numbers clearly show that the users were generally happy with the application they had just tested.

However, despite the overall positive feedback, in response to these usability tests, some minor changes to the user interface were introduced. The need for these changes was identified by observing the users while they were testing the application and by directly asking them about any sort of difficulties they had. These improvements constitute the materialized outcome of the usability tests.

5.2 Knowledge transmission

The design and execution of the knowledge transmission tests were heavily based on Richard Mayer’s proposed methodologies (5). Two similar
testing sessions took place. They both used the same knowledge retention and knowledge transfer questionnaire but had different knowledge sources: one used SimBody and the other one used a page of a Portuguese official health education website. This way it is possible to compare the effectiveness of a traditional web health education media with our new simulator.

In the application test session guide, the users were asked to try SimBody for a full life, that is, filling in their profile and use the application until the eventual heart attack took place. Afterwards, they were asked to fill out a questionnaire that contained two knowledge retention questions and three knowledge transfer questions, apart from a series of one to ten grading questions related to the overall satisfaction and impact of the user experience. The retention questions aim to measure how much the user remembers of what was presented, while the transfer questions look to measure the ability of the user to apply the gathered knowledge to new situations. To be able to measure and compare the results, each of the five questions was awarded a point. Each question had a predetermined number of items that the user should mention in its answer to get the whole point. Therefore the score attributed to a given answer is the number of correctly mentioned items divided by the total number of expected items. Note that we are not necessarily looking for the correct terms, if the user uses other words to describe the right idea, that will count as a correct item.

Ten users, without any specific knowledge in the subject, completed each testing session and the results were very positive, as shown in Figure 3. After their test session with the simulator, users scored an average of 0.81 points in the retention questions. The most noticeable absence in these answers was the fact that eight users did not mention the clinical history of cardiovascular diseases as a risk factor. This points out a flaw in the application, as this information is only conveyed by the profile creation screen and implicitly, through the risk meter. Nevertheless, this also serves to point out that all of the risk factors actively involved in the simulation were remembered by the vast majority of the users. This constitutes a strong indicator of the effectiveness of interactivity to transmit information.

The transfer questions were designed to be able to determine if the users were able to absorb the concepts and establish the connection between them while also being able to apply the recently acquired knowledge to new situations. Users scored an average of 0.84 points in their answers to transfer questions. This is a highly satisfying result, with almost half of the sample group scoring a perfect 1.0 in all of the three questions and an overall set of correct and well-formed answers. However, question T3, which asks the user to apply the knowledge to their own lifestyle, was the lowest scoring, due to three participants that were not able to enumerate the majority of behaviors that they could improve.

Comparing the results of the SimBody test session with the control session with Portal da Saúde’s website, the application obtained better scores in all of the questions (except one retention question, where the scores were exactly the same). This positive trend clearly shows that the application performed better in its health education mission than the control website. However, most of the differences are close enough to argue that a different textual content might invert the situation. But there is one clear exception: the last transfer question, the aforementioned T3, where only two users that analyzed the website were able to score higher than 0.5, averaging 0.25. When compared to the satisfactory 0.73 average score of the SimBody sample group, this inability of the users to apply what they have just read reveals the strength of an application that was built to actually simulate the user’s life. Across all of the answers it was very clear that the sample group that tried SimBody was able to give more detailed explanations. Even when sometimes they did not remember the correct technical terms, the actual concept was there and the answers had more vivid descriptions.

### 5.3 User experience

The ten members of the sample group that tried SimBody answered another questionnaire that contained a few questions related to the user experience that they just had. The results were extremely positive, all of the users stated that they would use an application like SimBody if it was available on the internet. That pronounced interest is surely reinforced by the conviction expressed by 90% of the users that, after using SimBody, state that they are more aware of the dangers of cardiovascular diseases and will introduce changes in their lifestyle to mitigate the risk of related problems.
When asked to quantify, from 1 to 10, the potential of an application like SimBody in the field of health education, the users gave an average of 8.9 points. This confidence is also reflected in the users’ appreciation of SimBody, as they praised its ease of use (8.5) and acknowledged its usefulness (7.6), summing up their overall satisfaction with the application at 8.2 points. These numbers are very positive and constitute a sign that SimBody has been very well-received by the sampled users. However, they also indicate that there is room for improvement. After the test session each user was interviewer, in order to identify their reasons to not give a perfect score. Their main suggestions were the inclusion of a weight simulation process that would give visual feedback of the bad diet decisions and that the application should also include other pathologies related to eating disorders, providing an insight into the whole picture and being even more useful.

6. CONCLUSIONS

The journey from crafting the first idea to building the actual application was long but fruitful. With the help of medical consultants it was possible to build a risk simulation model that served the educational purposes of the application, maintaining a relevant scientific message. That strong pre-production work concluded with a very solid set of requirements and led to a stable architecture. The clear separation between the simulator and the viewer modules allows the use of the same simulator in other future applications, with different visualization solutions, like a user interface natively built for mobile platforms, which constitutes a promising expansion of this project. As far as the implementation is concerned, choosing Unity as the main tool revealed to be the right choice, as it was possible to maintain high visual quality and ensure a proper web performance, through the use of pre-loading and streaming techniques.

The preliminary user interface studies and the usability tests were crucial paving the way for a successful learning experience. The knowledge transmission tests showed that SimBody in its current form is already an effective health education tool, being able to educate and influence behaviors. Naturally, there is still work to be done. The learning process has significant variations from person to person so, from a global point of view of applying interactive simulators to health education, it would be of extreme importance to have more research projects around the world, testing different solutions applied to different cultures. Specifically in the context of SimBody, further testing should take place, using a larger and more diverse sample group. These results should also be compared with more forms of traditional health education media. In the future, the project can be evolved to include more pathologies, other than then the heart attack and the cardiovascular diseases. The architecture and core implementation were built with this in mind and will be able to support such a venture.

All summed up, SimBody emerged as a proof of concept that interactive simulations can be used for health education purposes. The work developed in the context of this dissertation has achieved its goals, posing as a valuable indicator that we can rely on interactive simulations to deliver effective health education messages and thus contribute to public health efforts.

REFERENCES