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Gamifying autonomous CPR training

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M

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Abstract

Across the world, sudden cardiorespiratory arrest is one of the main causes of death. Cardiorespiratory resuscitation when performed immediately and correctly may prevent this outcome. Chest compressions in particular are one of the main steps in the survival chain. It is extremely important that these manoeuvres are performed correctly as it increases the victims' survival success rate.

Several studies have shown that the resuscitation technique can be less effective due to the lack of training. The usage of medical simulation tools, such as manikins for autonomous CPR training, in the educational area has been obtaining positive results both in the learning process as well as in knowledge retention. However, there is still lack of training because is an expensive option, which implies the respect of a very tight training schedule.

Researchers have been using several approaches to make training CPR more appealing. To this end, they took inspiration from games, since it is a well-known fact that users enjoy them and put them in learning situations. The use of certain game elements in a non-game context, which characterizes gamification, may also promote a more engaged training.

The main objective of this thesis was to design and evaluate a gamified approach for CPR training. To this end, a first study aimed to review the literature regarding how serious games for the training of cardiorespiratory resuscitation incorporate the game elements. A second study focused in designing a gamified software for autonomous training of resuscitation using an existing software, named CPR.PT, as a base. And third and final study aimed at evaluating the adopted approach.

The literature review revealed that most of the games contribute to knowledge acquisition and learning of CPR, however work still needs to be done, particularly regarding the actual training of important CPR components (depth, recoil). It is also possible to conclude that external hardware components may play an important role in allowing digital games to include the practice of technical skills.

The design was developed by identifying and using a gamification framework, named 6D, and resulted in a set of software requisites. Game elements were based in the framework and chosen according to the system needs.

Finally, a randomized control trial with health professionals and students was conducted which included training and a pre and post-tests sessions where users answered a questionnaire and were submitted to a practical evaluation on their CPR technical skills.

From the results obtained it was possible to conclude that that the system helps to improve the skills of the CPR technique, however it was not possible with this study to distinguish if there is any difference between the two systems. Nevertheless, the opinions expressed in the questionnaires and occasional conversations with the users confirmed that they felt more compelled to train when they had the gamified application with 79% of the professionals and 77% of the students preferring the CPR.PT gamified.

This thesis concludes that the use of a gamified software approach can be a feasible solution to promote the interest in training CPR, creating a conducive environment to learning, and better knowledge retention as a consequence of higher training frequency.

Keywords: Cardiopulmonary Resuscitation, serious games, gamification, game elements

Resumo

No mundo, a paragem cardiorrespiratória súbita é uma das principais causas de morte. A reanimação cardiorrespiratória quando realizada corretamente e de imediato é a solução para prevenir estes casos, principalmente as compressões torácicas que é um dos principais passos da cadeia de sobrevivência. É de extrema importância que a reanimação seja realizada corretamente pois aumenta a taxa de sobrevivência das vítimas.

Vários estudos demonstram que a técnica de reanimação é menos eficaz devido à falta de treino. O uso de ferramentas de simulação médica, como os manequins para o treino autónomo de CPR, na área da educação, tem vindo a obter resultados positivos tanto no processo de aprendizagem como na retenção de conhecimento. No entanto, ainda existe muita falta de treino, pois é uma opção cara, o que implica um agendamento dos treinos muito rígido.

Investigadores têm vindo a estudar diferentes abordagens para tornar o treino de CPR mais atrativo. Desta forma, inspiraram-se nos jogos que, como todos sabem são aplicações muito utilizadas e reconhecidas pelos utilizadores, e colocaram-nos em situações de aprendizagem. O uso de elementos de jogo num contexto não relacionado com jogos (gamificação) também pode promover um treino mais motivador.

O principal objetivo desta tese foi realizar o design e avaliar uma abordagem gamificada para o treino de CPR. Consequentemente, o primeiro estudo teve como objetivo rever a literatura de como os jogos sérios para o treino da técnica de reanimação cardiorrespiratória incorporam os elementos do jogo. Um segundo estudo focou-se no *design* de um *software* gamificado para o treino autónomo de reanimação, usando um software pré-existente, designado CPR.PT, como base. Em terceiro e último, teve o objetivo de avaliar a abordagem adotada.

O *design* foi desenvolvido através da identificação e utilização de uma estrutura de gamificação, de nome 6D, e resultou num conjunto de requisitos de *software*. Os elementos do jogo foram baseados nessa estrutura e escolhidos de acordo com as necessidades do sistema.

Por fim, foi realizado um estudo de controlo randomizado com profissionais e estudantes de saúde. Este estudo incluiu treinos e sessões de pré e pós-teste, em que os utilizadores responderam a um questionário e foram submetidos a uma avaliação prática das suas habilidades técnicas de CPR.

A partir dos resultados obtidos, foi possível concluir que o sistema ajuda a melhorar as habilidades da técnica de CPR, contudo não é possível, com este estudo, distinguir se existe alguma diferença entre os dois sistemas. No entanto, as opiniões expressas nos questionários e conversas pontuais com os utilizadores, em que 79% dos profissionais e 77% dos estudantes, confirmaram que o CPR.PT gamificado foi o sistema mais interessante.

Esta tese conclui que o uso de uma abordagem de software gamificado pode ser uma possível solução para promover um maior interesse no treino de CPR, criando um ambiente propício à aprendizagem e uma melhor retenção de conhecimento como consequência da realização de treinos mais frequentes.

Palavras-chave: Reanimação cardiopulmonar, jogos sérios, gamificação, elementos de jogo

Preamble

I have a degree in Biomedical Engineering since 2017 from the *Instituto Superior de Engenharia do Porto* (ISEP) and in the same year I applied for the Master's degree in Medical Informatics from the *Faculdade de Medicina da Universidade do Porto* (FMUP).

I decided to accept this study, because I believe it is an asset for everyone to learn how to perform the CPR technique in away much more interesting. So, with this thesis I want to evaluate a gamified system and discovered if it can help learning be more interesting and make people more motivated to train more often.

During the development of this thesis, two articles were submitted , accepted and presented at the *14º Conferência Ibérica de Sistemas e Tecnologias de Informação* (CISTI).

Scientific Results

- Santos, I., Sa-Couto, C., & Vieira-Marques, P. (2019, june). Gamification in CPR-a Review of Game Dynamics and Mechanics. In *2019 14th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1-4). IEEE
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Abbreviations and Acronyms

AED	Automated External Defibrillator
ALS	Advance Life Support
BLS	Basic Life Support
CA	Cardiac Arrest
CPR	Cardiopulmonary Resuscitation
ERC	European Resuscitation Council
GM	Game
ILS	Immediate Life Support
NG	No Game
SCD	Sudden Cardiac Death
SUS	System Usability Scale
UES	User Engagement Scale

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1. Introduction

This initial chapter describes the global view of the development of this thesis, starting with the motivation that boosted its development, following the objectives to be achieved and finally the structure in which the thesis is presented.

1.1. Motivation

Currently, one of the main causes of death worldwide, is Sudden Cardiac Death (SCD). The chances of a victim surviving a heart attack may vary between 5% and 60 %. These values fluctuate when taken into consideration several variables, such as hearth diseases and even if a witness has previously been in a similar situation [1].

It is of extreme importance that a victim who is suffering from cardiac arrest (CA) is assisted immediately by applying CardioPulmonary Resuscitation (CPR) as fast as possible, enabling the blood to keep flowing until more specialized medical assistance comes to rescue [2]. Being such a fundamental technique to the victims' survival, it is crucial that every healthcare professional and even the general population can effectively perform it.

Studies show that skills acquired during CPR training are lost at a fast pace, that being the case, opportunities to keep healthcare professionals CPR skills updated should be provided more often, since they have a higher chance to come across situations where such skills can be applied [3, 4].

Yet, another situation to keep in mind, is the security and comfort of patients. Some show concerns when medical students train their abilities on patients. But there have been answers to this problem and the medical education field has gone through changes to prevent this from happening, while still being able to train future healthcare professionals adequately [5].

With these needs in mind, researchers and teachers have come to develop tools with the purpose of helping people achieve their maximum potential.

Simulation is a great help in filling these gaps in education [5]. It is defined by Gaba, as being “a technique to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner” [6]. The first time this practice was used to perform the CPR manoeuvre was back in the 1950s [7]. An interactive manikin was developed, that replicated human response and had unique interactions [8]. However, even to this day, it still is an expensive option, which implies the respect of a very tight training schedule, not allowing the training frequency necessary to keep the technique up to date. Other variables that may compromise a higher frequency of training are the need for courses to be held in groups, being difficult for everyone to be available, and sometimes lacking in commitments, such as work [9]. As an attempt to solve these limitations and to take advantage of the digital interest existent in students of this century, software-based approaches may play an important role in training healthcare professionals because they allow a more flexible, autonomous and self-managed training.

Recently, serious games and gamification approaches have been used to motivate and encourage training and learning [10]. A serious game is a game where education is the primary goal, rather than entertainment [11] and it has become increasingly used as a method to learn (and practice) CPR. Gamification, according to Cambridge dictionary

[12], is “the practice of making activities more like games in order to make them more interesting or enjoyable”.

In this work game elements are integrated in an existing application for the autonomous training of CPR, creating a gamified version and evaluate the impact on the behaviour of users regarding training frequency and technique improvement. This thesis was integrated into an existing project and a development team collaborated in the gamified application programming.

1.2. Aim and Objectives

In a broader perspective, the main objective in this thesis is to design and evaluate a gamified version of a CPR training software when compared to the standard version.

To meet this aim, a set of specific objectives were defined

- Review the available literature regarding game-based CPR training software and how gamified elements are adopted;
- Design a gamified version of the CPR.PT;
- Evaluate if the gamified application promotes higher engagement by users and its impact on technique acquisition;
- Evaluate the system’s usability;

1.3. Thesis Structure

This thesis is composed by 3 major works: literature review, gamified application proposal and impact study results. These works compose the thesis, and are described in 6 chapters.

Chapter 1 presents the motivation that led to the development of this thesis, its objectives and organization. In chapter 2, it is introduced the CPR concepts relevant for this work. The next chapter, chapter 3, presents a literature review on game-based CPR training and the game elements present. For chapter 4, gamification concepts are introduced as well as the gamified application proposal. Chapter 5 has the presentation of the impact study, along with the results obtained and discussion. Chapter 6 is an overall discussion of the achievements and possible improvements of this thesis.

2. Background

This chapter presents the relevant concepts on CPR. It is explained how to perform correctly each manoeuvre, based on current guidelines, and how the CPR training is normally performed.

2.1. Cardiopulmonary Resuscitation

Across the world, the main cause of death amongst the adult population is sudden cardiac death (SCA) [1]. Myerburg e Castellanos [13] define SCA as: ‘Natural death due to cardiac causes, heralded by abrupt loss of consciousness within one hour of the onset of acute symptoms; pre-existing heart disease may have been known to be present, but the time and mode of death are unexpected’.

To prevent death, the application of each element of the “Chain of Survival” (figure 2.1) is fundamental. This protocol is described in the Guidelines for Resuscitation 2015 Section 2, developed by the European Resuscitation Council (ERC) [14]. According to that document, the first step to take, immediately improving the chances of surviving a Cardiac Arrest (CA) is “Early recognition and call for help”, this way medical assistance has a higher chance to arrive in time to save the victim [15]. A fundamental step in the chain is an immediate initiation of CPR manoeuvres to allow adequate circulation and oxygenation of the vital organs, gaining time, until medical assistance arrives at the scene. If applicable, probability of surviving may increase up to 50-70% if the victim is defibrillated in the first 3 to 5 minutes after collapse. This probability drops drastically to 10-12%, after 5 minutes [15, 16]. When medical assistance arrives, advanced life support is instituted in case the victim has not recovered. Otherwise, they conduct post-resuscitation treatment. This is an important factor, since it can influence quality of life after the incident [17].



Figure 2.1 - Chain of survival

In this protocol, CPR is a critical step in increasing the chance of survival since it keeps the blood flowing providing the brain and heart with oxygen, while the heart fails to get back to its regular rhythm [18].

CPR consist in performing chest compression at a rate of 100 to 120cpm with a ratio of 30 compressions per 2 ventilations. This process is repeated until the victim recovers or medical assistance arrives. In the case of the rescuer being untrained or unprepared on the overall process, he or she must proceed with continuous compressions, always

trying to maintain a frequency of 100 to 120 per minute. CPR must only be stopped when the medical assistance arrives or if the victim recovers.

Multiple aspects are relevant for good quality compressions. Several studies show that when compressions are realized in the lower stern (middle zone of the chest), there is a better hemodynamic response [19, 20].

According to current Guidelines for Resuscitation from the ERC, the compression depth must not be less than 5cm nor greater than 6cm. ERC acknowledges that making compressions with not enough depth may cause more damage when compared to extra depth, that is why, training this component is of top priority [14].

Depth is also related to the correct rate of compressions. Several studies [21, 22], including a total of 13469 patients, show that a greater percentage of patients survived when compressions were performed at a rate between 100 and 120 per minute. High compression rate, greater than 120 per minute, is associated to a reduced depth (< 5 cm). Time between compressions, time used to perform ventilations, must not exceed 10 seconds [23]. Additionally, it is common to neglect the full chest recoil when performing compressions [24, 25]. Allowing a full recoil after each compression allows a greater blood flow, and consequently increases the CPR effectiveness [25].

A mathematical model suggests that the ratio between compressions and ventilations must be 30:2 to achieve an optimal supply of oxygen and blood flow [26]. This ratio is recommended since the 2005 guidelines by the ERC.

2.2. CPR Training

Training a skill allows a person to recognize, analyse any flaws and work to emend them by repeating countless times until the trainee eventually learns. Some situations cannot be trained in real life and everything related to human life must be first trained in a safe environment.

CPR protocol and technical skills training relies on courses facilitated by professional instructors that include lectures, technical demonstrations and hands-on practice. To practice in a safe and controlled environment, it has been used a technology capable of imitate some of the operation of the real world. This process is called simulation [27].

Manikins are human shaped models that are regularly used to simulate the human presence in medical, clinical and surgical scenarios. There is an increasingly presence of these devices in medical simulation, with a wide range of products, going from high fidelity ones, with high end technology such as sensors and some can move, speak, react to user input and even show facial expressions. These features are not available in a low fidelity manikin as expected, as these are less expensive, and most of the time are composed of only a part of the body.

Manikins serve the purpose of helping students and healthcare professionals learn and practice new skills in a controlled and most importantly a safe environment, since this approach does not put a patient's life on the line. Due to the delicate subject that the medical field deals with, simulations have found their way into a wide spectrum of medical areas [28].

Following this, manikins have a lot of advantages and should be made available to the fitting population. This leads to a lack of availability to projects that could benefit from this important tool. As an example of this, when taking a CPR course, a class is around 6 to 8 people with a single instructor and most of the time a single manikin.

These situations encourage less training time while using the manikin, since the instructor must supervise the training and the manikin must be used by one student at a time. These are not the only barriers, but it is a rather common one when it comes to generalizing the problem.

As of recently, new ways of helping and complementing currently used methods, are under study. Utilizing self-training videos might be a viable option, since there are studies validating their effectiveness in the introduction to learn CPR [29-31]. Another option is using an automated voice advisory manikin system which gives real-time feedback to the user (usually quite expensive) [32-34]. This reduces some of the main limitations, as there is no need of an instructor present (the system guides and provides feedback to users), and there is no time restriction (no need to schedule a time that fits an entire class demands).

There are some relevant restrictions that have to be overcome, such as availability to a wider range of the population, as well as new applications capable of taking full advantage of this technology. This type of equipment is at an infant state, meaning that there is room for improvement.

Usually autonomous training is only possible in high end costly manikins. In 2015, an autonomous CPR training software was developed at FMUP by a team from Centro de Simulação Biomédica/Centro de Investigação em Tecnologias e Serviços de Saúde (CSB/CINTESIS), the CPR Personal Trainer [35-39].

CPR Personal Trainer (CPR.PT) (figure 2.2) is a system developed for CPR self-training. CPR.PT is composed by a standard CPR manikin with multiple sensors, connected to a data management system. Collected data is stored and further analysed allowing the calculation of several parameters and a total score at the end of a training. Analysis has in consideration obtained values relative to compression's performance: hand positioning, compression's depth as well as frequency and chest recoil. Utilizing this software allows users to visualize in real time each component previously presented through a Graphical User Interface (GUI) (figure 2.3). If needed, users also have the option to view informative videos, helping them train and sharpening their skills.

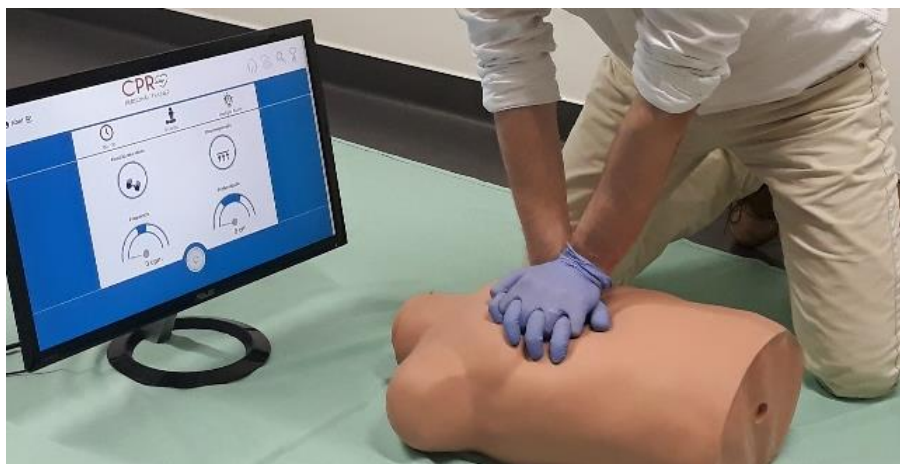


Figure 2.2 - CPR Personal Trainer



Figure 2.3 - Graphical User Interface (GUI) CPR.PT

2.3. Serious Games and Gamification

Serious Games emerged to comply with the demand of motivating a younger generation to learn the technical skills needed to be successful. These games go to a deeper extent, because they provide a connection with reality, allowing the person who is playing, to feel in touch with what is happening, while at the same time, learning and being more motivated to do so. This happens since humans associate the word “Game” with a more physical activity or with a mental challenge that is subconsciously fun to the player. This way of approaching a game is what makes Serious Games such an interesting learning strategy when applied to the academic field. It makes the learning process feel more entertaining, making the user more engaged and prone to unconsciously learn with greater efficiency.

That said, it is possible to describe a Serious Game as, a game which primary objective is to educate instead of providing entertainment [11], although it is important to note that a serious game must exceed greatly at both areas. Playing a game that is not amusing will most likely lead to a drop out.

Serious games belong to a specific genre, one that uses entertainment as a mean to educate.

Games have their own personality, meaning that every game tries to give its players a different feeling and teach something unique. Serious games pass the message of knowledge, and that can be applied to every area that needs teaching since games teach whatever fits their specific educational needs [11].

Recently, gamification is being used to promote additional engagement in training and promote rapid learning. As a result, gamification can describe as a next generation tool with potential use in several fields, from education to industry.

Gamification can be defined as adding game elements and game-design to processes or systems previously created on a non-game context, with the objective of improving the system. This area is now gaining traction in the midst of the academic community, which will most likely lead to a great impulse in new concepts and explore full potential that gamification can truly provide [40].

It is a fascinating concept that draws ideas from different areas such as psychology and design, and it is almost possible to point these two as the major topics of this area. But it has greater substance than this as it shown further into this thesis.

Gamification is mostly applied to non-game contexts, because of that, it is important to understand their meaning. As the name implies these contexts are activities where a task has to be performed that does not involve any entertainment. Gamification mostly acts upon these kind of tasks, even though it is also possible to gamify games as well [41], meaning that systems that are focused to entertainment can also take advantage of this area.

Serious games and gamification both use elements present in games for purposes outside of their original use. Both have to be seen as individual components, even though both share a strong gaming component. Serious games have a more general approach while gamification is applied to specific parts [42].

3. State of the Art of Game-Based CPR Training

In this section, a literature review on game-based CPR training is presented.

First, the query used for the search in different repositories is demonstrated, as well as the method of selecting the articles. Next, the results obtained from the variables analysis are presented and discussed, together with the main conclusions.

3.1. Introduction

A literature review was performed in order to understand how serious games are involved with the learning process of the CPR technique and how it could be improved. Before conducting the research, the games were categorized into several variables, in order to create groups and make it possible to subsequently compare them and draw conclusions. The variables were chosen according to the final objective of the literature review.

Game Aspects: Games were classified in 5 different aspects. This classification allowed to distinguish the games from each other according to the information which was found convenient for this study.

- *Game Type:* If systems are digital or analog. It was decided to define the games described by the articles.
- *Game Genre:* This variable describes a classification for each game based on a predefined list. Assessing if a game is a simulation or a quiz [43].
- *Player Interaction:* Games were classified by the numbers of players (single and multiplayer) [43].
- *Game Elements:* Categorization of elements from each of the category in the Pyramid of Gamification Elements[44]: “Game Dynamics; “Game Mechanics” and “Game Components”. With these elements the goal was to understand what game elements were used more commonly.

Hardware: Whether the system uses any kind of external hardware that is used during the training. Used in order to understand if only software approaches are used or if there is the necessity to use hardware to allow training and feedback.

CPR Training Elements: These elements were chosen because they define the CPR manoeuvre and are the ones usually evaluated in CPR training. As presented in Chapter 2, the relevant elements are the compression rate, the compression depth, the chest recoil and the hands positioning. Parameters related to ventilations are also considered. Some of the components, both related to compressions and ventilations, are considered to be in the game, but were classified as simulated because they cannot be learned without a physical interface (e.g. compressions depth). The specific elements for both the compressions and ventilations are as follows:

- Compressions
 - *Hands Positioning*: Whether the game includes aspects regarding hands positioning training. It is an important aspect of the technique, because if done incorrectly may cause some damage to the victim.
 - *Compression Rate*: Whether the game considers the frequency with which the player performs the compressions.
 - *Compression Depth*: Whether the game considers the depth at which the compressions are performed by the player. There are cases where the game shows the depth to which the compressions are being performed, however the perception is simulated. The user does not know exactly how deep the compressions are being made.
 - *Chest Recoil*: If the game presents chest recoil. This is another case where the game can check whether or not this component is performing correctly, however the player has no physical perception of what is happening.
- Ventilations:
 - *Hyperextension*: Whether the game considers the hyperextension during the training. The realization of this component is simulated.
 - *Volume*: If the game considers the amount of air necessary to proceed with the CPR manoeuvre correctly. This is one more case where the component is simulated.
 - *Pinch nose*: If the game considers if the gamer pitches the victim nose before venting. This is another case where the component is simulated.

3.2. Methods

The protocol was divided into 3 phases: 1) Studies Collection; 2) Title and abstract analysis; 3) Full text analysis.

For the first phase, named *Studies Collection*, 3 different repositories: PubMed, Scopus and ISI. In these three, the following query was used: ("cardiopulmonary resuscitation" OR "cardiopulmonary resuscitation" OR "cardio-pulmonary resuscitation" OR CPR OR "basic life Support" OR BLS) AND (game* OR gaming). A total of 307 articles were extracted (61 from PubMed, 143 from Scopus and 103 from ISI).

After duplicates removal, 186 were selected to the next phase of review.

In the second phase, *Title and Abstract analysis*, inclusion criteria were defined:

- The study should be aimed at the general population or health professionals;
- The study should use a gamified approach;
- The study should describe a system/method related to CPR or BLS training;

Only 46 complied with the defined criteria. If the criteria assessed was not clearly stated in the paper's abstract it was still included for the next stage.

Lastly, in the phase *Full Text analysis*, 13 works were eliminated (6 that could not be retrieved after author contact and 7 because they did not comply with the previous criteria). The final number of articles included was 33.

Given the fact that some studies referred to the same game or system, they were aggregated into a single Game. In total, 21 games were identified from the 33 papers.

The entire length of the papers was read and classified according to two main axes: game elements, like rewards, levels, players' progression or score and the CPR technical elements, such as hand positioning, depth, recoil and frequency of the compressions and ventilations. The review was performed using Cadima [45] and data was processed using SPSS statistics.

The figure 3.1 presents the flow chart of the review stages throughout the article selection.

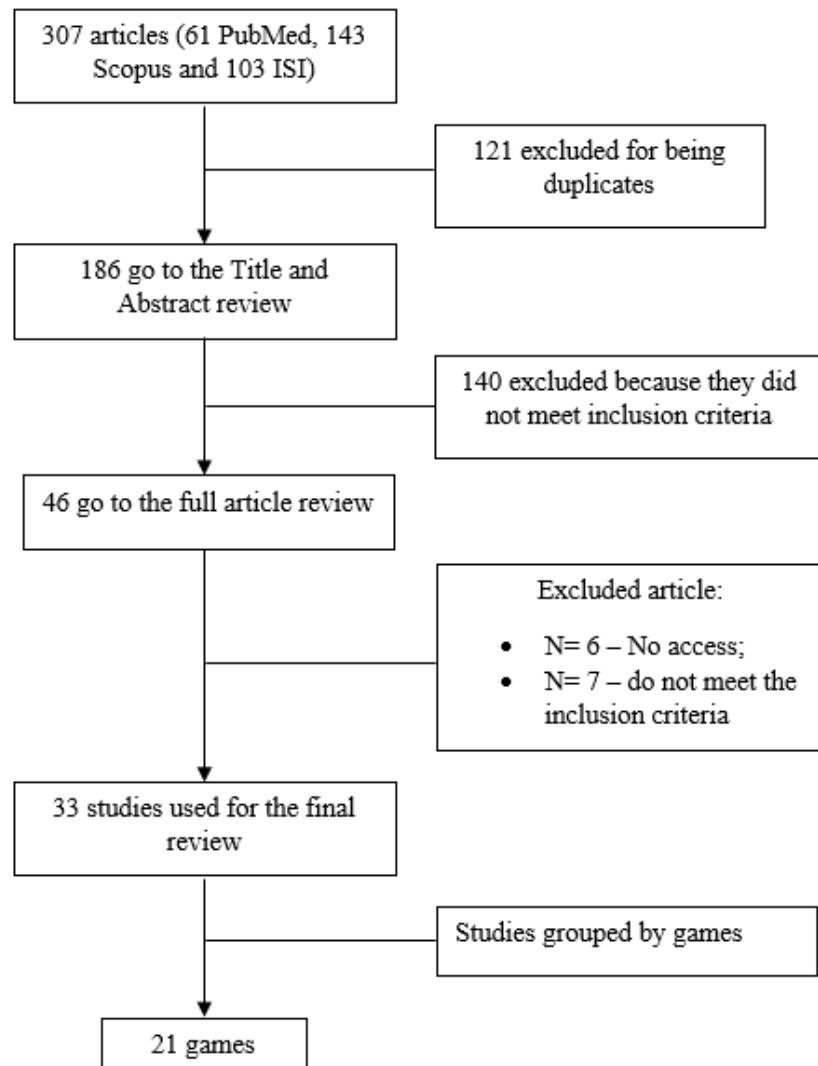


Figure 3.1 - Article selection flow chart

3.3. Results

Figure 3.2 shows the number of articles by year of publication and the respective game.

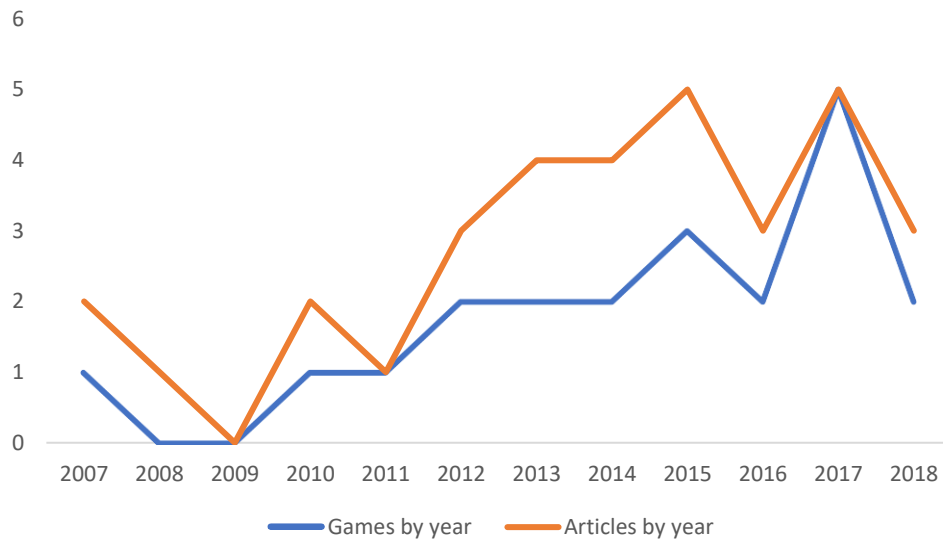


Figure 3.2 - Number of articles by year of publication and number of games by year

Table 3.1 presents every game and respective reference article(s). Cases exist where the authors did not present a name for the developed system. Due to this absence, they were denominated by author's first name followed by the word Game. That is the case shown by the example FoldagerGame, being Foldager (author's first name) + Game.

Table 3.1 - Games analyzed and references of the articles related to the games

<i>Game</i>	<i>Reference</i>	<i>Game</i>	<i>Reference</i>
30:2	[46]	NatalieCharlierGame	[47]
AEDApp	[48]	PULSE	[49]
BlindCPR	[50]	Relive	[51]
FoldagerGame	[52]	SeGTE	[53]
HeartRun	[54-57]	Staying Alive	[58]
LA-VIE	[59]	The Held Game	[60]
Lifesaver	[61]	HeartSaver	[62]
LISSA	[63, 64]	FujiokaGame	[65]
LISSA Kinect	[66, 67]	OakGame	[68]
MarchioriGame	[69]	LamboyGame	[70]
MVW	[71-78]		

From the analyzed games, 95% were classified as digital and based on simulation. Only 19% of games have external hardware, these are the ones that allow the user to practice compression depth with a physical interface. The main game elements found in the analyzed games were the points, with a percentage of 62%, and the avatar with 57%. These two elements correspond to the components of the pyramid presented by figure 4.2. Regarding mechanics, feedback is the most used, being present in 62% of games.

Tables 3.2, 3.3 and 3.4 present more detailed results.

Table 3.2 - Game elements by layers from the Gamification Elements Pyramid (Figure 4.2)

	n (%)	Game's Name Reference
DYNAMICS		
Emotions	5 (24 %)	[52], [54-57], [61], [63, 64], [66, 67]
Narrative	3 (14 %)	[65], [59], [51]
Relationships	4 (19 %)	[54-57], [71-78], [47], [51]
Players Progression	7 (33 %)	[46], [52], [61], [63, 64], [66, 67], [68], [60]
MECHANICS		
Rewards	4 (19 %)	[46], [52], [61], [60]
Feedback	13 (62 %)	[46], [52], [65], [54-57], [59], [61], [63, 64], [66, 67], [47], [49], [51], [53], [60]
Challenge	3 (14 %)	[70], [52], [47]
COMPONENTS		
Achievements	1 (5 %)	[52]
Levels	7 (33 %)	[46], [52], [59], [63, 64], [66, 67], [49], [53]
Activity Scores (Points)	13 (62 %)	[46], [48], [50], [52], [54-57], [61], [63, 64], [66, 67], [69], [68], [51], [53], [60]
Avatar	12 (57 %)	[46], [62], [59], [63, 64], [66, 67], [71-78], [68], [49], [51], [53], [58], [60]

Table 3.3 - Classification of each game by type, genre, player interaction and hardware

GAME TYPE	n (%)	Game's Name Reference
Analog Board Game	1 (5 %)	[47]
Digital	20 (95 %)	[46], [48], [50], [70], [52], [65], [54-57], [62], [59], [61], [63, 64], [66, 67], [69], [71-78], [68], [49], [51], [53], [58], [60]
GAME GENRE		
Quiz	1 (5 %)	[47]
Simulation	20 (95 %)	[46], [48], [50], [70], [52], [65], [54-57], [62], [59], [61], [63, 64], [66, 67], [69], [71-78], [68], [49], [51], [53], [58], [60]
PLAYER INTERACTION		
Multiplayer	3 (14 %)	[54-57], [71-78], [47]
Single Player	18 (86 %)	[46], [48], [50], [70], [52], [65], [62], [59], [61], [63, 64], [66, 67], [69], [68], [49], [51], [53], [58], [60]
HARDWARE		
Hardware	4 (19 %)	[70], [65], [66, 67], [51]

Table 3.4 - CPR Components

	Games n (%)	Reference	Games with Simulated component N (%)	Name
Compressions				
Hands Position	8 (38 %)	[46], [48], [65], [61], [63, 64], [66, 67], [58], [60]	0 (0 %)	-
Compression Rate	13 (62 %)	[46], [48], [50], [70], [65], [59], [61], [63, 64], [66, 67], [68], [51], [58], [60]	0 (0 %)	-
Compression Depth	4 (19 %)	[70], [65], [66, 67], [51]	6 (29 %)	[46], [48], [59], [63, 64], [58], [60]
Chest Recoil	0 (0 %)	-	1 (5 %)	[58]
No defined component	2 (10%)	[61], [52]		
Ventilations				
Hyperextension	0 (0 %)	-	1 (5 %)	[61]
Volume	0 (0 %)	-	0 (0 %)	-
Pinch nose	1 (5 %)	[61]	0 (0 %)	-
No defined component	9 (43 %)	[68], [53], [58], [60], [46], [50], [59], [61], [63, 64]	0 (0 %)	-

3.4. Discussion

By analysing the data referred in the previous section, it is possible to conclude that the increase in articles publication observed since 2012, is related to a wider usage of serious games approaches. This information is in conformity with a previously conducted study by Fedwa Laamarti [79], where it is seen an increase of articles being published in the serious games field, through the years. Regarding the evaluated games, it can be observed that the compression rate is the most used element from the CPR training elements. It was also observed that although there is a use of other elements such as compression depth and ventilations, these are simulated and do not allow a real practice of the manoeuvre. It is in most cases observed through a computer and resulting from finger interaction in a touch screen, in a mouse and/or in a keyboard. It was identified that there were only 4 games that allow for training of compression's depth and these are the ones using external hardware add-ons.

All digital games adopt simulation and the role play approach, putting the user in a real-world context. From games' component analysis, it is possible to observe that most games reflect a single training driven approach, given that, the most frequent used aspect, is score from an activity, and game elements that relate to continuous engagement, while trainings progression assessment are not commonly adopted.

3.5. Conclusions

Serious games and gamification are two methods with increasingly popularity among specialists in the learning of the health field. In this study 33 articles were reviewed and classified to identify the main characteristics regarding serious games and CPR learning. From the analysis of 21 games and their respective articles it was conclude that most of the games contribute to knowledge acquisition and learning of CPR and BLS protocol however there is still space for additional work, particularly regarding the actual training of important CPR components in a more realistic fashion (depth, recoil). Additionally, from the obtained results, it is possible to conclude that external hardware components play an important role in allowing digital games to include the practice of technical skills. With this hardware component the user can train all the necessary CPR elements, exploring the full potential of digital serious games for training motivation alongside with the inclusion of additional game elements that reflect user's progression.

This section resulted in the publication of an article on the *14^o Conferência Ibérica de Sistemas e Tecnologias de Informação*: Santos, I., Sa-Couto, C., & Vieira-Marques, P. (2019, June). Gamification in CPR-a Review of Game Dynamics and Mechanics. In *2019 14th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1-4). IEEE.

4. Gamifying CPR.PT Software

This chapter presents important basic concepts for the implementation of gamification aspects in the existent system. After this background, the elements that were included in the system as well as the final version of gamified CPR.PT are presented.

4.1. Background

Gamification concept is about adding game elements and game-design to processes or systems previously created on a non-game context, with the objective of improving the engagement to the system.

Understanding how a game element augments a system, requires an analysis to games, and their impact in human behaviour. While playing an enjoyable game, players tend to feel happy and motivated to willingly keep on playing. As long as players feel engaged, chances are they will continue to play and perform better, being this the ultimate objective of gamification.

Gamification is a recent phenomenon, it gained more attention around 2010 (figure 4.1), although this does not mean that it only started to be implemented around that time.



Figure 4.1 - Worldwide Google trends of Gamification [80]

The origins of gamification go back as far as the beginning of the XIX century. In 1819, Sperry & Hutchinson Co distributed green stamps, that the clients would put on a booklet, which later were redeemed for rewards from their catalogues. This is one of the first examples of successful gamification, as it had a lot of people hoarding those stamps in America [81].

Companies with more resonating names such as Microsoft and Facebook and even non-tech giants like Nike, implement gamification in their working teams to boost productivity, or in services to their customers. Giving Microsoft example, they developed a gamified platform named Language Quality Game, to help them improve linguistic accuracy in their software. They launched a gamified system, to language native speakers, which then helped Microsoft with that task. This used the broad community using Microsoft software, giving users an opportunity to contribute and at the same time keeping costs low. This implies a development effort, as there are many aspects to be considered, to remove any cultural and political influences. Nevertheless, it was a successful project, as they had 100% language participation and quality review came to a relevant average of 71% [82].

Nowadays, gamification has many uses such as: companies trying to boost their employees' productivity, reducing students learning curve in education, and even aviation training.

4.1.1. Psychology of Gamification

Motivation can be defined as the psychological energy that is channelled to achieve a certain objective [83].

Games are great at motivating. Games are mainly played voluntarily and achieve something extraordinary which is luring players to come back, through the promise of progression and rewards.

This is because games focus on three important components: pleasure, rewards and time. These aspects are what make players take actions, that normally they would not take, in a predictable manner. This power of psychological elements in games is what provides advantage to the gamified systems [83].

Human motivators

Understand what captures a person's motivation allows to develop methods can be used to keep it going for as long as possible. Two aspects that influence human motivation is game flow and reinforcement.

- Flow: Game flow can be seen as the path a game takes, and what consequences it has on the player. A good flow never lets a player feel bored. Boredom should never occur since it leads to an almost instant loss of interest. Boosting the flow too high may contradict boredom but also cause anxiety on players. If the pace is too fast, players have no time to adapt and feel comfortable with the situation. Flow should be kept in a good balance between these two points.
- Reinforcement: This concept revolves around on how it is possible to convert expected rewards into more player actions, by changing the rate to which they are rewarded [83].

Types of motivation

There are two main types of motivation: Intrinsic and Extrinsic.

- Intrinsic motivation: This occurs when a person willingly performs an action. The motivation is centred in the user rather than the task.
- Extrinsic motivation: Being extrinsic motivated means that a person feels he/she has to do a task. This means that the motivation lies more in the activity rather than on the user.

Self-Determination Theory

Autonomy, competence and relatedness are the three psychological necessities people have according to this theory.

Autonomy reflects a need of feeling free and sense of imposing own will, while competence is about accomplishing tasks and goals, and finally relatedness is the basic social need of feeling integrated in a group as well as accepted by others [84].

By fulfilling these 3 needs a person is more prone to respond with relevant actions to whatever the setting might be [85].

4.1.2. Game Elements

Considering the previous principles, gamification consists in adopting several elements (game elements) that allow building an attractive and engaging system. It is important to take notice that these elements are not games themselves.

Points, Badges and Leaderboard (PBL)

Points, Badges and Leaderboards are the most basic elements , included in the majority of videogames or gamified systems.

- Points

This is a fundamental aspect to have in a gamified system as it is an extremely versatile one. It can work either in the background or being directly presented to users. In the later, it is possible to identify how users react to points. Most of the times two types of people are easily identifiable: those who enjoy collecting points and those who are competing to have the highest score. There are also several types of point systems such as: experience points, redeemable points, skill points, karma points, and reputation points, among others[83].

The developers should choose what kind of points are going to be used and how, being the latter of extreme importance as it can be a weak spot when handled incorrectly. When points are easily obtained, users will not pay attention to them, being seen as abundant, leading to interest degradation. Making them hard to get, will lead to an higher percentage of users giving up, as players do not get a sense of advancing, and this is a quintessential feature of points.

A function that most of the times goes unnoticed is that, points provide valuable data to analyse, allowing for further system improvements [44].

- Badges

Badges provide a tangible sense to the previously presented point system. It is possible to address badges as achievements, since both share a core purpose. As all members of this trio, badges have a lot of potential when used correctly, being this the reason why it is a continuously used resource.

It is periodically used in all kinds of video games as it gives players a goal to look towards, providing a motivation boost as well as giving more motifs to play, and that is ultimately what a gamified system tries to achieve.

These objectives can be repurposed to provide player's guidance, since people tend to pursue badges, as previously mentioned. Creating badges encourages players to perform certain actions, for example, rewarding new players for watching 5 tutorials.

This component heavily the self-satisfaction people obtain by showing their conquers to others. By having a badge, players have something meaningful to exhibit to others, especially when others do not have the same badge, giving them a sense of

expertise. At the other end of the spectrum, players that share the same badges, have a sense of community and connection with the remaining player base.

- Leaderboards

This is the last element of PBL and possibly the most volatile. Leaderboards have tremendous potential since it complements previous game elements, giving context to progression, being undoubtedly, a good feature to have in a system. Truly a great motivator under the right circumstances but at the same time could turn out to be extremely demotivating. If players see themselves at the bottom of the leaderboard, they may stop trying to get to the top, as it seems unreachable. There are ways to go around a classical view of a leaderboard, for example, by not tracking a single attribute as some people are better at some things than others. That will motivate players to try to improve their worst aspect.

PBL is undoubtedly a great starting point for designing a gamified system, especially when correctly implemented. This is reflected in almost every game or gamified system, where these exact elements or some variation are present. Before implementing them, developers should analyse the project in hands and evaluate if these elements are a right fit.

PBL is part of three game elements categories, crucial to gamification: Dynamics, Mechanics and Components (figure 4.2). These categories are explained below.

Components

Components are dynamics and mechanics in a more fine and detailed form. Three components previously mentioned were points, badges and leaderboards, those being high-level elements based on dynamics and mechanics.

Mechanics

Mechanics can be seen as the bridge between these three components. These mechanics essentially are behaviours and control mechanisms provided to players. As previously explained, dynamics and mechanics work side by side and adjusting game mechanics facilitates the dynamics' improvement.

Being a parameter standing in middle ground also means that when used with components, it essentially leads to the process of dynamics' creation [86].

Dynamics

Game dynamics are the component with the highest level of abstraction. Gamification dynamics are the player executed actions when playing. It is a direct consequence of Mechanics as that is the component that players interacts with [87].

Dynamics can be unpredictable, as players tend to respond differently to one another, even when submitted to the same set of mechanics. This can act as a double-edge sword on the system by either adding to the experience or discarding the intended purpose entirely.



Figure 4.2 - Game Elements Pyramid derived from [88]

After considering the above elements and categories, they must be integrated in a system. This requires great effort as well as planning, since different perspectives, aspects and elements must be considered. Regardless, this is the task that will either create a magnificent gamification design or one that will fail its purpose.

To correctly construct a system it is possible to follow an already defined algorithm acting as guidance [44].

4.2. Methods

Knowing what elements compose gamification is not enough. A methodical strategy to know what is best for a certain system is needed, making the most out of this concept. Design methodologies assist with the task of accomplishing a great game design that attends to user's needs.

A framework presented by Kevin Werbach and Dan Hunter lays on the idea of 6 steps to follow (table 4.1), based on design knowledge:

Table 4.1 - 6D Framework

6D	Definition
DEFINE objectives	As commonly known, a great way to approach a new project is to first know its purpose, since planning is as important as execution. For that reason, before starting development, a specific goal must be determined as this will help guide all remaining steps avoiding some setbacks.
DELINEATE target behaviours	<p>Once every objective is properly defined, it should come next what path players should take as well as how their actions will be evaluated. This step should meet ends with the previously define objectives since they ought to be encouraged.</p> <p>Upon tracing all target behaviours, comes creating a metric system to each one of them since not all actions should be credited the same way. This has to be done carefully and some ways to quantify actions already exist and are encouraged.</p>
DESCRIBE your players	<p>Businesses do this all the time, develop a product based on a population specific need. So, when developing a gamified system, developers should study players who will use it.</p> <p>Something important to take note is what can be motivational to the player base, since motivation plays a major role here, and obviously not discard information about what could be demotivating as well.</p>
DEVISE activity cycles	<p>Games are not entirely linear since some mechanics can be in a loop. There are two loops, the <i>engagement loops</i>, this is a basic process that essentially captures the attention from users by never leaving three states. When a player performs an action, it can trigger feedback from the system, and when given feedback users tend to be more motivated, such will cause users to play more and therefore performing more actions, thus being in a loop.</p> <p>The remaining loop is called <i>progression stairs</i>, this is to react to the fact that people are not new to a game all the time and will pick up on key aspects of the game as progression is made. This model should not be linear as difficulty, is important in the sense of progression, to obey this non-linear design it is implemented the progression stairs.</p>
DON'T forget the fun!	<p>This is a key aspect that can be overlooked from time to time, and if a gamified system is not fun, most people will see a new shiny system as the same job with extra steps.</p> <p>There is no magic formula to make it fun, but a good starting point is to develop everything with that intent in mind and continuous testing and improvement.</p>
DEPLOY the appropriate tools	<p>Now reaching the actual implementation, this is where everything previously described comes together to create a gamified system. There is not an algorithm to follow here, since every system is different and has its own set of requirements.</p> <p>Following these steps is a step in the right direction to produce an interesting and well-constructed gamification implementation [44].</p>

This framework was used as the basis for defining the elements to include in the existent CPR.PT system.

4.3. Results

Using the 6D framework presented above, and after defining, the following requirements were established.

1. **DEFINE** objectives

The primary goal is to develop a gamified software so that its users can learn and train in a motivated way. In other words, the objective is to use external hardware to promote a real practical training of all CPR components and incorporate game elements in order to create a motivating system that promotes training and interest in all of its users.

2. **DELINEATE** target behaviors

When the user makes a training, an assessment of that training is performed, presenting, at the end, the corresponding score. This is a component that had already been implemented in the original CPR.PT. Two requested actions were previously included:

- Perform training with at least 30 compressions.
- View training videos.

The gamified CPR.PT version also included the following action:

- Daily perform a short test with theoretical questions (quiz);

In addition to the score that is given to players at the end of each training, in the gamified system is also associated a certain amount of points that varies according to the score obtained.

Points are split into two types, experience points (xp) and utilization points (up). xp are delivered every time that the performed activity is anyway related to trainings and compressions. When it comes to up, these are awarded when users use the application beyond training.

This point system is of extreme importance to the gamified system development since they persist across all system's actions. Users get a score after finishing trainings, ranging from 0% to 100%, this is calculated based on compressions performed on the manikin. If a user training score is inferior to 75%, it is given a marginal reward of 25 xp. In case the percentage is between 75% and 84% the reward increases to 150 xp. From 85% to 94% it goes up to 200 xp. Finally for any score above or equal to 95%, the reward is 250 xp. These are the respective values if the players choose guided training (figure 4.3); otherwise the awarded points are doubled (figure 4.4). Of notice is that for a training to be valid, users must perform at least 30 compressions.

For each video that the users see while using the system, they receive 25 up.



Figure 4.3 - Training with help



Figure 4.4 - Training without help

3. **DESCRIBE** your players

This system is being developed to be used by people who already know the CPR technique and have already attended courses, but also by laypeople that are not familiar with the technique. To keep the system usable for everyone, care had to be taken with the amount of points needed to advance through the levels. To develop the points system, a survey was conducted on the amount of points awarded in one of today's most popular games, League of Legends (LOL) [89]. The system developed here is not the same as that of LOL, but served as a guide.

The points system created presents an increasing difficulty (figure 4.5). It was developed in this way, hoping that even those who started with worse results as they

trained would get better and better. The increasing difficulty of passing the level, would act as motivation to be better and get better scores.

Regarding the number of points that are awarded for each score obtained, presented in 2. *Delineate target behaviours*, several tests were performed. These served to prevent passing more than one level at once, or having very easy or too difficult levels.

Xp points are the only ones that count towards levelling up. With this measure, users are required to train to get enough points to pass to the next level, so it is prevented that players, for example, watch videos just for the need to get points.

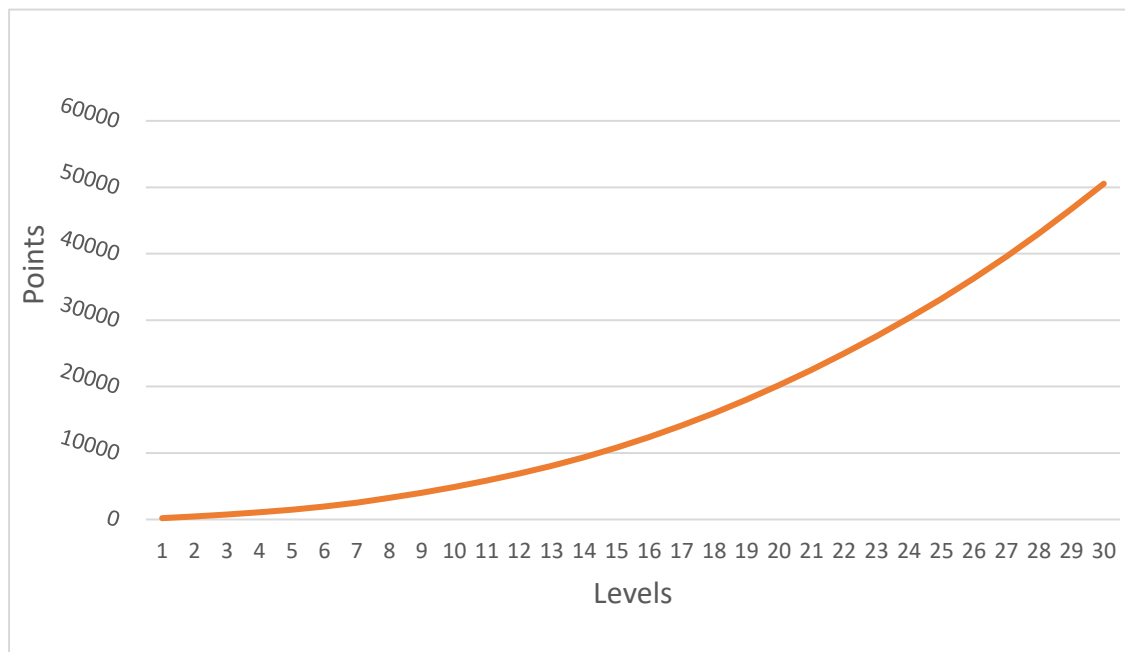


Figure 4.5 - Relationship between levels and points

4. **DEVISE** activity cycles

Regarding engagement loops, elements such as feedback, rewards and leaderboards have been chosen to promote engagement by users so that they are always tempted to return.

Considering rewards, 4 milestones were established by system provided activities. Whenever a player reaches these milestones, he is rewarded a medal and points relative to the accomplished level. Bronze medals gives 50 up, silver doubles the up to 100, gold medallists get 150 up and diamond get the highest number of 200 up. These points are relative to certain objectives such as: doing a predefined number of logins, the number of watched videos, and how many trainings the user did both with and without assistance. Aspects like, number of correct compression depth and recoil, correct hand positioning and number of correctly done compressions, get players the same number of points, but in this case xp instead of up.

Tables 4.2 and 4.3 have the represented limits to each objective, as well as respective points.

Table 4.2 - Points for each goal related with the system usability

Goal/Points	Bronze Medal (50 up)	Silver Medal (100 up)	Gold Medal (150 up)	Diamond Medal (200 up)
Number of logins	2	6	15	20
Number of videos	2	10	20	30
Number of trainings	10	30	60	100
Number of trainings without help	10	30	60	100

Table 4.3 - Points for each goal related with compressions experience

Goal/Points	Bronze Medal (50 xp)	Silver Medal (100 xp)	Gold Medal (150 xp)	Diamond Medal (200 xp)
Number of compressions with correct depth	10	30	60	100
Number of compressions with correct hands positioning	10	30	60	100
Number of compressions with correct recoil	10	30	60	100
Number of correct compressions	10	30	60	100

The points that count towards the leaderboard rank is the sum between the xp and up obtained by the user.

Figure 4.6 shows how the rewards interface was represented in the gamified system.



Figure 4.6 - Rewards Interface

Every time the user levels up, a message reinforces this achievement as depicted in figure 4.7. A similar message is also shown when the user ranks up.

The challenges are based on a daily quiz with extra points where the users may test their knowledge about BLS. This element was not implemented in the software due to the limited time to develop all the system (figure 4.8).

These aspects are expected to prevent the possible existence of a loop, which is to counteract the fact that the training is always the same, leading the users to no interest in training.

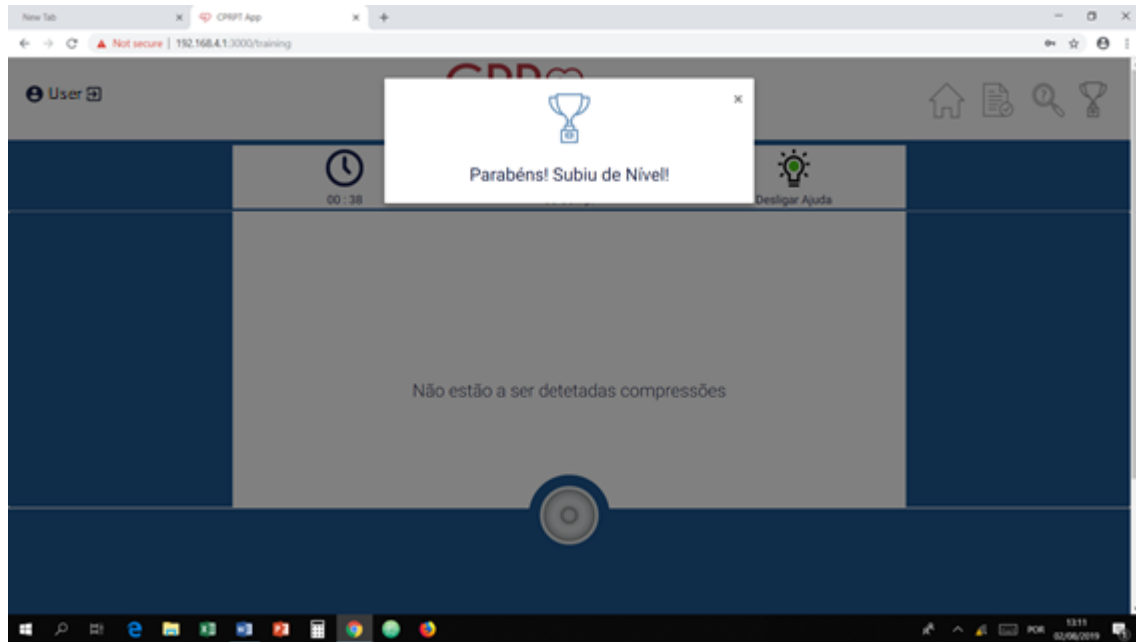


Figure 4.7 - Feedback Message

CPR
PERSONAL TRAINER

Quizz 18/02/2019

1. Select the wrong answer(s) for chest compressions:

- ☐ Keeps blood flow to the heart, brain and other vital organs
- ☐ They should be performed in order to compress the sternum 5 to 6 cm
- ☐ Must be stopped more than 10 seconds

2. Indicate which of the following procedures is not part of the Basic Adult Life Support:

- ☐ Search for normal breathing
- ☐ Perform 5 breaths before starting chest compressions
- ☐ Assess the victim's state of consciousness

SEND

Figure 4.8 - Daily Challenge Page

All these elements together will constitute our system and as Werbach and Hunter said: “each mechanic is tied to one or more dynamics and, each component is tied to one or more higher-levels elements” [44]. At the end, all these elements design the progression of the player.

5. **DON'T** forget the fun!

Regarding the fun, no specific elements have been included for this aspect, but it is expected that the above elements create the necessary entertain, for the player and between players.

6. **Deploy** the appropriate tools

At this point, all the elements are integrated in the CPR.PT system creating the gamified software and achieve the primary goal.

4.4. Conclusions

Gamification has become a method used both in industry and academia to promote a better learning experience. Also it is becoming a predominant training method in healthcare professionals' training [90]. In this work, following a widely adopted framework, it is proposed a gamification approach to be introduced in an existing CPR self-training system [35].

Several gamification aspects are discussed and proposed, alongside the major components of gaming to promote user engagement. It is expected that this approach will increase training frequency and knowledge acquisition.

This work resulted in the publication of an article on the *14^o Conferência Ibérica de Sistemas e Tecnologias de Informação*. The reference to the article is: Santos, I., Sa-Couto, C., & Vieira-Marques, P. (2019, June). Gamifying Autonomous CPR Training. In *2019 14th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1-3). IEEE.

5. Gamification Approach Evaluation

In this section, the evaluation study of the gamified system is presented focusing in the study design and the protocol followed to evaluate the system. Subsequently, the results obtained are presented and discussed. The objective of this evaluation was to assess if the gamified application promotes higher engagement by users and its impact on technique acquisition and the system's usability.

5.1. Target Population and Sampling

The study population was composed by two groups: healthcare professionals and medical students.

Healthcare professionals' population included doctors and nurses from intermediate care unit (UCIM) of the Centro Hospitalar Universitário São João. The CPR.PT was made available in situ so trainings were conducted at the unit during their shifts.

Students were recruited with the help of the students' association (AEFMUP) from Faculdade de Medicina da Universidade do Porto (FMUP) and included students from all the six years of the medical course.

The group of students accessed the CPR.PT at the CSB. Due to the opening hours of the CSB, students could only train from 10am to 6pm on weekdays.

5.2. Study Design and Protocol

The study was a randomized control trial and included pre and post-tests sessions where users answered a questionnaire and were submitted to a practical evaluation on their CPR technical skills. The pre-test was conducted in order to create a baseline to compare with the post-test. The participants logged into their own account, so that the test would be registered in the system log, for later analysis. The practical exercise consisted in two-minute CPR where they should perform consecutive compressions, without interruptions, or at a ratio of 30:2, pausing compressions for a few seconds after 30 compressions, to simulate ventilations. This was necessary because the system did not monitored ventilation. The performance instant feedback was disabled in order to get values that truly demonstrated the CPR technical skills of each user.

Scheduling healthcare professionals' pre-tests were performed according to their shifts and an effort was made to try to be as less intrusive as possible into their work. Age, gender and professional background were collected with the collaboration of the head nurse and chief-physician.

Students were contacted via e-mail and phone which then proceeded to select their preferred time for the pre-test through an online timetable. Students' sociodemographic data (gender, age, academic year, previous CPR training course) were collected at this time.

Based on the sociodemographic variables two homogenous groups of healthcare professionals and students were created: the group named NG (No Game) corresponding to those who were assigned to use the original version of CPR-PT, and GM (Game) to the users assigned to the gamified version of CPR-PT.

Throughout the first week it was delivered, to each professional and student, every necessary information, such as their login credentials, as well as informed consent for them to read and sign, if they choose to accept it (Appendix I, in Portuguese).

Out of the initial 32 registered healthcare professionals, thirty attended to the sessions and completed the practical pre-test together with a sociodemographic questionnaire (Appendix II, in Portuguese). Concerning the students, 27 registered through the online timetable, but only 17 completed the practical pre-test and questionnaire (Appendix III, in Portuguese).

After 3 weeks both groups switched the software version (game or non-game) they were using. Meaning that NG, having the original software switched to the gamified version, while GM had this process reversed and started to train with the non-gamified version.

After 3 more weeks, everyone performed another practical test as well as filling a final questionnaire regarding engagement and usability issues (Appendix IV, in Portuguese). Post-tests were scheduled using the same method as the pre-tests.

As each participant used their respective account, data from evaluations was kept in a data base and later extracted and analysed. Figure 5.1 represents the study protocol.

At pre-test, the sociodemographic questionnaire was conducted to gather important and relevant information about each of the users, while at post-test, a questionnaire was delivered to all users in order to gather participant opinions on System Usability Scale (SUS), Game components evaluation, User engagement scale (UES), study participation, General Features, CPR.pt system features and other questions regarding the system.

Users' engagement evaluation regarding the CPR-PT gamified version used a short version of user engagement scale (UES) questionnaire [91]. This is a questionnaire consisting of 12 questions rated in a 5-points Likert scale (from strongly disagree to strongly agree). Scoring the UES consists of: first step is to reverse code the following items: PU-S1, PU-S2, PU-S3; Following this step, scores for each of the four subscales can be calculated by adding the values' respective responses for the three items contained in each subscale and dividing it by three. An overall engagement score can be calculated by adding all items together and dividing by 12 [91].

The questionnaire regarding the System Usability Scale (SUS), proposed by John Brooke and previously validated by Camille Peres, was used. Users received a Portuguese version. This questionnaire consisted of 10 questions that had to be rated in a 5-points Likert scale (from strongly disagree to strongly agree), 5 out of the 10 questions are positive while the remaining are negative.

To calculate the SUS score, it is first summed the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7, and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. The sum of the scores is multiplied by 2.5 to obtain the overall value of SUS. SUS scores have a range of 0 to 100 [92]. Any score below 70 indicates a system with usability issues that are cause for concern [93].

Data from the pre and post-tests, and from the training sessions was stored in the system database, which was posteriorly exported to Excel for an initial data analysis and finally transferred to IBM SPSS Statistics® software for a thorough analysis.

Data management in Excel consisted of separating data relative to pre and post tests and to training. There was also an exclusion of data respective to occasions when the system faced technical problems and corrupted the gathered data.

Descriptive and inferential analyses were performed in the SPSS software. Within groups and independent groups analysis used non-parametric tests, due to the reduced sample size. A significance level of 5% was used.

The study was approved by the institution's ethics committee.

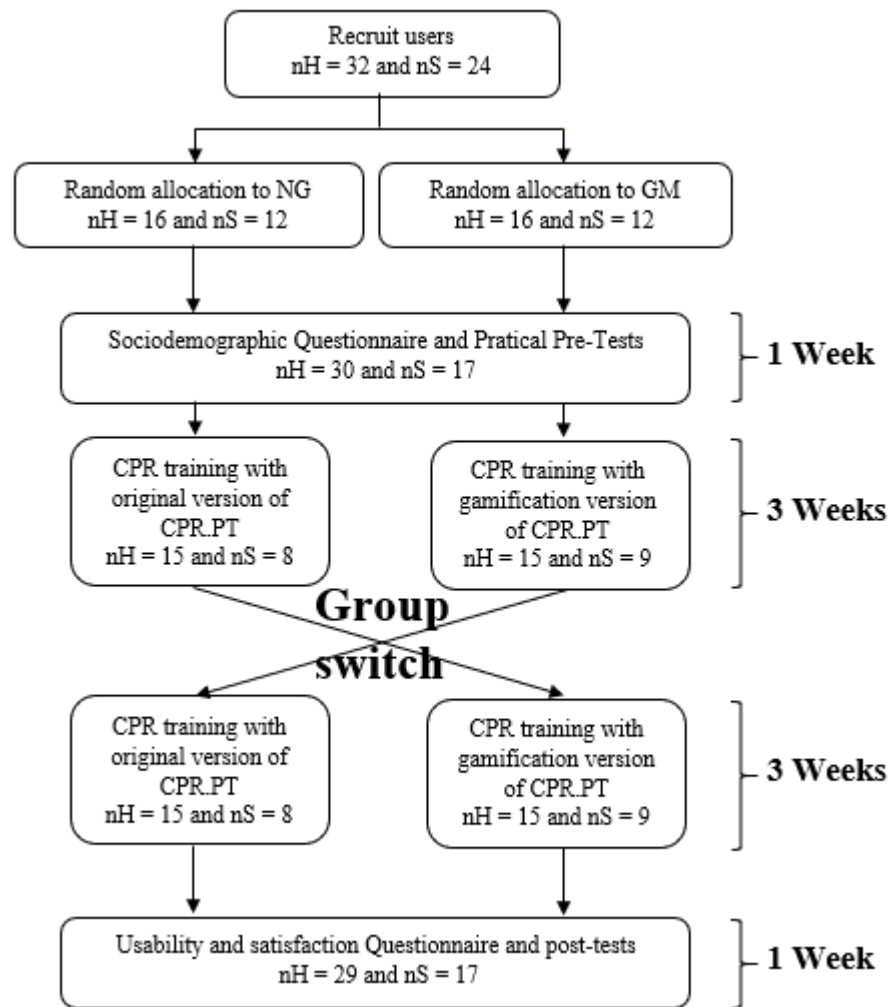


Figure 5.1 - Study Protocol (nH: number of healthcare professionals; nS: number of students)

5.3. Results

To facilitate discussion, the results are presented separately for each group included in the study: healthcare professionals and students.

5.3.1. Healthcare Professionals

The healthcare professional's database was reviewed and analysed to perform the tests afterwards.

5.3.1.1. Sample description

Healthcare professionals test population was distributed into two groups. The No Game group designated as NG (group started with the original CPR.PT) had 15 people, 6 of those being male and 9 females. Game group designated by GM (group started with the updated CPR.PT) had 14 individuals, where 8 were male and 6 females.

NG average age was 36 years old, while GM was 38.

Inter-group analyses were performed to confirm homogeneity between groups, in terms of age and gender. No statistical differences were observed confirming groups homogeneity (table 5.1).

Table 5.1 - Healthcare professionals demographic characterization – gender and age

	NG (n= 15)	M (n=14)	p-value**
Gender, n			
Male	6	8	0,466
Female	9	6	
Age, Mean \pm SD	36,93 \pm 6,86	38,43 \pm 5,97	0,539

**Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

The demographic questionnaire also assessed the CPR courses previously taken, and when the last course took place. These questions provided some insight on the sample basic knowledge. The results of these questions show that, 31% of the healthcare professionals took a course on CPR last year, 24% between 2017 and 2015, and also 24% between 2014 and 2010. Twenty-one percent of the healthcare professionals took the course before 2009.

Considering the type of course, some healthcare professionals took more than one. Ninety percent of the healthcare professionals had the Basic Life Support (BLS), 48% Advance Life Support (ALS) and 35% the Immediate Life Support (ILS).

When asked, about 93% of users think that skills they learnt is enough to perform a CPR manoeuvre in an efficient manner.

5.3.1.2. Overall Results

In total, the 29 healthcare professionals performed 74 trainings. In both groups, users performed more trainings before the group switch with NG performing 39 before and 6 after the switch, and GM performing 17 before and 12 after the switch. The median number of trainings between the two periods and groups are very similar, although the NG after the switch presents the biggest difference with a median of 0 and not exceeding the 5 trainings (figure 5.2).

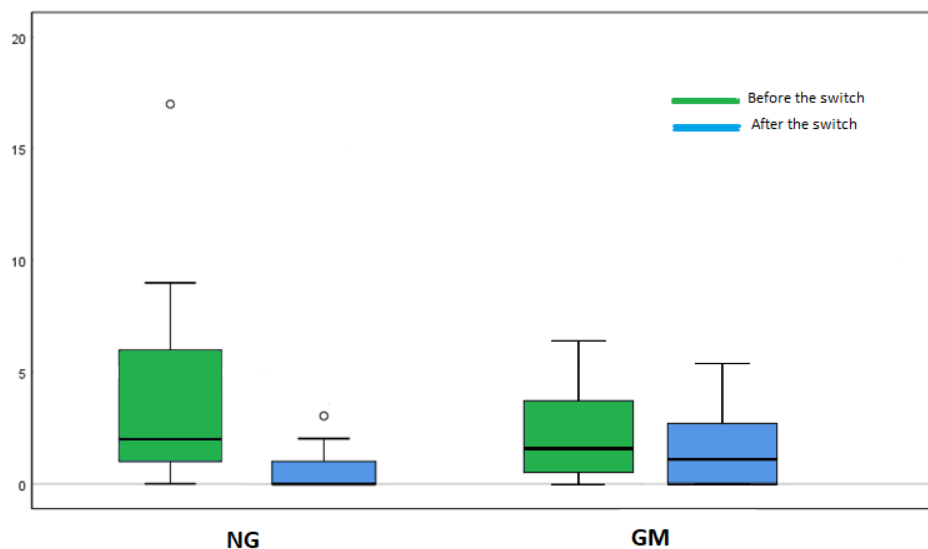


Figure 5.2 - Health professionals' number of trainings by group – before and after the switch

The healthcare professionals had access to the system 24h a day. According to figure 5.3 the only period that no one used the CPR.PT was during 3 am and 8 am. The most active period is around lunch time for NG and the evening for GM.

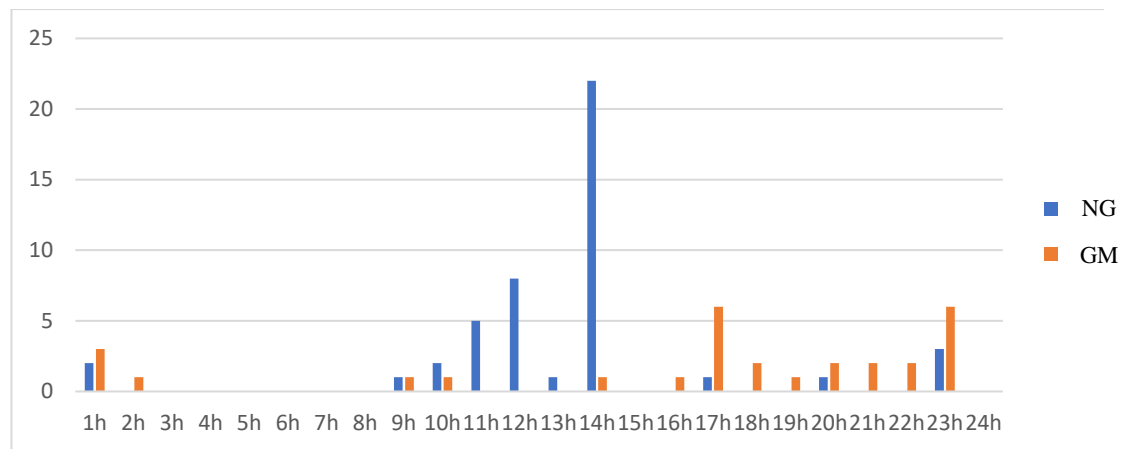


Figure 5.3 - Number of logins per hour from healthcare professionals

As already referred the system provides videos about the CPR technique in both systems. Group NG saw a total of 17 videos and GM committed more time to that task ending with a total of 27 visualizations. The video with more views was the one that explains how the compressions' depth is done correctly.

5.3.1.3. Gamification Elements

This section presents some of the results related to the gamification elements inserted in the original CPR.PT.

Both groups, NG and GM had a 3-week period with the gamified CPR.PT. Figure 5.4 shows in which level (y axis) each user (x axis) reached during the study. The maximum level reached by two healthcare professionals was 5 and they were both from GM, corresponding to user 33 with 2420 points and user 34 with 1660 points. In NG the maximum level was 2.

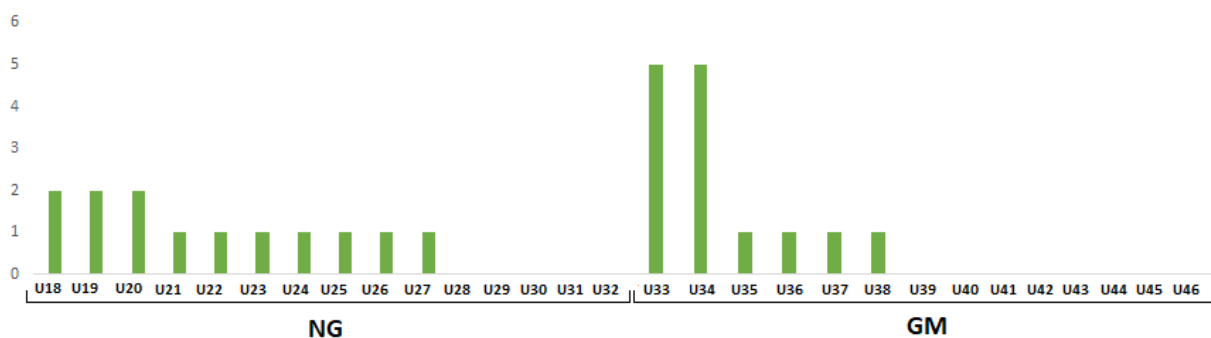


Figure 5.4 - Levels achieved by healthcare professionals

Regarding the medals acquired during trainings, there is some difference between NG and GM. The healthcare professionals from NG only conquer 5 medals and GM got a little more, in a total of 12 medals. Both groups conquered a total of 17 medals out of 32 possible. All of these medals concern the use of the system. User U35 was the healthcare professional with more medals conquered.

Concerning the training with or without assistance, in NG 96% of the users trained with help, and in GM with 76% choose training with assistance.

5.3.1.4. *Pre and Post-Test Score: Pratical Total Score (Overall)*

Both pre and post-test were performed under the same conditions. According to the collected data, although on average there is an increase in performance only GM had statistical significant differences (p-value < 0.05) between the total scores obtained in the tests. There were no significant differences between groups, both in the pre- and post-test. Table 5.2 presents the collected data in more detailed with the mean and standard deviation (SD) of the total score from pre and post-test of each of the groups.

Table 5.2 - Healthcare professionals comparison between the pre and post-test mean scores and between groups (NG e GM). Scores presented as Mean \pm SD

Overall (%)	Pre-test	Post-test	P-value **
NG (N=15)	52 \pm 32	71 \pm 22	0,112
GM (N= 14)	55 \pm 25	73 \pm 23	0,0085
P-value*	1,000	0,598	

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

** Pre-post test difference, Wilcoxon signed rank test, 1-tailed ($\alpha=0.05$)

5.3.1.5. *Pre and Post-Test Score: Compressions Related Parameters*

In table 5.3 it is represented the average and standard deviation (SD) of each assessed parameter related with compressions in the pre and post-test. Regarding these parameters, it is possible to verify that there are improvements in practical skills from one test to another, however, there are only a few parameters with a statistical significant difference: 1) The depth parameter has a significant difference between the two tests from the NG; 2) Both, NG and GM, have a significant difference in the frequency parameter between the two tests. In the tests between subgroups, there are no significant differences in any parameter.

Table 5.3 - Healthcare professionals comparison between pre and post-test compressions related measurements mean scores. Scores presented as Mean \pm SD

	Pre-test	Post-test	P-value**
Hands (%)			
NG (N=15)	79 \pm 40	99 \pm 4	0,063
GM (N= 14)	92 \pm 27	100 \pm 0	0,125
P-value*	0,646	1,000	
Depth (cm)			
NG (N=15)	4,8 \pm 0,8	5,4 \pm 0,6	0,006
GM (N= 14)	4,7 \pm 0,8	5,3 \pm 0,7	0,094
P-value*	0,974	0,510	
Recoil (%)			
NG (N=15)	73 \pm 37	66 \pm 4	0,304
GM (N= 14)	72 \pm 36	88 \pm 18	0,112
P-value*	0,644	0,638	
Frequency (cpm)			
NG (N=15)	130 \pm 22	112 \pm 20	0,022
GM (N= 14)	136 \pm 19	100 \pm 22	0,000
P-value*	0,336	0,304	

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

** Pre-post test difference, Wilcoxon signed rank test, 1-tailed ($\alpha=0.05$)

5.3.1.6. Training Scores

In addition to the pre and post-test evaluations, training scores were evaluated. Table 5.4 presents the mean values for the training scores obtained in the 6 weeks of the study. No statistical differences were observed between the two groups. Of notice is that the values of depth and frequency are between the parameters established by the guidelines.

During the study period 17 (59%) people used the system for training.

Table 5.4 - Healthcare professionals comparison between NG e GM about training compressions related measurements mean scores. Scores presented as Mean \pm SD

Trainings (Mean \pm SD)	
Overall (%)	
NG (N=9)	78 \pm 9
GM (N= 8)	75 \pm 19
P-value*	0,795
Hands (%)	
NG (N=9)	100 \pm 0
GM (N= 8)	97 \pm 8
P-value*	0,471
Depth (cm)	
NG (N=9)	5,00 \pm 0,26
GM (N= 8)	5,00 \pm 0,58
P-value*	0,872
Recoil (%)	
NG (N=9)	93 \pm 7
GM (N= 8)	93 \pm 10
P-value*	0,752
Frequency (cpm)	
NG (N=9)	109 \pm 16
GM (N= 8)	106 \pm 17
P-value*	0,655

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

5.3.1.7. *Final Questionnaire from Post-Test*

Engagement Questionnaire

The user engagement was assessed using the UES questionnaire. According to the UES scale, the global score of the new version of the CPR.PT was approximately 4 out of 5 for both groups.

It was also asked in the questionnaire which of the modalities they liked the most. Seventy nine percent of healthcare professionals indicated to prefer the gamified version of the CPR.PT system (table 5.5).

Table 5.5 - Healthcare professionals' opinion about CPR.PT versions

	n (%)
Indicate which of the modalities you preferred.	
Original CPR.PT	5 (17 %)
Gamified CPR.pt	23 (79 %)

Regarding how often users have used the system, two questions have been asked: *"Has the use of the system been conditioned by any external factor?"*. This was a Yes or No question and if the user answered "yes" he should elaborate to *which external factors have been the conditioners*. Sixty nine percent of the healthcare professionals answered yes. Table 5.6 presents the answers justifying the lack of trainings by the healthcare professionals. Seven percent indicated other reasons such as having backache and being at work.

Table 5.6 - Healthcare professionals' opinion regarding external factor that were impediments for training

Answer	n (%)
Difficulty in accessing the room	5 (17 %)
System unavailability	2 (7 %)
Unavailability of schedules	17 (58 %)
Difficulty in using the system	1 (3 %)
Other	2 (7%)

In the same questionnaire, it was given the option to comment on the negative and positive aspects of CPR.PT. Several users indicated more than one (positives and negatives) aspect, while 3,4% did not indicate any positive aspects, and 41% did not indicate any negative aspects. Relevant answers were grouped in the aspects presented in table 5.7.

Table 5.7 - Healthcare professionals' opinion regarding positive and negative aspects

	n (%)
Positive Aspects	
Practical and easy application	7 (24%)
Technical improvement	13 (44%)
Evaluation of compressions	3 (10%)
Intuitive	3 (10%)
Negative Aspects	
Computer error	2 (7%)
Manikinn Accessibility	5 (17%)
Timetables	4 (14%)
Lack of ventilation component	2 (7%)

An additional asked question in the questionnaire was if the users would recommend this application to people who could benefit from it, and if users would pay to use this app. All healthcare professionals recommend this application but only 38% would pay for it.

Usability Questionnaire

Regarding the usability questionnaire, the individual score from each healthcare professional was calculated and then the median was determined. This corresponds to the global SUS score of the CPR. PT. Healthcare professionals from the NG group rated the system with an overall score of approximately 83 out of 100 and the GM group with approximately 88 out of 100.

The functionality of the system was assessed through several questions. Ninety-three percent of the healthcare professionals considered the system easy to use. Regarding the terminology used and switching between screens, 97% thought the terminology was clear and the change was logical and uninterrupted. Eighty-six percent considered that the application features (functions) and components (buttons and menus) work perfectly and timely or minor/insignificant errors. Ninety-six percent considered the menus and buttons easy to find and understand or found in an immediately, intuitively and simply manner. Table 5.8 and 5.9 present these results in detail.

Final questions concerning the functioning of the system, indicated that 97% of healthcare professionals felt confident using the app and would like to use this app more often. Only one user considered that he would need the support of a skilled person to be able to use this application.

Table 5.8 - Healthcare professionals' opinion regarding system usability

	Yes	It is not immediate	No
The application is quick to learn and easy to use?	27 (93 %)	1 (3%)	1 (3%)
Is the language used in the instructions, menus, and icons clear?	28 (97 %)	1 (3%)	0 (0 %)
Is switching between screens logical/correct/appropriate and uninterrupted (all required connections are present)?	28 (97 %)	1 (3%))	0 (0 %)
Are interactions consistent and intuitive across multiple screens and components?	28 (97 %)	1 (3%)	0 (0 %)

Table 5.9 - Healthcare professionals' opinion regarding system buttons and menus

	Yes n (%)
How accurately/quickly do the application features (functions) and components (buttons and menus) work?	
The answer is perfect and timely. No fault/error encountered	13 (45 %)
It is functional with minor/insignificant problems	12 (41 %)
The app crashes, has flaws/errors and the answer is nonexistent or insufficient	4 (14%)
Some functions work, but they contain major technical problems	0 (0 %)
In general the application works, but has some technical problems	0 (0 %)
Are menus and buttons easy to locate and understand?	
The menus and buttons are easy to find and understand	14 (48 %)
Localization and understanding is done in an immediate, intuitive and simple way	14 (48 %)
No, the menus and buttons are confusing and complicated	1 (3 %)
You can only find and understand after a lot of time/effort	0 (0 %)
Located and understood after some time/effort	0 (0 %)

5.3.2. Students

5.3.2.1. Sample Description

Similarly to the healthcare professionals, students were distributed into two groups, the NG group (started with the original application and change after to the updated one) included 8 individuals and GM (started with the updated application and then changed to the original one) included 9 individuals. Both groups had 3 male participants while NG had 5 female ones leaving the remaining 6 to GM. Average age in NG was 22 years old and 20 in GM. Both groups were compared for age and gender and no statistical differences ($p\text{-value} > 0,05$) were found, confirming the homogeneity of the groups (table 5.10).

Table 5.10 - Students demographic characterization – gender and age

	NG (n=8)	GM (n=9)	p-value**
Gender, n			
Male	3	3	1,000
Female	5	6	
Age, mean\pmSD	22,63 \pm 5,68	20,89 \pm 1.76	0,838

**Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

The analysis of the questions regarding CPR technique and the digital gaming habits of the participants showed that 100% of students know what the CPR technique consists and have previously attended to courses with practical and theoretical components. Fifty-three percent of the students attended a course within one year, while the remaining attended within two or more years. Concerning the type of course, all attended BLS. One student attended in addition to BLS, ALS and ILS courses.

Knowledge wise, 77% feels that they have enough insight to reproduce the technique efficiently.

5.3.2.2. Overall Results

Students performed a total of 208 trainings throughout the 6 weeks of study.

Regarding the number of trainings, NG group perform 24 trainings before the switch, while GM group perform 63. After the switch, NG perform a total of 102 trainings and de GM group perform 19. The median of trainings was very similar between the two groups and between the two periods of time, the biggest difference is the outlier in NG after the switch (figure 5.5).

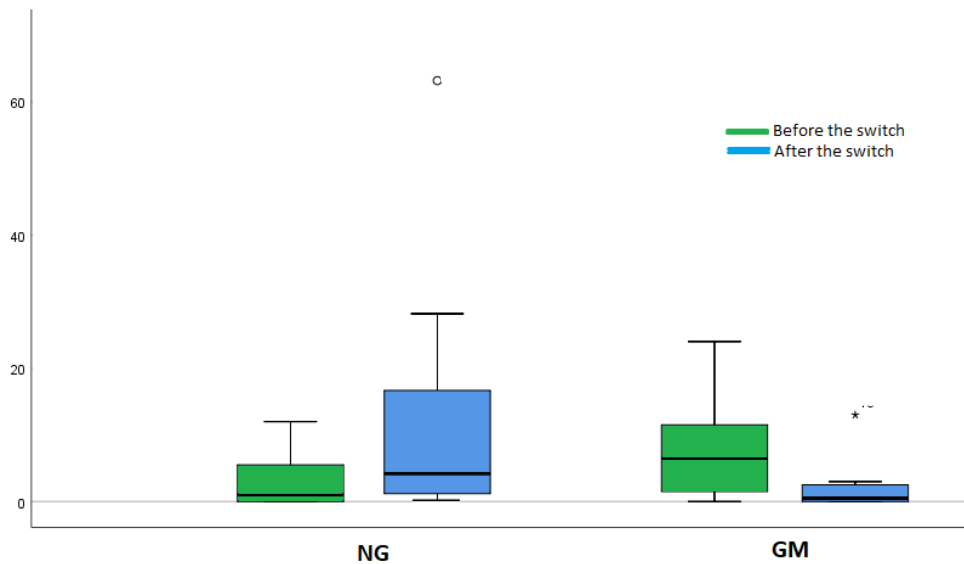


Figure 5.5 - Students' number of trainings by group – before and after the switch

The students' group only had 8 hours during the day to perform trainings. Figure 5.6 shows the number of logins per hour. It can be observed that students' moments of training are distributed throughout the day although with a slightly higher frequency in the morning.

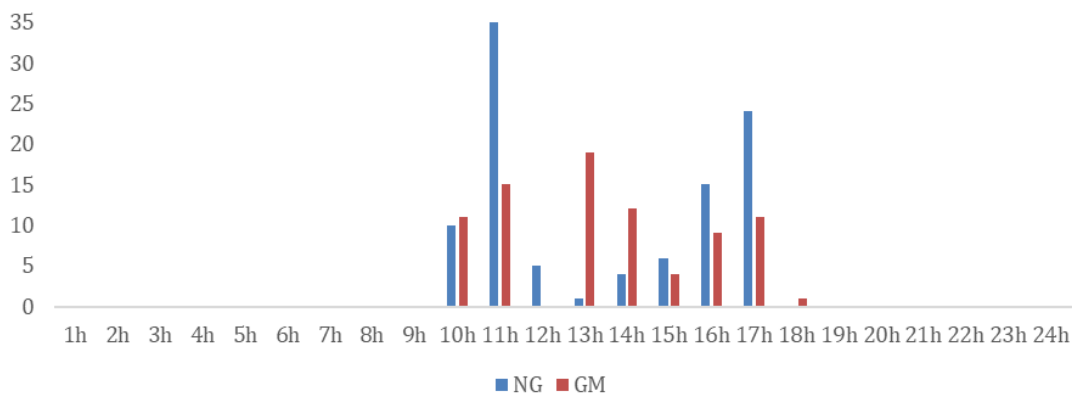


Figure 5.6 - Number of logins per hour from students

Both CPR.PT versions provided videos that users could view to clarify and learn about technique components. After each training, in case of a parameter not being performed correctly, users were given the option to view a short video corresponding to the aspect they need to improve. The group NG saw a total of 28 videos, while the GM group saw 73. Once again, the video for the compression's depth was the most popular one.

5.3.2.3. Gamification Elements

Both groups, NG and GM, had three weeks with the gamified version of the CPR.PT system. Regarding the points, user U8 from NG and users U15, U16 and U17 from GM did not get enough points to reach at least level one. The maximum level reached was 13 with 8695 points in NG group by user U1 followed by level 9 with 5050 points in the GM by user U9. Figure 5.7 presents the levels reached by each user, per group.

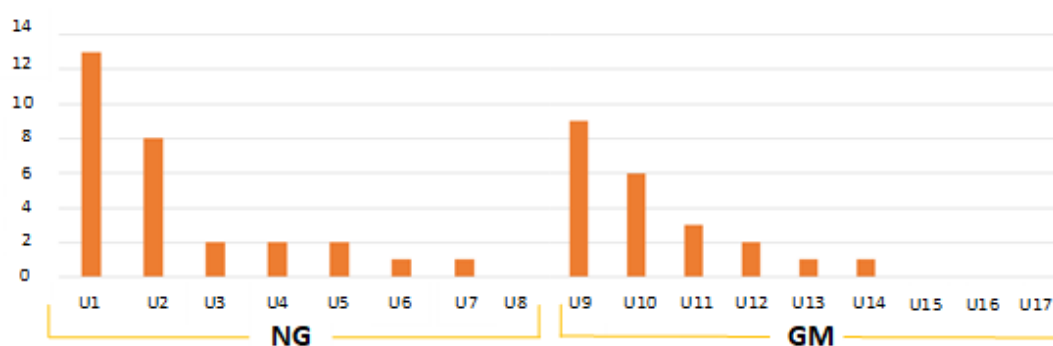


Figure 5.7 - Levels achieved by students

Regarding the medals acquired, the difference between NG and GM is negligible. The students from NG conquered 21 while GM obtained 24. There was a total of 32 medals that each user could obtain and user U1 obtained the higher number of medals, with a mark of 12. Contrary to what happened to the professionals, 29 of the medals obtained concerned the use of the system (UP) and 16 the training itself (XP).

Prior to starting a training, users had the option to increase the difficulty by removing tips given by the system. This way any feedback given in real-time during the training session was hidden and feedback was only provided in the end of the session. In NG group, 65% preferred to use the extra help while in GM group, 73% of the trainings were made without help.

5.3.2.4. Pre and Post-Test Score: Practical Total Score (Overall)

Both pre and post-test were performed under the same conditions.

Table 5.11 represents the mean and standard deviation (SD) of the total score from pre and post-test of each group. According to this data, although in both groups there are an increase in score, only in GM was observed an increase in the score with statistical significance between tests. On the other hand, no significant differences were observed between groups, for each of the phases of assessment.

Table 5.11 - Students comparison between the pre and post-test mean scores and between groups (NG e GM). Scores presented as Mean \pm SD

Overall	Pre-test	Post-test	P-value **
NG (N=8)	60 \pm 21	68 \pm 18	0,277
GM (N=9)	42 \pm 28	66 \pm 18	0,041
P-value*	0,114	0,793	

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

** Pre-post test difference, Wilcoxon signed rank test, 1-tailed ($\alpha=0.05$)

5.3.2.5. *Pre and Post-Teste Score: Compressions Related Parameters*

In addition to the overall score, scores of each individual component (hand position, depth, recoil, frequency) from the tests were analysed and compared. Table 5.12 represents the comparisons between test phases as well as between NG and GM for each of the above components. No statistical significant differences were found either in the comparison between pre and post-test, or between groups.

Table 5.12 - Students comparison between pre and post-test compressions related measurements mean scores, presented as Mean \pm SD

	Pre-test	Post-test	P-value**
Hands (%)			
NG (N=8)	87 \pm 28	100 \pm 1	0,188
GM (N=9)	89 \pm 33	100 \pm 0	0,500
P-value*	0,435	0,471	
Depth (cm)			
NG (N=8)	5,9 \pm 0,4	5,5 \pm 0,5	0,070
GM (N=9)	5,8 \pm 0,5	5,3 \pm 0,7	0,082
P-value*	0,723	0,865	
Recoil (%)			
NG (N=8)	69 \pm 32	57 \pm 40	0,219
GM (N=9)	45 \pm 42	60 \pm 35	0,191
P-value*	0,207	0,658	
Frequency			
NG (N=8)	103 \pm 12	106 \pm 9	0,254
GM (N=9)	94 \pm 23	106 \pm 13	0,172
P-value*	0,622	0,724	

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

** Pre-post test difference, Wilcoxon signed rank test, 1-tailed ($\alpha=0.05$)

5.3.2.6. Training Scores

The results of the training period (between pre and post-test) were also analysed. Data presented in Table 5.13 shows that only in recoil and overall score a statistically significant increase was observed.

Table 5.13 - Students comparison between NG e GM about training compressions related measurements mean score, presented as Mean \pm SD

	Trainings (mean \pm SD)
Overall (%)	
NG (N=7)	67 \pm 11
GM (N=8)	83 \pm 8
P-value*	0,003
Hands (%)	
NG (N=7)	99 \pm 0,9
GM (N=8)	100 \pm 1,
P-value*	0,354
Depth (cm)	
NG (N=7)	5,8 \pm 0,3
GM (N=8)	5,8 \pm 0,3
P-value*	0,973
Recoil (%)	
NG (N=7)	73 \pm 11
GM (N=8)	74 \pm 25
P-value*	0,593
Frequency(cpm)	
NG (N=7)	102 \pm 6
GM (N=8)	103 \pm 5,6
P-value*	0,514

* Difference between groups, Mann Whitney U-test, 2-tailed ($\alpha=0.05$)

5.3.2.7. Final Questionnaire from Post-Test

Engagement Questionnaire

The user engagement was assessed using the UES questionnaire. The total score was calculated based on the calculation of the individual score from each student. The median value of these scores represent the UES global score, which was approximately 4 out of 5 in both groups.

It was also asked to the students, *which of the modalities they liked the most*. Seventy seven percent of students preferred the gamified application of the CPR.PT system (table 5.14).

Table 5.14 - Students' opinion about CPR.PT versions

	n (%)
Indicate which of the modalities was your preferred.	
Original CPR.PT	4 (24 %)
Gamified CPR.pt	13 (77%)

Forty nine percent of the students answered that some external factors conditioned their use of the system. The schedule unavailability was pointed by all students as the main external factor. There were three students that chose the option “other”, but their answers were considered as schedule unavailability. Out of the 49, 2 indicated that they did not participated more often in the study because it was conducted during the examinations period, and the remaining responded that it was due to the lack of time.

Two open questions were asked in order to know the positive and negative aspects of the developed system (table 5.15). Nearly all students replied to the positive aspects (94%), although only 47% indicated negative aspects. about the system. Some students indicated multiple aspects. Students consider positive aspects, the possibility of self-assessment of the technique of BLS, as well as the ease of use and access. Regarding the negative aspects, they mainly considered access to the progress unintuitive.

Table 5.15 - Students' opinion regarding system positive and negative aspects

	n (%)
Positive Aspects	
BLS self assessment	4 (24%)
Achievement System/Points	2 (12%)
Ease of use and access	4 (24%)
Real-time Feedback	3 (18%)
Results with specific values	2 (12%)
Useful	2 (12%)
Intuitive	3 (18%)
Negative Aspects	
Not having the entire BLS algorithm	1 (6%)
Computer error	1 (6%)
Incorrect depth measurement	1 (6%)
Do not have the ventilation component	1 (6%)
The menu, access to progress is not intuitive	2 (12%)
Videos should have sound	1 (6%)
Little explanatory videos	1 (6%)
Lack of ranking	1 (6%)

Similarly to the healthcare professionals, all students recommend this application but only 41% would pay for it.

Usability Questionnaire

Regarding the usability questionnaire, the individual score from each healthcare professional was calculated and then the median was determined. This corresponds to the global SUS score of the CPR. PT. Students from NG rated the system with an overall score of 90 out of 100 and GM with 93 out of 100.

The functionality of the system was assessed through several questions, which received positive feedback ranging from 88% to 100% (table 5.16).

Two questions were asked regarding the system buttons and menus. One was, *how accurately / quickly do application features (functions) and components (buttons and menus) work* and second was, *are menus and buttons easy to find and understand*. All students answered that features and components are perfect and timely or present insignificant errors, and consider that the menus and buttons are easy to find and understand or found in an immediately,

Table 5.17 presents these data in more detail.

Table 5.16 - Students' opinion regarding system usability

	Yes	It's not immediate	No
The application is quick to learn and easy to use?	17 (100 %)	0 (0 %)	0 (0 %)
Is the language used in the instructions, menus, and icons clear?	16 (94 %)	1 (6 %)	0 (0 %)
Is switching between screens logical/correct/appropriate and uninterrupted (all required connections are present)?	16 (94 %)	1 (6 %)	0 (0 %)
Are interactions consistent and intuitive across multiple screens and components?	15 (88 %)	2 (12 %)	0 (0 %)

Table 5.17 - Students' opinion regarding system buttons and menus

	Yes n (%)
How accurately/quickly do the application features (functions) and components (buttons and menus) work?	
The answer is perfect and timely. No fault/error encountered	11 (65 %)
It is functional with minor/insignificant problems	6 (35 %)
App crashes, has errors, and the response is missing or is insufficient	0 (0 %)
Some functions work, but they contain major technical problems	0 (0 %)
In general the application works, but has some technical problems	0 (0 %)
Are menus and buttons easy to locate and understand?	
The menus and buttons are easy to find and understand	9 (53 %)
Localization and understanding is done in an immediate, intuitive and simple way	8 (47 %)
No, the menus and buttons are confusing and complicated	0 (0 %)
You can only find and understand after a lot of time/effort	0 (0 %)
Located and understood after some time/effort	0 (0 %)

5.4. Discussion and Conclusions

The evaluation study demonstrated that the CPR.PT system improves the skills acquisition or refreshment. Both samples (healthcare professionals and students) presented higher scores in the post-test compared to the pre-test. Of notice, is that in both samples, the increase in score was only statistical significant in the Gaming Group (GM). For specific compressions parameters, the differences between pre and post-test for the professionals is less visible than for the students. Of notice, is that for both samples and both groups, the post-test results for hands position, depth and frequency are all within the guidelines recommendations.

Also, to be noted is that the standard deviations in the pre-test is considerably high, while in the post-test it decreases, suggesting that the participants converged to a same level of competence.

Gamification elements included in the CPR.PT were evaluated in both groups. In general, from the questionnaires answered it is possible to identify that both groups appreciated this modality. There were however some restrictions regarding its use particularly from health professionals. This group identified some obstacles to a more intensive use, such as unavailability of schedules, difficulties in accessing the room, system unavailability, among others.

In fact, from the activities logs it was possible to verify that there are relevant differences between the groups regarding the levels reached, which might be explained by the obstacles present before.

Regarding the points system used, it was possible to verify that it may not be possible to use the same system for all types of users. In this case, the healthcare professionals reported having little time during the day to train (despite the longer period available for training), compared to the students, who were able to train more often.

This is observed in the levels reached by both samples, which are completely different: while the maximum level reached by professionals was 5, in students it was 13. When the point system was developed, users were expected to reach levels between 14 and 20.

Users like healthcare professionals, who would use the system less often, would perhaps need a more “gratifying” system, in order to be able to pass levels faster, thus reaching higher levels, promoting greater interest in a shorter time period. In the case of students, the proposed point system seems to be adequate, as they reached levels similar to those expected from the design phase.

Concerning the use of help during trainings (real-time feedback), the healthcare professionals, both NG and GM groups, mostly trained with this option on. At the post-test it was noted that some of the healthcare professionals no longer remembered that this option existed suggesting the need to make its existence more evident and reinforcing the extra points attribution. Given this recognized difficulty, it would be important to find a way for the on / off help switch to capture better the user's attention. For students, the NG group prefer to use the extra help, contrary to GM group.

The healthcare professionals, in addition to the information collected in the questionnaires, there was also informal verbal communication indicating that GM users were disappointed when they switched to the NG group. They expressed to feel more fun, and even requested to go back to the previous system, as this would allow them to compete with colleagues and compare the level and ranking at which they were positioned. With students the situation is different, as this kind of feedback was not provided due to the fact that the evaluation team was not so close to the participants.

However, by the questionnaires it is also possible to conclude that they also preferred gamified CPR.PT.

Finally, the use of the system was not as frequent as initially expected, and the causes behind this limitation were the high-demanding shifts in the hospital unit for healthcare professionals and the examination period for students. However, there is still a big difference between the number of trainings performed by both samples. Given the pre-test and post-test score overall data, it can be seen that practitioners had better results, leading to the belief that they would not need to train so often.

6. Overall Conclusions and Discussion

With the literature review that was performed, it was possible to conclude that serious games usage is increasing in the field of medical education, which is in line with other literature reviews by Graafland et al[94], Wit zuurendonk et al[95] and Ryan Wang [96]. All of these reviews also agree that serious games still need additional evaluation. This is also present in the particular setting of CPR training and following our gathered evidence there is still room for improvement particularly in the completeness of the training elements and that for these to be available the use of external hardware in addition to game software is necessary to overcome the limitations encountered in serious games for CPR technique training.

The review supported the approach taken previously in the CPRPT development regarding the adoption of a hybrid system that uses external hardware (manikin) allowing, through the addition of a gamified approach, a system that allows a more complete training approach along with a new approach to increase the motivation to train. To create the gamified software it was used the 6D framework, which allowed the development of this addon in a structured and validated way.

A study was conducted, in order to evaluate the new version of CPR.PT with healthcare professionals and students. With this study it was possible to observe that it may be important to adopt different point systems for each type of people who will use it, that is, in the case of healthcare professionals they trained considerably less than the students, but obtained higher scores in training. This may result from the higher experience of healthcare professionals in performing the manoeuvre. However, although they generally had better individual training scores, they did not achieve a much higher level when compared to students, as they did not play enough times to be able to do so. This reveals the need to better adjust to the number of workouts they need. Considering the results, the points system is more suited for students. This could also be due to not using the feature of training without help, which allowed to receive twice the points than in normal training. Despite the lack of significant differences between tests, post-test results were higher to those obtained in the pre-test.

Through questionnaires provided and conversations with some of the users, it can be said that users enjoyed using the gamified system more.

In conclusion, gamification seems to be a helpful approach to promote clinical skills training. However, although it is on a good track, it needs to be further worked and evaluated so that can be used as an autonomous learning method. This application solves issues such as the lack of manikins and instructors in courses and the need to retrain the technique as these skills rapidly deteriorate [97].

Future Work

In case of the system, new elements of CPR.PT, it would be interesting to add a daily quiz to the system, as referred in section 4. It is predicted that this will be one more element to help with users' motivation, leading to more trainings and helping them review some theoretical aspects of CPR technique which is also necessary to consider.

Regarding the game element, points, it is necessary to revise them, creating a more dynamic table, for example instead of always increasing, there would be periods when it would be easier to advance the level due to a stability in the points needed to advance. This would have a beneficial impact on users as it made them feel more active.

Also the help button should be changed. It is possible that mainly healthcare professionals have not used this option so much, because the button goes unnoticed. Perhaps when the user enters the practice page, it would be more useful to appear a pop up where the player would choose whether or not to want extra help.

Regarding the study, it would be important to conduct a new study with a larger sample and a considerably longer study period. Thus, it would be possible to observe the behaviour of healthcare professionals, confirming if really when they feel the need to train the technique of CPR, if they go to the CPR.PT.

Finally, it would also be interesting to perform a third test. When changing the systems, if a practical test is performed, similar to the pre and post-test, it is possible to verify which system promotes a greater presence and, consequently, a greater learning of CPR skills.

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Appendices

Appendix I: Informed Consent

CONSENTIMENTO INFORMADO, ESCLARECIDO E LIVRE	
	PARA INVESTIGAÇÃO CLÍNICA <small>Considerando a "Declaração de Helsinki" da Associação Médica Mundial (Helsinki 1964; Tóquio 1975; Vienna 1983; Hong Kong 1989; Somerset West 1996; Edimburgo 2000; Seoul 2008; Fortaleza 2013)</small>
SÃO JOÃO	
Designação do Estudo (em português)	
Avaliação da adesão a um novo sistema de treino autónomo em reanimação cardiopulmonar	
Confirmando que expliquei ao participante/representante legal, de forma adequada e compreensível, a investigação referida, os benefícios, os riscos e possíveis complicações associadas à sua realização.	
Informação escrita em anexo: <input type="checkbox"/> Não <input type="checkbox"/> Sim (Nº de páginas _____)	
O Investigador responsável	
Nome: _____	_____
Assinatura	Assinatura
Identificação do participante	
Nome: _____	
BI/ CC nº: _____	
Participante/ Representante legal	
<ul style="list-style-type: none">- Compreendi a explicação que me foi facultada acerca do estudo que se tenciona realizar: os objetivos, os métodos, os benefícios previstos, os riscos potenciais e o eventual desconforto.- Solicitei todas as informações de que necessitei, sabendo que o esclarecimento é fundamental para uma boa decisão.- Foi informado da possibilidade de livremente recusar ou abandonar a todo o tempo a participação no estudo, sem que isso possa ter como efeito qualquer prejuízo na assistência que é prestada.- Declaro não ter sido incluído em nenhum outro projeto de investigação nos últimos três meses.	
Concordo com a participação neste estudo, de acordo com os esclarecimentos que me foram prestados, como consta neste documento, do qual me foi entregue uma cópia.	
Data: ____/____/____	_____
Assinatura	Assinatura
Nome (Pai/Mãe/Representante legal): _____	
BI/ CC nº: _____	Grau de parentesco: _____
Data: ____/____/____	_____
Assinatura	Assinatura

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO EM INVESTIGAÇÃO

de acordo com a Declaração de Helsinquia¹ e a Convenção de Oviedo²

Por favor, leia com atenção a seguinte informação. Se achar que algo está incorrecto ou que não está claro, não hesite em solicitar mais informações. Se concorda com a proposta que lhe foi feita, solicita-se a assinatura do mesmo, em duplicado.

Título do estudo: Avaliação da adesão a um novo sistema de treino autónomo em reanimação cardiopulmonar.

Enquadramento: O estudo decorrerá na UCIM do CHS. Este estudo é realizado no âmbito de um projeto de investigação do Centro de Simulação Biomédica da Faculdade de Medicina da Universidade do Porto, tendo como investigadores principais a Doutora Carla Sá Couto (csacouto@med.up.pt) e o Doutor Pedro Marques (pmarques@med.up.pt). Este estudo foi aprovado pela Comissão de Ética para a Saúde (CES) do Centro Hospitalar de S. João – EPE.

Explicação do estudo: O estudo pretende avaliar a adesão a um novo sistema de treino em SBV. O sistema estará disponível numa sala da UCIM, durante o período da avaliação (aprox 1 mês). Os participantes receberão informação sobre como usar o sistema. Os dados demográficos serão recolhidos antes do estudo através de questionário. Os indicadores de adesão (número de participantes, tempo de uso, número de vezes) e de aquisição/manutenção de competências (score dos treinos) serão extraídos do sistema. Antes e após o período de avaliação, os participantes serão avaliados sobre os seus conhecimentos teóricos e práticos, através de um questionário (teórico) e do sistema (prático). Esta avaliação só será usada no âmbito deste estudo e de forma anonimizada. O abandono a meio do estudo não terá quaisquer implicações para o participante. A amostra de participantes será de conveniência, sendo convidados a participar todos os elementos da UCIM (médicos e enfermeiros).

Condições e financiamento: A participação no estudo é de caráter voluntário. Não há contrapartidas (financeiras ou outras) associadas ao estudo.

Confidencialidade e anonimato: Os coordenadores do estudo garantem a confidencialidade e uso exclusivo dos dados recolhidos para o presente estudo; Todos os participantes serão mantidos em anonimato e a sua identificação nunca será tomada pública;

ⁱ http://portal.arpente.mil-seade.sp.gov.br/portal/base/portal/ARTE/Morte/Comunicacao/Idade%20Mortificacao/Fichas/Denuncia_Helicoptero_2008.pdf

⁴ <https://doi.org/10.1016/j.jmbs.2019.105444>

Appendix II: Sociodemographic questionnaire for healthcare professionals

Idade: _____ G nero: F M M dico(a) ☐ Enfermeiro(a) ☐

Login: _____

1. Sabe em que consiste o Suporte B sico de Vida/Reanima  o cardiopulmonar? S ☐ N ☐

2. J  participou em forma  o de suporte B sico de Vida/Reanima  o cardiopulmonar? S ☐ N ☐

Se **s m**, indique as componentes inclu das na forma  o:

Te rica ☐ Te rica e pr tica com ☐
uso de manequim

3. Indique o ano em que realizou a  ltima forma  o que inclu a Suporte B sico de Vida/Reanima  o Cardiopulmonar: Ano: _____

4. Indique quais as forma  es que realizou relacionadas com reanima  o cardiopulmonar:

- a. Suporte B sico de Vida (SBV) ☐
- b. Suporte Imediato de Vida (SIV) ☐
- c. Suporte Avan ado de Vida (SAV) ☐
- d. Outra: _____

5. Considera que nessas forma  es adquiriu conhecimentos suficientes para a realiza  o de manobra de reanima  o cardiopulmonar de forma eficiente? S ☐ N ☐

6. Costuma jogar jogos l dicos no computador/tablet/smartphone? S ☐ N ☐

7. Com que frequ ncia joga?

- a. Menos de 1 vez por m s ☐
- b. Menos de 1 vez por semana ☐
- c. 2-3 vezes por semana ☐
- d. Todos os dias ☐

8. Quantas horas, em m dia joga por semana?

- a. Menos de 1h ☐
- b. 2h e 3h ☐
- c. Entre 4h e 6h ☐
- d. Entre 6h e 10h ☐
- e. Mais de 10h ☐

9. Indique 2 ou 3 exemplos de jogos que habitualmente joga:

Appendix III: Sociodemographic questionnaire for students

Idade: _____ G nero: F M Ano que frequenta _____ Ano de conclus o do curso _____
Login: _____

10. Sabe em que consiste o Suporte B sico de Vida/Reanima  o cardiopulmonar? S ☐ N ☐

11. J  participou em forma  o de suporte B sico de Vida/Reanima  o cardiopulmonar? S ☐ N ☐

Se **sim**, indique as componentes inclu das na forma  o:

Te rica ☐ Te rica e pr tica com uso de manequim ☐

12. Indique o ano em que realizou a  ltima forma  o que inclu a Suporte B sico de Vida/Reanima  o Cardiopulmonar: Ano: _____

13. Indique quais as forma  es que realizou relacionadas com reanima  o cardiopulmonar:

- e. Suporte B sico de Vida (SBV) ☐
- f. Suporte Imediato de Vida (SIV) ☐
- g. Suporte Avan ado de Vida (SAV) ☐
- h. Outra: _____

14. Considera que nessas forma  es adquiriu conhecimentos suficientes para a realiza  o de manobra de reanima  o cardiopulmonar de forma eficiente? S ☐ N ☐

15. Costuma jogar jogos l dicos no computador/tablet/smartphone? S ☐ N ☐

16. Com que frequ ncia joga?

- e. Menos de 1 vez por m s ☐
- f. Menos de 1 vez por semana ☐
- g. 2-3 vezes por semana ☐
- h. Todos os dias ☐

17. Quantas horas, em m dia joga por semana?

- f. Menos de 1h ☐
- g. 2h e 3h ☐
- h. Entre 4h e 6h ☐
- i. Entre 6h e 10h ☐
- j. Mais de 10h ☐

18. Indique 2 ou 3 exemplos de jogos que habitualmente joga:

Appendix IV: Post Test questionnaire for students and professionals

Login:

Avaliação da componente de Jogo

1. Classifique as afirmações tendo em consideração a sua experiência com a componente de jogo:

a. Enquanto usei a aplicação fiquei absorvido pela experiência

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

b. Enquanto usei a aplicação perdi a noção do tempo

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

c. Senti-me envolvido nesta experiência

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

d. Senti-me frustrado ao utilizar a aplicação

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

e. Achei esta aplicação confusa de utilizar

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

f. Foi necessário muito esforço para utilizar a aplicação

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

g. Esta aplicação foi atrativa

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

h. A aplicação é esteticamente apelativa

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

i. Esta aplicação apelou aos meus sentidos

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

j. Valeu a pena utilizar esta aplicação

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

k. A experiência foi recompensadora

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

l. Senti interesse nesta experiência

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

2. Classifique as afirmações tendo em consideração a sua adesão/motivação para o treino:

a. A atribuição de pontos motivou-o a utilizar o sistema.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

b. A existência de um ranking de participantes motivou-o a utilizar o sistema.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

c. Existirem níveis como forma de progressão motivou-o a utilizar o sistema

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

d. O sistema de conquistas e pontos motivou-o a utilizar o sistema

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

Participação no estudo

Responda às afirmações tendo em consideração a sua adesão ao treino/estudo:

1. A utilização do sistema foi condicionada por algum fator externo.

S ☐ N ☐

2. Se respondeu sim, indique quais os fatores (selecione todas as opções que considerar relevantes).

- ☐ Dificuldade no acesso à sala
- ☐ Indisponibilidade do sistema
- ☐ Indisponibilidade de horários
- ☐ Dificuldade no uso do sistema

Outro: _____

Avaliação de usabilidade

3. Classifique as afirmações tendo em consideração a usabilidade do sistema

a. Acho que gostaria de usar este sistema com frequência.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

b. Acho o sistema desnecessariamente complexo

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

c. Acho o sistema fácil de usar.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

d. Acho que preciso do apoio de uma pessoa especializada para ser capaz de usar este sistema.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

e. Acho que as várias funções deste sistema estão bem integradas.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

f. Acho que existe muita inconsistência neste sistema.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

g. Imagino que a maioria das pessoas aprende a usar este sistema muito rapidamente

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

h. Acho o sistema incómodo de usar.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

i. Senti-me muito confiante a usar o sistema.

Discordo totalmente	1	2	3	4	5	Concordo totalmente
------------------------	---	---	---	---	---	------------------------

j. Preciso de aprender muitas coisas antes de começar a usar este sistema

Discordo totalmente	1	2	3	4	5	Concordo totalmente
---------------------	---	---	---	---	---	---------------------

Funcionalidades gerais

4. É rápida a aprendizagem e fácil a utilização da aplicação?

☐
☐
☐

- a. Não, só se consegue usar depois de muito tempo e esforço
- b. Não é imediato, requiere algum tempo e esforço para se utilizar
- c. Fácil aprendizagem e utilização (ou tem instruções claras)

5. É clara a linguagem utilizada nas instruções, menus e ícones?

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- a. Não, só se consegue perceber e usar depois de muito tempo e esforço
- b. Não é imediato, algumas referências requerem algum tempo e esforço para se perceber/utilizar
- c. Sim, são claras e de fácil compreensão as instruções e/ou menus e ícones

6. A mudança entre ecrãs é lógica/correta/apropriada e sem interrupções (todas as ligações necessárias estão presentes)?

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☐

- a. Não, é necessário muito tempo e esforço
- b. Não é imediato, requiere algum tempo e esforço
- c. Sim, toda a utilização é clara e sem interrupções

7. As interações são consistentes e intuitivas nos vários ecrãs e componentes?

☐
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☐

- a. Não, são muitas vezes inconsistentes e não intuitivas
- b. Não, tem algumas inconsistências e nem sempre são intuitivas
- c. Sim, são bastante consistentes e intuitivas

Funcionalidades do Sistema CPR-PT

8. Com que precisão/rapidez os recursos da aplicação (funções) e componentes (botões e menus) funcionam?

☐
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- a. A app bloqueia, tem falhas/erros e a resposta é inexistente ou insuficiente
- b. Algumas funções funcionam, mas contêm grandes problemas técnicos
- c. De uma forma geral a aplicação funciona, mas tem alguns problemas técnicos
- d. É funcional com problemas menores/insignificantes
- e. A resposta é perfeita e oportuna. Nenhuma falha/erro encontrado

9. Os menus e os botões são fáceis de localizar e compreender?

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- a. Não, os menus e botões são confusos e complicados
- b. Só é possível localizar e compreender depois de muito tempo/esforço
- c. Localizados e compreendidos após algum tempo/esforço
- d. É fácil localizar e entender os menus e os botões
- e. A localização e compreensão é feita de forma imediata, intuitiva e simples

10. Sente-se confiante a usar a aplicação?

N ☐

S ☐

11. Gostaria de usar esta aplicação com mais frequência?

N ☐

S ☐

12. Acha que seria necessário o apoio de uma pessoa especializada para ser capaz de usar esta aplicação?

N ☐

S ☐

Questões finais

1. Indique o(s) aspeto(s) positivo(s) da aplicação:

2. Indique o(s) aspeto(s) negativo(s) da aplicação:

3. Recomendaria esta aplicação a pessoas que poderiam beneficiar da mesma? S ☐ N ☐ Talvez ☐

4. Pagaria para utilizar esta aplicação? S ☐ N ☐

5. Quantas vezes pensa que usará esta aplicação nos próximos 12 meses?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

- a. Nenhuma
- b. Entre 1 - 2 vezes
- c. Entre 3 - 10 vezes
- d. Entre 10 - 50 vezes
- e. Mais de 50 vezes

6. Indique qual das modalidades foi mais do seu agrado:

Com jogo ☐ Sem jogo ☐ Indiferente ☐

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