UNIVERSIDADE DE LISBOA
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Serious Games for Learning: A Model of Driving Attributes for the Medical Domain

Cláudia Sofia Sevivas Ribeiro

Supervisor: Doctor José Luís Brinquete Borbinha
Co-Supervisor: Doctor João Madeiras Pereira

Thesis approved in public session to obtain the PhD Degree in
Information Systems and Computer Engineering
Jury final classification: Pass

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Doctor Sylvester Arnab, Senior Researcher, Serious Games Institute, Coventry University, UK.

2014

Resumo

Jogos Sérios é um termo para o qual não há uma definição única, embora seja atualmente aceite que se refere a jogos cujo propósito vai para além do entretenimento. Recentemente os Jogos Sérios ganharam um interesse como ferramenta de ensino que proporciona ambientes poderosos e eficazes de aprendizagem. No entanto, há uma falta de consenso sobre os aspectos de jogo (ou seja, atributos de jogo) que motivam os jogadores e promovem resultados de aprendizagem específicos. Esta falta de conhecimento representa uma das principais barreiras que impedem a adoção de Jogos Sérios em domínios como a educação médica.

Focando este problema, nesta tese proponho uma framework baseada em atributos de jogos e mecânicas de jogo para o desenvolvimento de Jogos Sérios para o domínio médico. Esta framework foi o resultado da realização de vários casos de estudo e estudos experimentais em conjunto com uma equipa médica num hospital académico. Estes casos de estudo permitiram investigar quais as mecânicas de jogo relevantes para a área médica e como os atributos de jogo devem guiar o desenho dessas mecânicas de jogo.

Os resultados mostraram que o uso de Jogos Sérios para a educação médica foram eficazes tanto no ganho como na retenção de conhecimento em estudantes de medicina, estagiários e especialistas.

Palavras-Chave

Jogos Sérios, Desenho de Jogos, Atributos de Jogos, Mecânicas de Jogo, Educação Médica

Abstract

Serious Games is a term for which there isn't a single definition, although is currently accepted that it refers to games that serve a purpose that goes beyond entertainment. Serious Games have recently gained interest as an instructional tool as they provide powerful and effective learning environments. Nevertheless, there is a lack of consensus on what aspect of games (i.e. game attributes) motivate players and promote specific learning outcomes. This lack of knowledge represents one of the major barriers preventing the adoption of Serious Games in domains such as medical education.

Therefore, focusing on this problem, in this thesis I propose an Attribute-Driven Game-Based framework for the medical domain that was the result of conducting several case studies and experimental studies with a medical team in an academic hospital. These case studies investigated which game mechanics are relevant to the medical domain and how game attributes should drive the design of these game mechanics. The results showed that using Serious Games for clinical education was effective both in knowledge gain and knowledge retention of medical students, interns and attending physicians.

Keywords

Serious Games, Game Design, Game Attributes, Game Mechanics, Clinical Education

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Lisboa, June 2014

Claudia Ribeiro

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1 Introduction

”Serious Games is a term that has been used to describe video games that have been designed specifically for training and education” [Annetta, 2010]. Serious Games have recently gained interest as an instructional tool as they provide powerful and effective learning environments that have the following characteristics: ”(a) they use actions rather than explanations and create personal motivation and satisfaction; (b) they accommodate multiple learning styles and abilities; and (c) they foster decision-making and problem-solving activities in a virtual setting” [Guillén-Nieto and Aleson-Carbonell, 2012].

Recently the field of medicine has also recognized the potential of Serious Games for clinical education. This interest is motivated by the increasing amount of medical information and research which makes it difficult for clinical education to stay current in its curriculum. ”Educators have faced these challenges by restructuring curricula, developing small-group sessions, and increasing self-directed learning and independent search” [Okuda et al., 2009]. Also, ”in the postgraduate arena, working time restrictions have raised concerns towards a more streamlined, shorter duration of higher professional training have also caused concern about the amount of direct clinical experience it is possible to provide” [Bradley, 2006]. It has been argued that due to Serious Games characteristics, some of the challenges could be overcome with the adoption of Serious Games in clinical education.

Nevertheless, the application of Serious Games in clinical education is still in its infancy. The number of Serious Games found in scientific papers is very small and the evaluation process that they were submitted to is either poor or fair [Graafland et al., 2012, Kato, 2012]. This lack of formal evaluation has resulted in mixed conclusions among the research community [Kato, 2010]. Some researchers point out that Serious Games could help solve the pedagogical needs and problems with which medical students and professional are battling today while some alert for the dangers of using poorly developed games. Also, with the exception of virtual reality surgical simulators, none of the Serious Games reported in the literature have been implemented in clinical practice or in formal clinical education.

The lack of adoption of Serious Games in clinical education, and in particular emergency departments, is connected to the ”lack of consensus on what aspect of games” (i.e. game attributes) ”support learning effectiveness, the process by which games engage learners, and the types of learning outcomes that can be achieved through gameplay” [Guillén-Nieto and Aleson-Carbonell, 2012]. Without this knowledge, developing a game can be a very daunting task since it depends mostly on the experience of the game developers and the participation of experts and target group. Also, if this type of knowledge is subjective in nature, validating that Serious Games had an impact on learning outcomes becomes as well a subjective conclusion, because it is not based on objective measures. In order to provide evidence that Serious Games could in fact be a fully fledged teaching instrument for medical students and healthcare professionals this research gap needs to be tackled.

Therefore, in this thesis we propose a representation of game attributes in terms of game mechanics in order to support learning effectiveness in Serious Games for clinical education. Game mechanics have been defined as ”any part of the rule system of a game that covers one, and only one, possible kind of interaction that takes place during the game, be it general or specific” [Lundgren and Björk, 2003]. With this aim in mind, several games covering a set of critical skills for Emergency Medicine were developed and validated in order to scientifically establish a causal link between game attributes and learning outcomes.

1.1 Problem Statement

”Enhancing learning processes with Serious Games has become a hot issue over recent years and can be considered an emerging research topic in the field of Technology-Enhanced Learning (TEL)” [de Freitas et al., 2012].

When considering how to enhance learning processes with Serious Games, several aspects must be considered. Namely, it is necessary to integrate seamlessly the pedagogical content with the entertainment aspect of games. Aiming to address this challenge several authors have proposed game design models and frameworks [Kiili, 2005, de Freitas and Oliver, 2006, Kiili, 2007, Amory, 2007, de Freitas and Neumann, 2009]. These models and frameworks attempt to connect the three main dimensions of Serious Games: pedagogical approaches, game attributes and learning outcomes [Garris et al., 2002].

Some models and frameworks put more emphasis on the motivational aspects of games and used this as the guiding idea for the design of Serious Games [Malone, 1980, Malone and Lepper, 1987]. Others have looked at the theory of flow proposed by Csikszentmihalyi [Csikszentmihalyi, 1991] and established a theoretical link between game challenges and player skill in order to accomplish the flow state. Other authors have focused their efforts in proposing a framework that relates game attributes to learning outcomes where both pedagogical framework, motivation theories and empirical work on the use of games for learning were taken into account [Wilson et al., 2009, Bedwell et al., 2012].

Although these proposals provide several interesting insights into the design process of a Serious Games, how to balance pedagogical content with game attributes in order to accomplish certain learning outcomes is still unclear. It has been argued that ”in order to bridge the gap between the learning outcomes and engaging game content it is essential to define the appropriate game mechanisms to promote both learning and gameplay” [Arnab et al., 2013].

In this thesis, we propose a set of game mechanics which should be considered when developing Serious Games for clinical education. In doing so, we provide insights into how game attributes should be realized and integrated in game mechanics and how game mechanics should be combined to create a meaningful gameplay that leads to learning outcomes.

1.2 Research Goals and Methods

Designing and developing Serious Games is still considered an art, as it is still dependent of the designer experience, the involvement of pedagogical experts and target users. A recent trend has proposed to investigate the concept of game mechanics and how these could be used in the design of Serious Games.

Our research goal was to investigate and propose game mechanics that should be considered when developing Serious Games for clinical education. By proposing such mechanics we hope to bridge the gap between game design and game development and also provide a manner of relating game mechanics with game attributes in order to achieve the design of effective Serious Games. We do not intend to propose game mechanics for every medical procedure, instead we propose to analyse different medical procedures and try to extract patterns which will form the basis for a model of driven attributes for the medical domain. This research goal can be described by the following research questions:

RQ1: How should the game attributes be realized in the gameplay through game mechanics?

Providing an answer to this question involved first and foremost understanding what are game mechanics and how they are currently used in the design of games. An initial consideration of the application of game mechanics to the design of Serious Games is the integration of pedagogical content with the appropriate mechanism in order to promote an experience that potentiates learning. This consideration separates game mechanics as applied to entertainment game design and Serious Game design. Therefore, game mechanics in the context of Serious Games, have their own characteristics and requirements.

Based on the knowledge gathered regarding game attributes several case studies were conducted involving the design and development of Serious Game targeted at healthcare professionals. Specifically, two Serious Games were developed with different medical teams that integrated the following pedagogical content: the recommendations for the transportation of critically ill patients; and the sepsis fast track protocol. These Serious Games were respectively targeted at medical students, triage nurses, interns, and attending specialists.

By analysing the results of the case studies using cross-case analysis several game mechanics patterns emerged, both in structure as well as representation. This knowledge was used to develop an Attribute-Driven Game-Based framework that relates game attributes and game mechanics.

RQ2. What are the advantages and limitations of the Attribute-Driven Game-Based framework?

Showing evidence of Serious Game effectiveness involves providing both internal validity and external validity. Providing internal validity implies providing clear evidence that it was the Serious Games that had an impact on learning outcomes, meaning the use of the Serious Game by the target group resulted in the target group having an increased level of knowledge regarding the pedagogical content. In order to provide internal validity, several experimental studies were conducted both with medical students, interns and attending specialists where knowledge gain, knowledge retention and impact on work practices were evaluated.

Providing external validity refers to whether or not the claimed effects of the Serious Game will transfer to people, environments and situations outside the original scientific study setting. This means, evaluating if the knowledge learned with the Serious Game was successfully transferred to real-world, if it had an impact on work practices. In order to provide evidence of external validity, hospital data was collected before and after the intervention (use of Serious Games) and analysed.

Based on the results of our experimental studies we have identified both advantages and limitations of our Attribute-Driven Game-Based Framework.

1.3 Contributions

Our work produced some scientific contributions that we believe to be relevant for the research field of Serious Games. The first one is related to the Attribute-Driven Game-Based framework that we describe in Chapter 5. This framework was developed having in mind the integration issues of two different aspects of games, namely game attributes and game mechanics.

These issues are usually not explored in an integrated form in frameworks that people typically use to develop Serious Games. Our proposal treated game attributes from a different perspective. Instead of abstract concepts that live in the realm of gameplay, we have treated them as requirements that drive the design and specification of game mechanics. Meaning, they help describe both the functionalities (e.g. actions) that a Serious Game must provide as well as the constraints (e.g. interactivity) under which it should operate.

Finally, we have conducted experimental studies that included different learning models (face-to-face and blended learning models) in different contexts and involved different target users (medical students, interns and attending specialists). To our knowledge, we have contributed with the first study that compares the level of knowledge retention between face-to-face classes and two different blended learning models in medical education.

1.4 Publications

1. Ribeiro C., Farinha C., Pereira J., da Silva M. M. (in press). Gamifying requirement elicitation: Practical implications and outcomes in improving stakeholders collaboration. *Entertainment Computing*.

2. Ribeiro C., Monteiro M., Pereira J., Antunes T., Baalsrud Hauge J.: ”Sepsis Fast Track: A Serious Game for Medical Decision Making”. 5th International Conference on Serious Games Development & Applications (SGDA). 2014

3. Ribeiro C., Antunes, T., Monteiro, M., Pereira J.: ”Serious Games in Formal Medical Education - An Experimental Study”. 5th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games). 2013

(selected to be published in a special issue of the International Journal of Game-Based Learning)

4. Monteiro M., Ribeiro C., Antunes T., Corredoura S.: ”Let’s play ER - videogames in pre-graduate medical education”. 7th Mediterranean Emergency Medicine Congress. 2013

5. Ribeiro C., Pereira J., Borbinha J.: ”Creating Awareness of Emergency Departments Healthcare Values Using a Serious Game”. 8th European Conference on Technology Enhanced Learning (EC-TEL). 2013

6. Ribeiro C., Tiago, J., Monteiro, M., Pereira J.: ”SeGTE: A Serious Game to Train and Evaluate Basic Life Support”. 9th International Conference on Computer Graphics Theory and Applications (GRAPP). 2013

7. Cowley B., Bedek M., Ribeiro C., Heikura T., Petersen S. ”The Quartic Process Model to Support Serious Games Development for Contextualized Competence-Based Learning and Assessment”. Handbook of Research on Serious Games as Educational, Business and Research Tools. IGI Global, 2012.

8. Ribeiro C., Fernandes J., Calado C., Pereira J. ”Challenges of Introducing Serious Games and Virtual Worlds in Educational Curriculum”. Cases on Digital Game-Based Learning: Methods, Models and Strategies. IGI Global, 2012.

9. Ribeiro C., Monteiro M., Fernandes F., Corredoura S., Candeias F., Pereira J. ”Games in Higher Education : Opportunities, Expectations, Challenges and Results in Medical Education”. New Pedagogical Approaches in Game Enhanced Learning - Curriculum Integration. IGI Global, 2013.

1.5 Outline

This document is divided into six different chapters including this one.

The second chapter describes the notions of Serious Game, game attributes models and frameworks used to drive the design of Serious Games and examples of Serious Games applied to clinical education.

On the third chapter we describe the case studies conducted to investigate how game attributes and game mechanics could be used in the design of Serious Games for clinical education. Two case studies were developed which resulted in the development of two Serious Games: the Critical Transport; and the Sepsis Fast Track.

The fourth chapter presents the experimental studies conducted to evaluate the effectiveness of the developed Serious Games. This includes a description of the method used (quasi-experimental, randomized controlled trial), descriptive and inferential statistical analysis and a discussion of the results.

The fifth chapter describes the Attribute-Driven Game-Based Framework. The development of this framework aggregates the knowledge and understanding provided by the literature review described in the second chapter as well as the cross-case analysis of the case studies and experimental studies described in the third and fourth chapter respectively.

Finally, in chapter six we present our contributions, conclusions and future work.

2

Related Work

2.1 Serious Games

In this section the current proposed definitions for the term Serious Game as well as a review of the characteristics that distinguishes a game, a simulation game and a simulator are presented. Finally, the main properties that separate a video game from a serious games through the perspective of the design process, the context in which the game is use and the game content are described.

2.1.1 Concepts and Definitions

Several authors have attempted to define what is the meaning of the term "Serious Games" (see for example, [Susi et al., 2007, Breuer and Bente, 2010]). In particular, [Djaouti, 2011, Djaouti et al., 2011] has undertake an analysis of its possible origin in which he described the use of the term starting in 15th century Italy where the term "serio ludere" was used to refer "to use of humour in literature when dealing with serious matters". Other domains that were referenced by the author were respectively:

- "in the literary novel Den Allvarsamma Leken by Hjalmar Södeberg, whose English title is "The Serious Game" ([Soderberg, 2001])",
- "In the book "The New Alexandria Simulation: A Serious Game of State and Local

Politics" ([Jansiewicz, 1973])", and

- "in the companion book of an artistic exhibition held in a Barbarian Art Gallery ([Graham, 1996])".

In providing these examples Djaouti [Djaouti, 2011,Djaouti et al., 2011], attempted to demonstrate the distinction between the use of the term "Serious Games" and the definition of "game" as proposed by [Huizinga, 1951]: *"Summing up the formal characteristic of play, we might call it a free activity standing quite consciously outside 'ordinary' life as being 'not serious' but at the same time absorbing the player intensely and utterly. It is an activity connected with no material interest, and no profit can be gained by it. It proceeds within its own proper boundaries of time and space according to fixed rules and in an orderly manner. It promotes the formation of social groupings that tend to surround themselves with secrecy and to stress the difference from the common world by disguise or other means."* Concluding that "Serious Game" therefore breaks with the definition of "game" [Djaouti, 2011, Djaouti et al., 2011].

Nevertheless, the proponent of the term "Serious Games" to refer to games that "have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement" was Clark Abt in his book entitled "Serious Games" where he also discussed the apparent duality between "serious" and "game": "The oxymoron of Serious Games unites the seriousness of though and problems that require it with the experimental and emotional freedom of active play." [Abt, 1970, p.11] .

Since then, many video games have been made to serve serious purposes. They were accompanied by several attempts to define "Serious Games", which are summarized in

Definition	Authors
”a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy and strategic communication objectives.”	[Zyda, 2005]
”Any game whose primary purpose is other than simple entertainment.”	[Michael and Chen, 2006]
”any meaningful use of computerized game/game industry resources whose chief mission is not entertainment.”	[Sawyer, 2007]
”A Serious Game is defined as games that engage the user, and contribute to the achievement of a defined purpose other than pure entertainment (whether or not the user is consciously aware of it).”	[Susi et al., 2007]
”A software application which initial purpose is to combine in a coherent way serious subjects such as teaching, learning, communication and information (this list being non exhaustive nor exclusive), with the entertainment resources of video games. This association, achieved with the implementation of a ”pedagogical scenario” and which at IT level corresponds to implementing a sound and graphic skinning, a history and appropriate rules, has therefore as goal to diverge from simple entertainment. This gap seems to be based on the salience of the ”pedagogical scenario”.”	[Alvarez, 2007]
”computer application, for which the original intention is to combine with consistency, both serious (serious) aspects such as non-exhaustive and non-exclusive, teaching, learning, communication, or the information, with playful springs from the video game (game).” Such an association, which operates by implementing an utility script, which, in computer terms is to implement a package (sound and graphics), a history and the same rules, is therefore intended to depart from the simple entertainment.”	[Djaouti, 2011]

Table 2.1: Proposed definitions for the term ”Serious Game”

Table 2.1.

The current definitions of Serious Games, as the last example, limit the scope of the concept to video games ([Zyda, 2005, Michael and Chen, 2006]). According to [Djaouti et al., 2011] ”all these definitions seem to be influenced by the vision of Ben Sawyer and his white paper entitled *Serious Games: Improving Public Policy through Game-based Learning and Simulation*”. Although this paper doesn’t make any reference to the oxymoron ”serious game” apart from the title, it describes and encourages the use of video games as educational and training tools. Due both Swayer’s white paper and the release of American Army game [1], [Djaouti, 2011, Djaouti et al., 2011] considered ”2002 as the starting point of the ”current wave” of serious games”. [Susi et al., 2007], also related the emergence of the term Serious Games with the year 2002, because this is when the Serious Game Initiative [2] was created, which provided the following description of Serious Games: ”The Serious Games Initiative is focused on uses for games in exploring management and leadership challenges facing the public sector. Part of its overall charter is to help forge productive links between the electronic game industry and projects involving the use of games in education, training, health, and public policy”.

Moreover, all these definitions are strongly related to the use of technology undermining the use of non-digital games for serious purposes. While leading a serious game design studio, [Corti, 2007] published an important article on this topic. It calls for expanding the usual definitions of Serious Games recalling that players that use business games do not recognize this expression and prefer the term Game-based Learning and Simulation. Nowadays, these are not the only terms used to refer to ”any meaningful use of computerized game/game industry resources whose chief mission is not entertain-

[1] http://www.americasarmy.com/
[2] seriousgames.org

ment" [Djaouti et al., 2011]. According to [Sawyer and Smith, 2008] there are a large number of terms in used, including :

> *Educational Games, Simulation, Virtual Reality, Alternative Purpose Games, Edutainment, Game-Based Learning, Digital Game-Based Learning, Immersive Learning Simulations, Social Impact Games, Persuasive Games, Games for Change, Games for Good, Synthetic Learning Environments, Games with an Agenda.*

[Susi et al., 2007] based on the works of [Prensky, 2001, Kiili, 2005, Squire et al., 2005, Michael and Chen, 2006, Corti, 2007, Prensky, 2007] has proposed the following distinctions for Serious Games, Edutainment, Game-Based Learning (GBL) and Digital Game-Based Learning (DGBL):

- "*Serious Games* encompass the same goals as *edutainment*, but extend far beyond teaching facts and rote memorization, and instead include all aspects of education - teaching, training, and informing - at all ages",
- "*GBL* has the potential of improving training activities and initiatives by virtue of, e.g., its engagement, motivation, role playing, and repeatability (failed strategies etc. can be modified and tried again)", and
- "*DGBL* is closely related to *GBL*, with the additional restriction that it concerns digital games".

In sum, although all these terms are use to refer to the use of games for educational purposes, they differ in terms of the context where the are use, what kind of games include (digital/non-digital), target users and application areas.

This multitude of definitions and terms reflects the diversity of interested stakeholders as well as approaches and applications. Also, its clear that a definition for Serious Games that is accepted within the academic community and industry still doesn't exist, although there are a set of key features that seem to be consistent across the different definitions. With the aim of clarity, a concept map (Fig. 2.1) was devised to highlight in an hierarchical manner the main concepts involved when working with Serious Games.

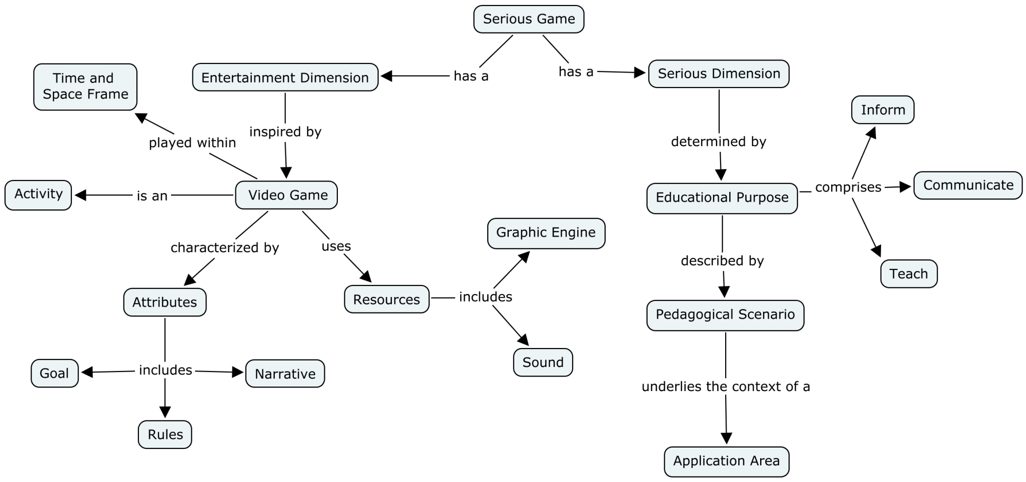


Figure 2.1: A concept map showing the key features of a Serious Game

Throughout the document, whenever we refer to Serious Games we mean, games that have an entertainment dimension and a serious dimension as shown in the above concept map 2.1

2.1.2 Games, Simulation Games and Simulators

There isn't an agreement regarding the boundaries of what is a game, what is a simulation and where do these two concepts meet (simulation game). In this section, an attempt is made to identify the individual characteristics of games, simulation games and simulators regarding, its attributes, design considerations and application areas. At the end of the section, a summary of this defining features is proposed through the use of concept maps.

[Narayanasamy et al., 2006] formally defined a game as ”a goal-directed and competitive activity that involves some form of conflict, conducted in a framework of agreed rules”, which is similar to the definition proposed by [Hays, 2005]: ”An artificially constructed, competitive activity with a specific goal, a set of rules and constraints that is located in a specific context” (p.15). In [Michael and Chen, 2006] games are described as: ”...a voluntary activity, obviously separate from real life, creating an imaginary world that may or may not have any relation to real life and that absorbs the player’s full attention. Games are played out within a specific time and place, are played according to established rules, and create social groups out of their players.” (p.19). [Susi et al., 2007] has also discussed the definition of ”game” where she described the definition put forward by ”The Serious Games Showcase and Challenge” [3], and the ”2006 I/ITSEC Conference (Interservice/Industry Training, Simulation and Education Conference)”, which stated: ”Entries will be considered a game if they involve an assigned challenge and employ a compelling form of positive and/or negative reward system. Entries will be considered a serious game if they use the gaming attributes described above to overcome a designated problem or deficiency, and provide appropriate feedback to the user about their efforts.”

[Sauvé et al., 2005] has conducted a systematic review to identify the essential elements that characterized the concept of ”game” from which they identified the following attributes: player or players, conflict/cooperation, rules and predetermined goal of the game for which they proposed the following definitions: 1) Player or players: ”in

[3] sgschallenge.ist.ucf.edu

games, the player or gamer is an individual or group of individuals who are placed in a position where she/he (or they) has to assume the role of the decision-maker in a game context." 2) Conflict/Cooperation: "conflict is represented in games by dynamic human- or computer-controlled obstacles that prevent the player from easily reaching her/his goal. Obstacles must be active, even "intelligent", to create conflict and may, minimally, provide the illusion of reacting to player action. Cooperation emerges when players ally themselves against other players in order to reach a common goal." 3) Rules: "Rules are a set of guidelines, being either simple or complex, which describe the relationships existing between players and the game environment. These guidelines specify the extent and the nature of allowable player action and they establish the sequence and the structure according to which participant actions may take place." 4) Predetermined goal: "he predetermined goal of a game refers to the end of the game and to the notion of victory, winning or reward. It indicates how the game ends and, for educational games, it includes the objectives which the player(s) seek to attain.". Another important characteristic of games was noted by [Narayanasamy et al., 2006], specifically the authors stated that a game is produced with the intent to generate "sales and profits", therefore it is "paramount that a game is fun to play", it offers an "imaginative and coherent experience and it presents a continuous and intelligent challenge".

Another feature of games is that there are differences in the representation form: the game can be "text-based, a game-board may be used, or a computer to display materials" [Leemkuil et al., 2000]. Different forms of representation represent different forms of interactions both between players and the game and amongst players, for example it can be "computer mediated" or "controlled by leader/trainer/instructor" [Leemkuil et al., 2000].

[Mcgonigal, 2011] in her book ”Reality in Broken” states that ”games today come in more forms, platforms, and genres than at any other time in human history”. Nevertheless, she also states that ”when strip away from the genre differences and the technological complexities, all games share four defining traits: a goal, rules, a feedback system, and voluntary participation”. Therefore, Regarding other traits mentioned in the previous definitions such as, interactivity, graphics, narrative, rewards, competition, etc, she states that ”these are common features of many games, but they are not defining features”, they are just ”an effort to reinforce and enhance these four core traits”. Specifically, a ”compelling story makes the goal more enticing. Complex scoring metrics make the feedback systems more motivating. Achievements and levels multiply the opportunities for experience success. Immersive graphics, sounds, and 3D environments increase the players ability to pay sustained attention to the work we’re doing in the game. And algorithms that increase the game’s difficulty are just ways of redefining the goal and introducing more challenging rules”. Finally, and in accordance to her train of though her choice for the best definition of a game is the one put forward by the philosopher Bernard Suits that states the following: ”Playing a game is the voluntary attempt to overcome unnecessary obstacles”.

Based on the definitions described a concept map was devised and can be depicted in Figure 2.2.

[Jones, 1995] in his book ”Simulations: A Handbook for Teachers and Trainers” defined a simulation game as: ”A simulation game attempts to replicate various activities in ’real life’ in the form of a game for various purposes: training, analysis, or prediction. Usually there are no strictly defined goals in the game, just running around, playing as a

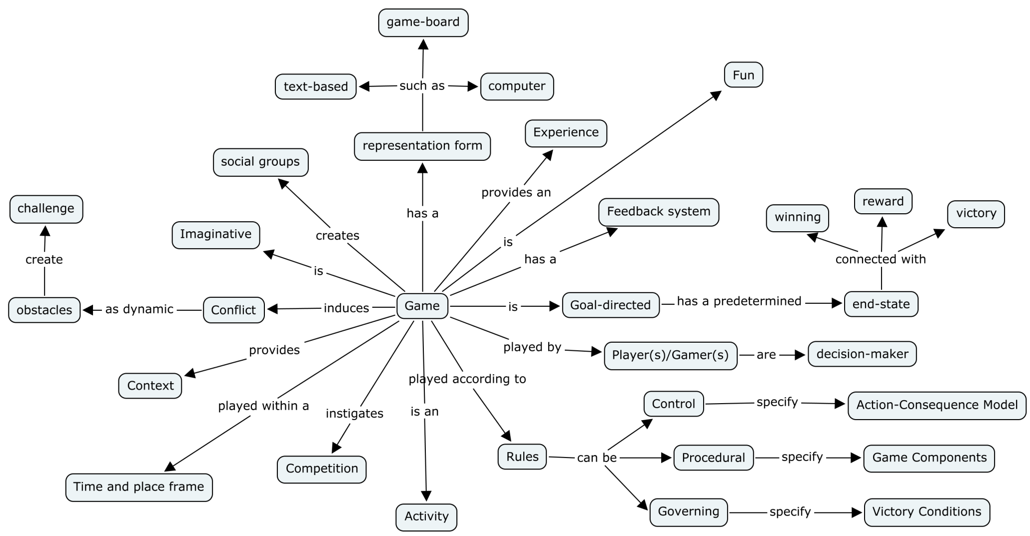


Figure 2.2: A concept map showing the key features of a Game

character." (p.21). [Galvão et al., 2000] has defined a simulation game as: "A simulation game is a mixed feature of a game - competition, co-operation, participants and rules, etc, with those of simulation - incorporation of critical features of reality. [Narayanasamy et al., 2006] classified a simulation game as a computer "game gender". The authors go further and state that "all games involve some form of simulation", but simulation games, in contrast to games, not always offer a "goal-oriented activity". This is because there may not be an obvious end state and no pre-defined patterns in game play. This is the case if uncertainty is important and therefore the model being simulation in stochastic in nature. An example of such games are business simulation games. Based on these assumptions they proposed the following definition: "Simulation Games can be defined as a mixture of a game of skill, chance and strategy that results in the simulation of a complex structure." [Narayanasamy et al., 2005].

[Narayanasamy et al., 2006] described the characterization of simulation games put forward by [Payne, 2005]: "participatory, iterative, procedural, or situational". Participatory simulation games involve positioning the player "within the game itself by means of physical simulation" (e.g. virtual reality and augmented reality games). Iterative simulation games refers to simulation games where the player "iteratively inputs known variables in order to create an end result" such as a business model or a computer simulation module. Procedural simulation games are related to the simulation of well defined process and are usually used to "train users to complete the process by following a well documented set of procedures". Finally, Situational simulation games refer to simulation games that include simulating "behaviours and/or emotions of people by using advanced artificial intelligence systems in complex environments in games such as The Sims" [4].

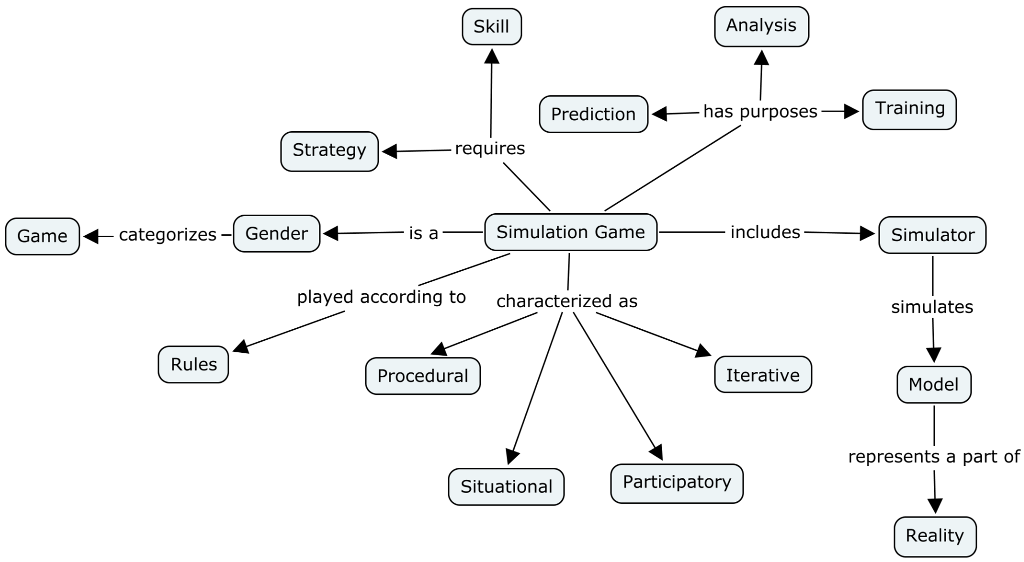


Figure 2.3: A concept map showing the key features of Simulation Games

When looking at the key features of simulation games as presented in the concept map is clear that it has both elements of games as well as simulators. Nevertheless, it also has some important differentiating feature. For example, contrary to games, simulation games aren't goal-driven, and contrary to simulators, they are played by player/gamer. This two difference already have a great impact in the design considerations as well as

[4] http://www.the-sims-4.com/

application areas where these two medium can be use.

As stated by Heinich et al., ”unlike games, which suspend the rules of reality in order to use the rules of a game, simulations attempt to model a system in a manner that is consistent with reality” [Heinich et al., 1996]. Simulation models ”physical or social systems based on assumptions that can be mathematical, logical, or symbolic relationships among entities and or objects of interest” and are ”validated before it can be used to predict or reproduce the behaviour of the system being modelled under varying sets of circumstances” [Narayanasamy et al., 2006].

Simulators and simulation technology are used for numerous applications. Namely, in management science and operations research (e.g. [Pidd, 2004, Murat and Mike, 2009]). Another common use is in the military field, where simulation is use in training systems [Smith, 2009]. In healthcare simulators range from low-tech, simple plastic models to realistic high-tech simulators that have been incorporate in medical curriculum to teach and evaluate skills, such as surgical skills, resuscitation, among others ([Teteris et al., 2012]).

[Squire, 2003] has discussed the used of video games in education where he also describes different types of simulation as put forward originally by [Thiagarajan, 1998]. In particular, he distinguished between high and low fidelity simulation. High-fidelity simulation ”attempt to model every interaction in a system in as life-like manner as possible, whereas low fidelity simulations simplify a system in order to highlight key components of the system”. For a more complete description of these different types of simulation please refer to [Squire, 2003].

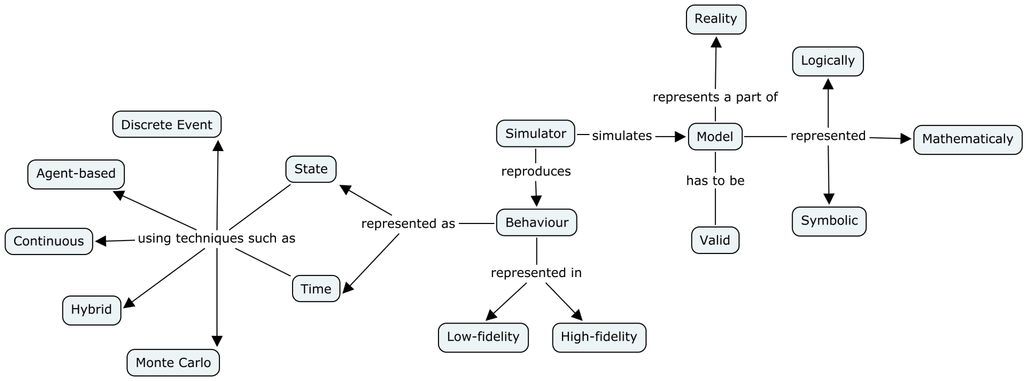


Figure 2.4: A concept map showing the key features of a Simulator

2.1.3 Serious Games and Gaming

In the previous sections we have presented a panoply of definitions that have attempted to define what is a serious game. Also, we have described and analysed the potential differences between what is a game, a simulation game and a simulator. While analysing such definitions and describing such differences the focus was given to game characteristics and attributes. In this section we look at another important feature of games which is related to gaming (playing games). In this respect we will only have into account video games and not other games supported in different types of media. Therefore, in this subsection it will be presented what are the main differences between a serious game and a video game regarding gaming.

At first glance, Trauma Center: Second Opinion [5], depicted in Figure 2.5, could be considered a serious game related to health, because this game proposes to embody a surgeon performing a set of surgical operations. However, beyond the hospital setting and some references to actual medical practice, this game offers little or no dimension that could be considered ”serious”. In this particular case, the game was clearly designed to entertain the user. The medical field is only used in the context of scenario building. How-

[5] http://www.atlus.com/tcso/

Figure 2.5: Trauma Center: Second Opinion

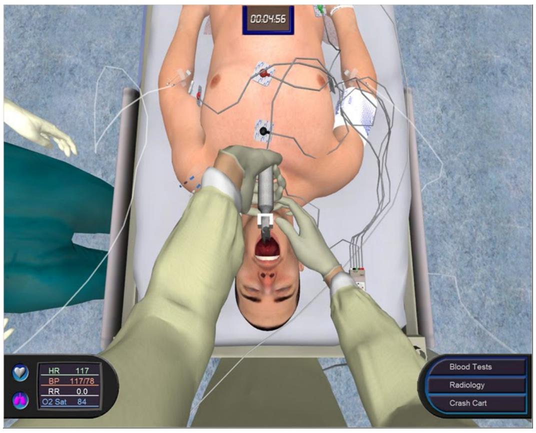


Figure 2.6: Pulse!

ever, Pulse! [6], depicted in Figure 2.6, can provide training about clinical skills required to deal with multiple emergency situations, such as evacuation of an accident setting or a bioterrorist attack. Where Trauma Center requires the player to destroy the virus' that appear in the form of dragons, Pulse! requires the learner to solve real medical cases using current medical technology.

Nevertheless, is possible to play Trauma Center by adopting a "serious" posture. This is also true for any game from the entertainment industry, as is the case of the works reported in [Prensky, 2007], [Gee, 2007] and [shaffer, 2007]. In particular, the karaoke game Singstar [7] is used as course material to improve college students English pronunciation. Another example is the game Buzz! Quiz TV [8] which has been used by history and geography teachers. This game allows the creation of custom made questions which permits the teachers to include content related to what is being taught in their classes ([Llanas, 2009]). Also, the "Réseau Ludus" [9], which allows teachers to use any type of games for educational purposes, also reported many experiences of using entertainment

[6] http://www.breakawaygames.com/serious-games/solutions/healthcare/
[7] http://www.singstar.com
[8] http://us.playstation.com/games/buzz-quiz-world-ps3.html
[9] http://lewebpedagogique.com/reseauludus/

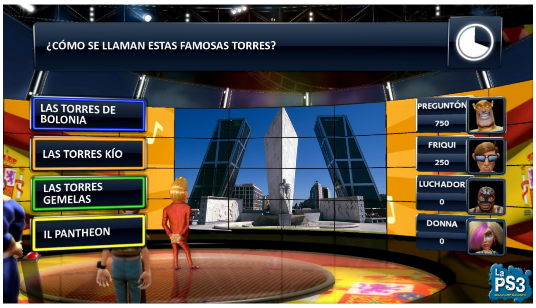


Figure 2.7: Buzz!

Figure 2.8: Sim City 4

video games in the classroom. One of the founders of this network, Yvan Hochet [Hochet, 2011] stated the following:

> ”The simple provision of a game doesn’t seem to change much regarding what students learn. [...] The mediation of the teacher, which thinks when/how to introduce the game in the learning process, remains therefore indispensable.” [p.107]

In this quote, Hochet introduces a very important aspect of using games for learning. Hochet used games such as SimCity [10] to teach geography and Lord of Realms II [11] to teach historical events. While doing these experiments it was notable the importance of the role of the teacher.

[Squire, 2003] also noted the importance of the teacher/instructor when using simulations as a tool for learning. Specifically he stated that ”simply using a simulation does not ensure that learners will generate the kind of understanding that educators might desire. Rather, learners need opportunities to debrief and reflect, and the amount of time spent

[10] http://www.simcity.com/
[11] http://www.mobygames.com/game-group/lords-of-the-realm-series

on reflection should equal the amount of time engaging in a game or simulation". He goes further and argues that "instructors play an important role in this process fostering collaboration, promoting reflection, and coordinating extension activities".

[Susi et al., 2007] also described one important difference between Serious Games and gaming "Serious Games often violate voluntariness in that trainees may be ordered to play a particular game as part of their training. An example could be a military squad leader using a serious game for training before or preparing a mission. Another person using the very same simulation game could instead regard it as a game".

Other important differences, are how the level of difficulty is defined or how it evolves during the game play. One of the characteristics that have been praise as central to making games good pedagogical tools is its ability to be personalized. That is, the content and the pace at which the game evolves can, in principle, be adapt to each player. Regarding learning processes this is a very important characteristic. While in video games the level of difficulty and the pace of game is adapt to the target audience, therefore has into account the evolution of the average player.

Content is also something that has to be taken into account. For example, in medical education, medical algorithms change and evolve as a reflection of the evolution in the pharmaceutical industry but also healthcare policies. Therefore, a serious game develop to teach medical professionals might became obsolete in a matter of 2 or 3 years. This is a concern that is not shared in the video game industry. Marios Bros [12] was developed in 1983, as it still a very popular game among gamers. Of course there have been new releases of this game but the changes introduced mainly concern adaptation to more

[12]http://mario.nintendo.com/

advance graphics card, the look and feel and the game play hasn't change at all.

In sum, its possible to identify several properties that separate a video game from a Serious Game when analysed through the perspective of the design process, the context in which the game is used, the game content, among others. A summary of such properties is as follows:

- The intent that motivated the design of the game;
- The importance of the role of the teacher/instructor: it fosters collaboration, promotes reflection, and coordinates extension activities ;
- The necessity of including a briefing and debriefing phase;
- the ability to update the game content;
- the ability to personalize the game difficulty and pace at which the game evolves;
- a video game is a voluntary activity while a serious game might not be.

2.2 Serious Games Attributes

"Numerous researchers have attempted to organize game attributes that constitute a true "game"" [Bedwell et al., 2012]. Malone and Lepper have identified four main attributes that defined a game, namely challenge, curiosity, control and fantasy [Malone, 1981, Malone and Lepper, 1987]. Since then, other researchers have tried to identify the core attributes of games for which the following attributes were proposed [Bedwell et al., 2012]: (a) "Task nature, roles of the player, presence of multiple methods to achieve goals and the level of player control"; [Gredler, 1996]. (b) "Conflict, closure and contrivance"; [Thiagarajan, 1987]. (c) "Goals, rules, constraints, competition, and specific game contexts [Leemkuil et al., 2000]; and finally, (d) "player's effort level, player attachment to the game outcome, and negotiable consequences" [Juul, 2003].

Garris and Ahlers have conducted several studies in order to identify which where the game attributes that increase the ""game-like" of simulations" from which they identified six gaming features that "contribute to the learning potential of games": (a) fantasy, (b) rules/goals, (c) sensory stimuli, (d) challenge, (e) mystery, and (f) control [Garris and Ahlers, 2001, Garris et al., 2002].

Wilson et al. reviewed theories of learning, specifically the framework proposed by [Kraiger et al., 1993] and based on learning outcomes extracted from this framework, namely cognitive, skill-based, and affective outcomes, they extended the attributes proposed by Garris et al. and proposed a relationship between games attributes and learning outcomes [Wilson et al., 2009]. Next, a description of the game attributes that are common to most research works or Serious Games is presented.

Fantasy

Malone [Malone, 1980] defined fantasy as an environment that evoked "images of physical or social situations not actually present". Thomas and Macredie [Thomas and Macredie, 1994] have described games as "worlds with no consequences", meaning players can act in a virtul environment without experiencing their real outcomes. Fantasy in games is has also been linked to feeling of being transported to a different world, where reality and fantasy are no longer discernible [Driskell and Dwyer, 1984]. Several researchers have also addressed two types of fantasy: intrinsic (endogenous) fantasy, when

”the skill being learned and the fantasy depend on each other” and extrinsic (exogenous) fantasy, defined as ”one in which the fantasy depends on the skill being learned but not vice versa” [Malone and Lepper, 1987, p. 240].

Representation

”On the opposite of the continuum from fantasy is representation, or the precision of reproduction” [Wilson et al., 2009]. Meaning ”the physical and psychological similarity between a game and the environment it represents, where ”physical representation is how accurately the game replicates the real-world environment” [Wilson et al., 2009]. Each type of similarity has its specific role in a game or simulator, as is the case of psychological similarity in flight simulators and physical similarity in games where skill-based knowledge is the focus of the learning task, as is the case with surgical simulators [Crawford, 1984, Prince and Jentsch, 2001].

Rules/Goals

”The rules of a game describe the goal structure of the game” [Garris et al., 2002]. Therefore, this attribute both defines the set of rules that govern the virtual environment and provides guidance when defining which feedback should be provided to the player. The feedback allows the player to detect when current performance does not meet established goals, allowing the player to improve his/her current strategy.

Games can include different types of rules: system rules, procedural rules and imported rules [Crookall and Arai, 1995]. System rules dictacte how the game environment behaves. Procedural rules are the set of actions available for the player and imported rules refer to rules that players bring to the game and can be considered common sense rules similar to the ones we used in real-life (e.g. don’t grab a hot recipient) [Garris et al., 2002].

Moreover, it has been argued that this attribute also contributes to the player level of engagement, in the sense that the game should provide appropriate goals that are interesting to the player and rules that allow the player to achieve goals during gameplay [Prensky, 2001, Mitchell and Savill-Smith, 2004].

Sensory stimuli

"Games imply the temporary acceptance of another type of reality" [Garris et al., 2002]. [Caillois, 1961] discussed the term vertigo to denote the sense of altering perception. This alteration can occur while performing activities such as riding roller coasters and spinning. In the context of games this can happen through the integration of sounds and visual effects that allow the player immerse in an alternate reality by creating experiences and sensations that are outside normal experience [Malone and Lepper, 1987]. In addition, sensory stimuli can be used as feedback for performance [Garris et al., 2002].

Challenge

Malone and Lepper [Malone and Lepper, 1987] have argued that intrinsic motivation can be produced in terms of challenges that are neither too easy nor too difficult to perform. This is also connected to the work of Csikszentmihalyi on Flow theory where he argued that "clear goals, achievable challenges and accurate feedback" are the main attributes that contribute to the attainment of the metal state of flow [Csikszentmihalyi, 1988]. [Wilson et al., 2009] has connected this attribute to the level of motivation while playing games: "Motivation is maintained by creating uncertainty about goal attainment". This uncertainty can be achieve by introducing a certain level of variability and randomness in player's actions [Malone, 1981, Malone and Lepper, 1987]. Performance feedback and score allows the individuals to be aware of their progress toward the game goals. Finally, goals should be interesting and important to the individual [Garris et al., 2002].

Mystery

Wilson et al. stated that ”mystery exists when a gap exists between known and unknown information” [Wilson et al., 2009]. It has been argue by Garris et al. that by manipulating this attribute is possible to create two types of curiosity, namely: ”(a) sensory curiosity, the interest evoked by novel sensations (which we have described as sensory stimuli above); and (b) cognitive curiosity, which is a desire for knowledge” [Garris et al., 2002]. Nevertheless, this information gaps need to be well balanced and adapted to the player current knowledge of the pedagogical content.

Assessment

The assessment attribute refers to the performance level achieved within a game [Chen and Michael, 2005, Wilson et al., 2009]. This information informs the player how well he did in the game and also provides indications of how he can improve his current performance. Moreover, is also a measure that can be used to compare different players. Assessment can occur during a gameplay through in-game feedback. Specifically, for each of the player action a positive or negative result is shown to the player via for example scores or visual cues [Prensky, 2001]. At the end of the game a summary of player achievement can also be provided as the overall player performance. This is a central game aspect that can potentiate learning, because is through this information that the player can establish connections between his actions and outcomes. Chen and Michael [Chen and Michael, 2005] have stated that ”this connection can be achieved through three forms of assessment: completion assessment, in-process assessment, and teacher evaluation”.

Control

Garris et al., has defined control as ”the exercise of authority or the ability to regulate, direct, or command something [Garris et al., 2002]. This sense of authority can be re-created in a game by providing the player with a set of choices that allows him to influence how the game evolve. Control is one of the five dimensions of flow antecedents which are related to flow theory and were describe by Kiili in [Ghani and Deshpande, 1994, Kiili, 2006]. In this context, the sense of control is something that is experienced without a person explicitly exert it. Is the personal sense that she/he ”can develop skills sufficient enough to reduce the margin of error to close to zero” [Kiili, 2012].

While developing this work the authors found a set of relationships that haven’t been explored when correlated with particular learning outcomes: cognitive, skill-based and affective. In terms of game attributes and cognitive outcomes the unexplored relationships were between the game attributes conflict, challenge and adaptation. Regarding skill-based outcomes the game attributes that were less studied and explored are: representation, fantasy, interaction (equipment) and control.

On a follow-up study Bedwell et al. [Bedwell et al., 2012] proposed a taxonomy of game attributes in order to try to solve limitations such as, lack of comprehensiveness or construct overlap. The authors argued that game attributes constructs must be as orthogonal as possible so that their unique contributions to outcome of interest can be isolated. This was accomplished by using a mental model elicitation technique, open card sorting, with subject matter experts (SME). Each of the SME was confronted with the game attributes proposed by Wilson et al. and asked to group them in categories. The main idea was to collapse the 18 game attributes into well defined categories that included all the related attributes and therefore avoid construct overlap. The card sorting was done on-line using WebSort [13]. After this experiment with 65 SME (games players and game developers), nine categories and their corresponding attributes were identified via cluster analysis. These initial results were further analysed by SME (that hadn't participated in the card sorting) in order to solve overlaps between clusters. The final result is summarized in Table 2.2.

According to the authors, these "categories are defined by a number of factors and cannot generally be viewed as being "present" or "absent" - rather, they are persistent qualities instantiated in different ways". This means that, after a category being identified for a serious game that has a particular learning outcome it is still necessary to understand what is the "best" way to incorporate the respective attributes in the serious game.

In sum, although several game attributes have been identified as relevant to attain learning outcomes, the relationship between game attributes, how they affect particular learning outcomes and how they should be represented in a particular learning context is still unclear.

2.3 Serious Game Design

Understanding how to harness the potential of games to enhance learning has been the subject of several research works. Some of this works has focused on the nature and design of the game itself while others have focus on identifying what are the game attributes that have an impact on learning outcomes from which taxonomies linking attributes to learning have been proposed.

[13] http://uxpunk.com/websort/

Category	**Attributes**	**Examples**
Action Language	Language, communication	A game has textual commands that the player must type in order to convey their intent vs. a game that uses a gaming pad or joystick to interpret commands.
Assessment	Assessment, progress.	A game that shows a log of objectives to complete and scores based on individual actions at the end vs. a game that leaves the player in the dark during game play and gives a raw point score at completion.
Conflict/ Challenge	Adaptation, challenge, conflict, surprise	A game that adapts the number of enemies faced or the power of those enemies based on how the player performs vs. a game that increases difficulty at a constant level.
Control	Control, interaction (equipment)	A game that allows players to pick up any object and manipulate it, throw it, damage it, etc. vs. a game that only renders objects as static obstacles. The manipulations a player exerts on a game.
Environment	Location	A game set in an office building vs. a game set in the jungles of Cambodia - the actual location where the game takes place.
Game Fiction	Fantasy, mystery	A game set in a military operation would have generally consistent reality vs. a game set in a military operation where it is possible for orbital lasers and balloon-borne crossbow infantry to suddenly join in an ambush in Afghanistan would have a rather inconsistent fantasy reality.
Human Interaction	Interaction (interpersonal), interaction (social)	A networked game that provides voice chat and has a supervisor giving support vs. a game that isolates the player from all other human contact.
Immersion	Pieces or players, representation, sensory stimuli, safety	A game that uses movie-quality sound effects and force-feedback vibration to capture sock and intensity of landing at the beach on WW2 Normandy vs. a game that uses blips and beeps to represent an oncoming low-fidelity space invader.
Rules/ Goals	Rules/ Goals	A game that makes it clear that the player must obtain three pieces of a key and combine then using their blowtorch, which can only be used for 2 minutes vs. a game that simply presents a locked door.

Table 2.2: Game Categories and Associated Attributes [Bedwell et al., 2012]

Independently of the approach used the main focus was to provide an answer to this main question: How to balance entertainment/fun with learning? More specifically, to create effective serious games is necessary to integrate educational theory with game design theory into one approach. Several authors have attempted to do so. In the next section a description of these works is presented.

2.3.1 Input-Process-Outcome Game Model

Garris et al. [Garris et al., 2002] goal was to ”develop learners who are self-directed and self-motivated, both because the activity is interesting in itself and because achieving the outcome is important”. For that purpose they adapted the general Input-Process-Output model in order to define an instructional model for games. The Input-Process-Output model is a functional model and a conceptual schema of a general system, which defines the sequence of steps of transforming inputs into outputs. In this context, they defined the input as the instructional content and game characteristics (game attributes) and the output as the learning goals. The process consists in the processing steps that will guarantee that the inputs will be transformed in learning outcomes. They defined this processing steps as a game cycle composed of three phases, namely ”user judgements, user behaviour and system feedback”. This instructional model is depicted in figure 2.9. The game cycle is an iterative process, such that the game play involves repeated judgement-behaviour-feedback loops. That is, game play can ”create user judgements or reactions such as higher level of enjoyment, or confidence; these reactions influence a change in the player behaviour such as more persistence; and these behaviours result in system feedback on performance in the game context” [Garris et al., 2002].

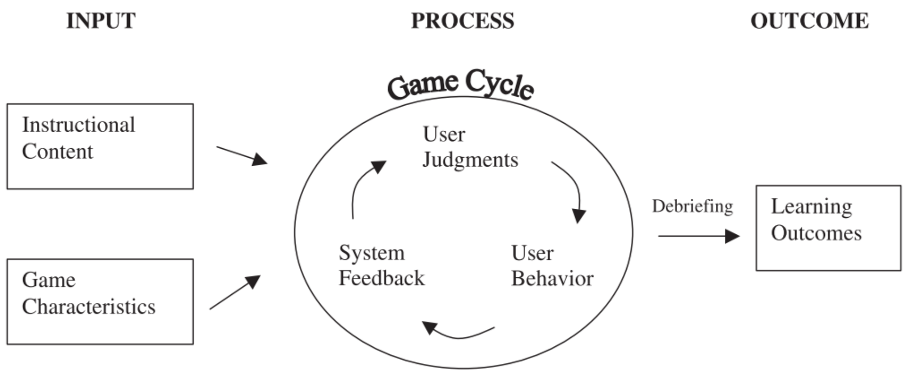


Figure 2.9: Input-Process-Outcome Game Model [Garris et al., 2002]

The authors argue that this game cycle is consistent with experiential learning approaches [Kolb and Kolb, 2008] and that although it is a cyclical process the authors recognize that not all learners learn exactly the same way, therefore these stages are not fix in a sequential linear manner. In this manner, the authors emphasis the following (i) ”people do learn from active engagement with the environment and (ii) this experience coupled with instructional support (i.e., debriefing, scaffolding) can provide an effective learning environment” [Garris et al., 2002].

2.3.2 Game Object Model

The game object model II (GOM II), proposed by Amory [Amory, 1999, Amory, 2001], describes a ”relationship between the pedagogical dimensions of learning and game elements and is loosely based on the Object-Oriented Programming paradigm which includes concepts such as encapsulation, inheritance and polymorphism”.

The GOM II is composed of three major spaces used to assemble a set of objects, which can be used to describe serious games. These three major spaces are: game space; problem space; and social space. The GOM II (Fig. 2.10) is composed of two main classes of objects, one are the abstract interfaces (●) which are related to educational objectives and the concrete interfaces (❍) which are related aspects of games.

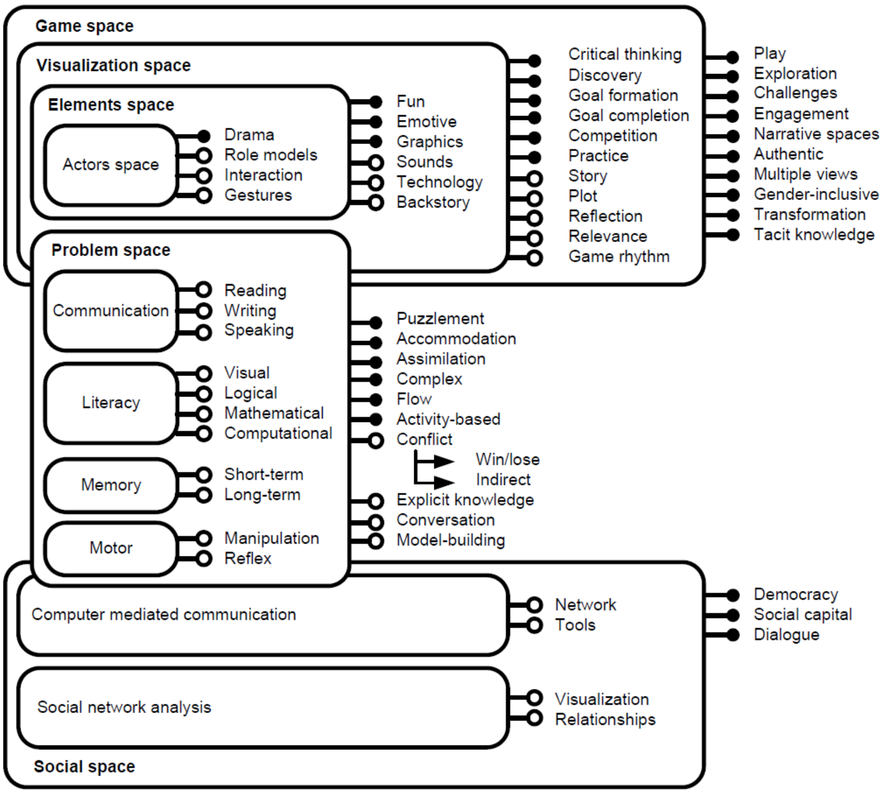


Figure 2.10: Game object model version II [Amory, 2007]

Each component can either be singular or an aggregation of more sub-components, as is the case of the problem space object. In this case, the problem space object also includes all the interface of both the visualization space and computer medicated communication objects. The core concept model is that ”educational games should present relevant, exploitative, emotive, and engaging environments where solutions to complex challenges are difficult, requiring multifarious dialogues” [Amory, 2007]. This is accomplished by defining a compelling story that enables the realization of the learning objectives. The story-line is composed by several acts, each encompassing a learning objective and realized by the visualization and problem space. How the actual story development and game design is accomplished is not included in the model as the author states that these two aspects ”require specific creative abilities not easily capture through reductionism” [Amory and Seagram, 2003].

The author explains that the GOM II can be used as a check list for two main purposes. On one hand, evaluating the abstract interfaces allows the verification of what is the pedagogical goal of the game and if it is according to expectation. On the other hand evaluating the concrete interfaces allows the verification of how efficiently a game can attain those pedagogical goals. However, the viability and veracity of the mode in the creation of serious games in practice needs to be evaluated [Amory, 2007]. Also, [Kiili, 2005] argues that the GOM II is too superficial and does not take game play and flow theory into account.

2.3.3 Experiential Gaming Model

The main purpose of Kiili's experiential model (Fig. 2.11) is to ”link game play with experiential learning in order to facilitate flow experience” [Kiili, 2005]. Therefore he used principles from Experiential Learning [Kolb and Kolb, 2008] and Flow Theory [Csikszentmihalyi, 1991] to devise his model.

In particular, the inner cycle of the model is concerned with the different phases of Kolb's cycle of experiential learning, which include active experimentation, reflective observation and schemata construction. This means that the player should interact with challenges that allow him to go form concrete knowledge (active experimentation) to abstract knowledge (schemata construction). Moreover, to guarantee an optimal experience for the player several principles from flow theory need to be taken into account. Specifically, and described by [Csikszentmihalyi, 1975], a person is ”in a state mental state of flow when she/he is so involved in the current activity that nothing else seems to matter”. Kiili has argued that this can be achieved that considering several flow antecedents, namely: ”challenges matched to the skill level of a player, clear goals, unambiguous feedback, a sense of control, playability, gamefulness, focused attention, and a frame story” [Kiili, 2006]. By integrating these two theories in a gaming cycle he attempts to guarantee that ”learning occurs as a construction of cognitive structures through action or practice in the game world” [Kiili, 2005].

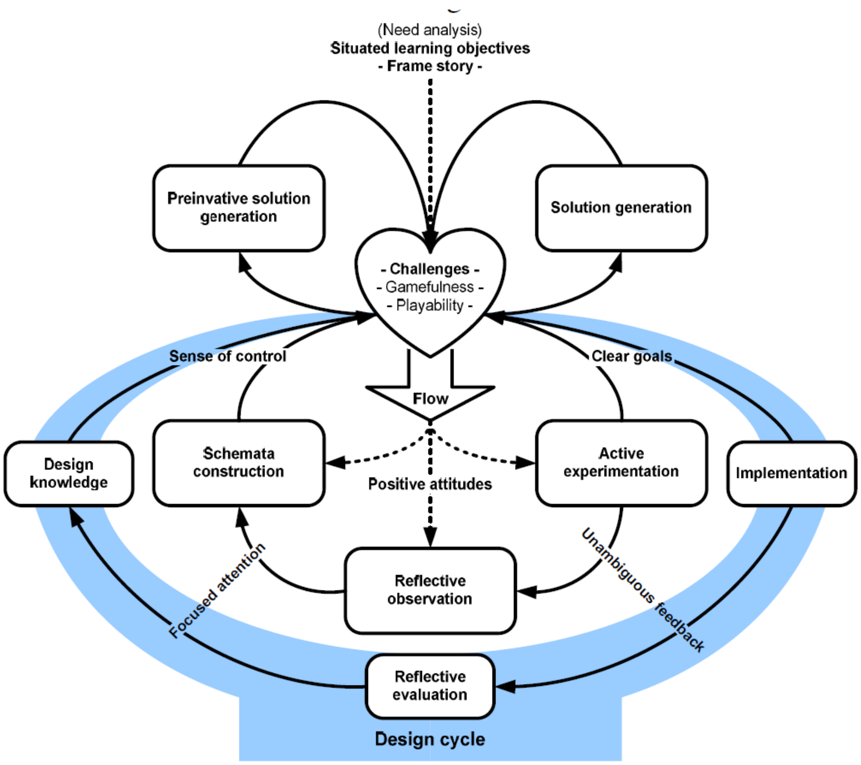


Figure 2.11: Experiential gaming model [Kiili, 2005]

Finally the outer cycle refers to the desing cycle, which describes the a set of guidelines that should be taken into account during the design process. This process is presented in a very high level manner, because Kiili states that this process is dependent on the game genre.

2.3.4 Problem-Based Gaming Model

The Problem-based Gaming Model (PBG) proposed by Kiili [Kiili, 2007] is "founded on the same principles of problem-based learning (PBL), which refers a student-centred learning approach helping learners to acquire and develop the knowledge skills and capabilities needed to solve problems effectively".

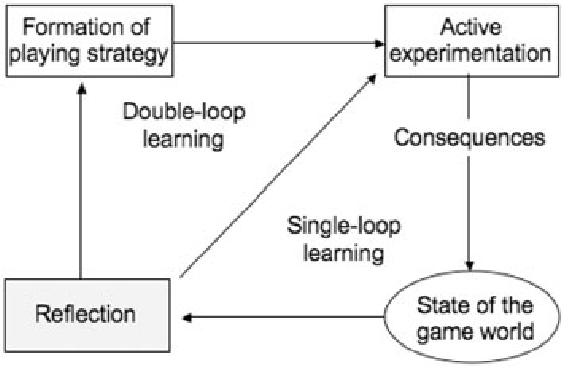


Figure 2.12: Problem-Based Gaming Model [Kiili, 2007]

With the PBG, Kiilli proposes to "provide an account of how learning happens within games". In order to do so, the proposed model describes learning as a cyclic process through direct experimentation in the game world. This direct experimentation allows the player to construct cognitive structures embodying the learning content of the game. The rationale underlying this idea is that "games usually allow players to creatively test hypotheses and reflect on outcomes in the game world which is the basis of experiential learning theory" [Kiili, 2007].

Figure 2.12 illustrates the "problem-based gaming (PBG) model distinguishing the learning process into elements" [Kiili, 2007]. This model presupposes three main phases: strategy phase; experimentation phase; and a reflection phase. In the strategy phase the player forms appropriate strategies based on her/his current knowledge. In the experimentation phase the player tests her/his strategy in the game world and perceives the consequence of her/his actions.

By proposing this model Kiili stressed two important points. One is related to the representation of game attributes. Namely, the author stated that the "authenticity of learning situations and tasks is a very important factor in facilitating higher order learning" [Kiili, 2007]. This is corroborated by situated learning which stresses that learning is dependent on the context where it will take place.

The other point is related to single/douple-loop learning. The player decided which is the best strategy to apply in the game world based on the feedback of previous strategies (actions). If the feedback is focused on one particular strategy this will enforce learning a particular part of the learning content while neglecting other important aspects which would ensure a more complete fluffiness of game's pedagogical objectives. This refers to single-loop learning. In contract, double-loop learning emphasis the "scrutiny of governing variables in order to generate better playing strategies and solutions to problems" [Kiili, 2007]. Therefore, the author stresses that "from a creative problem solving and comprehensive learning point of view, it is important that the player endeavours to test different kind of strategies in order to expand knowledge on the subject matter and optimise playing strategy".

2.3.5 Four-Dimensional Framework

The four-dimensional framework (Fig. 2.13) "was the result of a work that involved both tutors and learners in order to understand how games are selected and used" [de Freitas and Oliver, 2006, de Freitas and Jarvis, 2009]. With this work the authors showed

”that often tutors did not know which games to use in which contexts and what were the most effective deployments of games” [de Freitas and Oliver, 2006, de Freitas and Jarvis, 2009]. Therefore, four dimensions were proposed which occurred in learning processes to help tutors be more aware how to select a game and how to use it. These four dimensions are respectively: learning specifics which is concerned with player defining the player profile (e.g. who is the learner? What are her/his current competencies); Pedagogy which refers to the pedagogical approaches that are currently used to support learning (e.g. associative, cognitive); Representation refers to the level of fidelity, interactivity and immersion of the game; and, context refers to were will the game will be used (e.g. in a classroom? At home?).

Since its proposal, the four-dimensional framework has also ”been used as design tool for developing three serious games that were the result of the Serious Games: Engaging Training Solution Project” [De Freitas and Jarvis, 2007]. One of these games is the Triage Trainer that has shown to be efficient in training healthcare profession doing triage in a mass causality setting [Knight et al., 2010].

Four-dimensional Framework	
Learner Specifics Profile Role Competencies	**Pedagogy** Associative Cognitive Social/situative
Representation Fidelity Interactivity Immersion	**Context** Environment Access to learning Supporting resources

Figure 2.13: The four-dimensional framework [de Freitas and Jarvis, 2009]

2.4 Serious Games in Medical Education

2.4.1 Medical Education

Undergraduate medical education is still predominantly lecture-based and teacher-centred. But more and more medical schools have started a smooth transition to a student-centred paradigm. They are ”changing their educational programs and teaching strategies to ensure that students have active responsibility for their learning process and are prepared for life-long, self-directed learning” [Rendas et al., 2006]. ”Problem-based-learning (PBL), a method developed in the late 1960’s at the medical school at McMaster University in Canada, has been proposed as a student-centred strategy” [Monteiro et al., 2011]. It is progressively being established as pedagogical base of a real-life-teaching approach at medical faculties. PBL is problem centred, integrates different areas of knowledge, trains skills and competences, encourages problem-solving strategies and motivates. The teacher is a facilitator who guides the learning process.

Most of the postgraduate training, such as specialization, is done ”on the job” accompanied by reading textbooks and medical journals, as well as attending congresses and participating in practical courses, mostly on a voluntary basis. With exception of the latter, concrete learning objectives, a careful design of learning activities or the evaluation of outcomes is generally missed. Newer learning tools such as simulation labs are still an exception. The courses on Advanced Life Support provided by the European Resuscitation Council are therefore an example. Small groups of trainees simulate with mannequins in a role-play scenario resuscitations of patients in cardiac arrest under the guidance of tutors.

Most of the existing e- and b-learning programmes already overcome distance and time schedule issues by providing bibliography, slide presentations, videos and podcasts. They permit communication with tutors/ educators and classmates and give remote access to live sessions and evaluation tools like written tests. However they often do not explore their whole potential of creating simulation environments or engage by a highly interactive design of its learning contents. The offer of such programmes, unfortunately, is also still very limited. An example of a very interesting approach in this area is the UK's Department of Health project "e-Learning for Healthcare" [14]. By defining learning objectives and disseminating it through the whole British NHS, this programme not only answers individual education needs but also creates a powerful tool to set standards and homogenize good medical practice throughout the country.

Medical education is clearly much more than acquiring knowledge. It has a social responsibility. It has to train skills and competences like time-critical decision-making, dealing with risk and uncertainty, communication with peers, patients and relatives, to deal with error and failure and techniques of problem-solving. In conclusion: it must enable doctors to know, to put knowledge successfully into practice and to develop appropriate behaviour in order to accomplish their mission. "But how this goal can best be accomplished, given the time constraints faced by physicians, has challenged the profession and medical educators since the early 1900s" [Manning, 2005].

Foreman [Foreman, 2004] states "It is amazing to me that in the modern age, when we have technologies like the Internet and the hand-held and the computers and the computer games, we are still teaching inside four walls, where all the information is coming

[14] $http://www.e-lfh.org.uk/news_video.html$

from within those walls and where all students, regardless of the amount of preparation they have, are sitting together". Therefore, continuing professional development has to incorporate the principles of adult learning, shift from passive to active learning, adapt to individual needs while taking into account the new opportunities offered by the new technologies as well as important cognitive style changes of the new generation of trainees, the so-called "digital natives".

Following this trend recently, healthcare professionals, namely physicians and medical students, have become a target audience for Serious Games. These games appear to have a number of characteristics to answer the aforementioned current challenges [Ribeiro et al., 2012]. Serious Games potentially are powerful tools for training, as they are able to create immersive simulation environments and can easily be accessed at almost any time from almost any place. The player can train at his/her own rhythm and can be evaluated as well, which makes it possible to integrate the games into a learning curriculum or a crediting system. Examples for such games include Serious Games for training medical professionals in insulin management of diabetic patients [Diehl et al., 2011], advanced life support [Monteiro et al., 2011] or managing patients with suspected sepsis [15]. Next we summarize a set of Serious Games developed for medical education.

2.4.2 Surgical Skills

Surgical training has been predominantly been teach in the "operation room in a see one, do one, teach one manner" [Sabri et al., 2010a]. Nevertheless, because this type of training requires the constant presence of residents it has a negative impact on hospital resource management. Namely, it increases costs and occupies valuable resources, resi-

[15] http://cme.stanford.edu/septris/

dents and operating rooms [Sabri et al., 2010a]. In an attempt to overcome this limitation a rising trend in surgical training is the use of Serious Games.

We have found examples both for training lay people as well as healthcare professionals. For lay people, there is ”for example the Australian Broadcasting Corporation (ABC) Radio’s Virtual Open Heart Surgery, which is a 2D game that can be played in a web browser. The player takes the role of a surgeon performing a coronary bypass surgery” [Sabri et al., 2010a]. This procedure is represented in the game in thirteen simplified steps that are complemented with additional information to the player to guide him through the procedure. Another example is the game Nova Online [Online, 2000], which ”provides a simple heart transplant surgery for anyone wishing to learn about the procedure and consists in nineteen steps using non-technical instructions” [Sabri et al., 2010a]. Both games don’t require previous knowledge and although they present the pedagogical content in a simplified manner, they help lay people to have a basic understanding of the medical procedures.

Regarding physicians, [Sabri et al., 2010a] described how they developed a game with a ”3D rendering engine built ”in-house”” to teach the ”off-pump coronary artery bypass grafting (OPCAB) to cardiac surgeons/residents” [Sabri et al., 2010a] . In this game, the player takes the role of a ”cardiac surgeon, viewing the scene in a first-person perspective” [Sabri et al., 2010a] . The environment is a mimic of a real operating room, where the remaining team (assistants, nurses) are represented by avatars with which the player can interact. Every step of the procedure is complemented with a multiple choice question that tests the player knowledge regarding that step. Also, mini games were included in the game play that are unlocked whenever the player reaches a particular score. The authors have put a lot of effort in the underlying 3D technology (graphics and sound) to ensure the environment ”is consistent with the real-world” to facilitate ”that the knowledge gained within the serious game can be easily recalled and applied” in a real-world scenario [Sabri et al., 2010a]. Another example, is the serious game developed to train knee replacement surgery to orthopaedic surgical residents [Sabri et al., 2010b]. This game was developed by almost the same team as the previous one, so the game play is quite similar and also the same technology was used to develop the game environment and in-game characters, among other aspects.

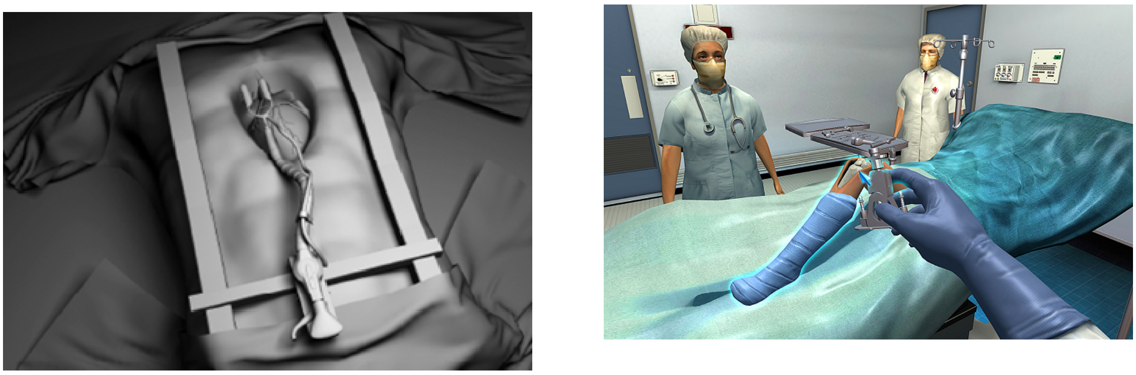


Figure 2.14: Serious Games to teach cardiac (left) and knee replacement surgical skills (right)

2.4.3 Clinical Skills

”Clinical medical education over the past century has been based on the apprentice system characterized by student-patient encounters in which trainees observe, or sometimes participate in, the care of ”private” patients in the practices of clinical instructors or learn by examining and treating ”public” patients assigned to them for care under the supervision of clinical instructors” [Heinrichs et al., 2008].

Recently, ”virtual reality simulator systems have been developed for anaesthesia, and trauma management” [Dev et al., 2011]. These first systems where based in CD-ROM computer-assisted learning. An example of such system is the Anesoft developed "designed for crisis management across different disciplines and with trauma and nerve toxin exposures, is supported by a complex set of mathematical algorithms for the pathophysiologic responses to injury and treatment" [Heinrichs et al., 2008]. Another example is the "Research Triangle Institute model based on the mathematical algorithms developed in The Body Simulation software" [Heinrichs et al., 2008].

Regarding Serious Games, Pulse! [16] (Fig. 2.15) is an immersive Serious Game for training healthcare professionals in clinical skills. High fidelity graphics are used to recreate a virtual environment similar to the real environment. This Serious Game is target at both civilian and military healthcare professional to train clinical skills in situation such as combat and bioterrorism.

Figure 2.15: Pulse!

3DiTeams is a first-person multi-player serious game developed using a commercial gaming technology (Unreal Engine 3) and it is targeted at teamwork training for medical students, residents, nurses and faculty in a large academic health system. The training is based on the "DoD Patient Safety Program and Agency for Healthcare Research and

[16]http://www.breakawaygames.com/serious-games/solutions/healthcare/

Quality's (AHRQ) TeamSTEPPS curriculum" [17]. 3DiTeams has three phases:

- Independent Learning Phase: "Individuals learn the principles of teamwork and communication by observing expert virtual teams perform in the virtual world while categorizing behaviours".
- Collaboration / Team Coordination Phase: "Multiple learners enter a virtual world together. Team members can be in the same room or spread throughout the world. Team members apply the principles they learned in the Independent Learning Phase while caring for virtual patients. Team members, instructors, and non participant observers comment and rate the interactions they witness."; and
- Debrief / After Action Review: "Video and voice recording of the Collaborative Phase is played back live or over the internet. A facilitator-lead debrief allows the learners to observe their behaviours, reflect on their actions, and discuss the positive and negative interactions that took place during the challenging scenario.".

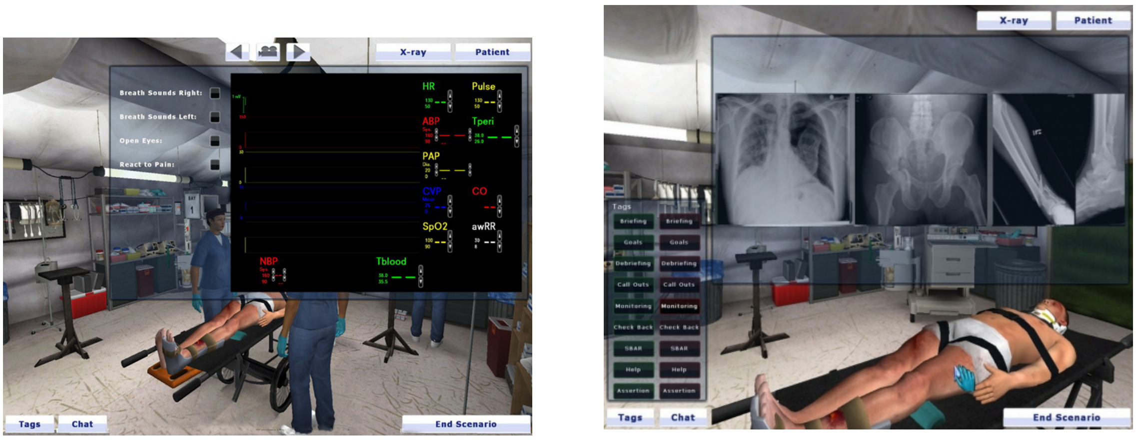


Figure 2.16: 3DiTeams

[17] http://www.virtualheroes.com/projects/3diteams

Clinispace is a game in which many rooms (intensive care/examination room/ emergency bays) of the hospital are represented. The virtual environment is 3-D and was modelled according to a real environment (from photos taken to real hospitals). The game can be played with multiple physicians and nurses (multi-player game). In this game the intra-personal communication skills and safety procedures can be trained by using voice communication via headsets.

Figure 2.17: CliniSpace

2.4.4 Triage

Pivotal Decision [18] is a serious game target at first responders for training pre-hospital mass casualty triage on-line programming. The game creates a virtual environment where the player has to "navigate through the incident area, locate casualties, and perform triage". The feedback is "provided in the form of an after-action report detailing both global game achievements and casualty level details". According to their website "CEU Credits are approved by Florida Bureau of Emergency Medical Services".

The environment of the Triage Trainer [19] game is a busy high street in which an

[18] http://www.humansim.com/projects/pivotal-decision
[19] www.trusim.com

Figure 2.18: Pivotal Decision

explosion has taken place with multiple victims. The purpose of the game is that the player helps the most critical victims first. A second purpose is that the player follows the protocol for helping a patient in a correct way. The game has been evaluated in the UK, by comparing the triage training game with the traditional method for learning. The triage training game was ”statistically significantly better at developing accuracy in prioritizing casualties and in supporting students to follow the correct protocol to make their decision” [Kapralos et al., 2011].

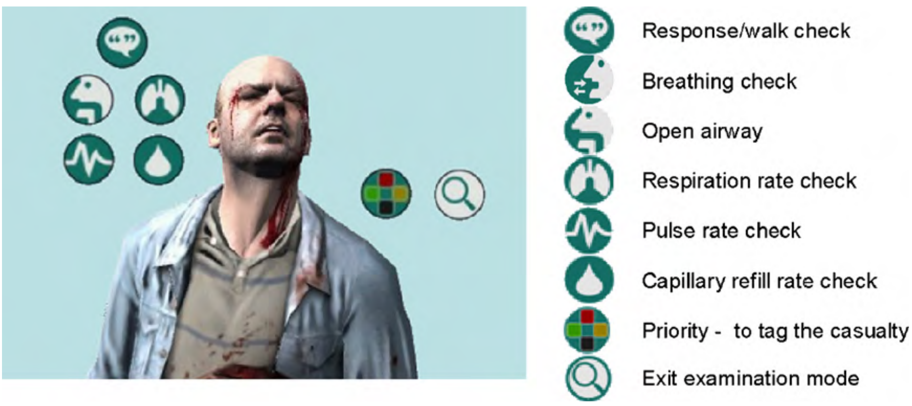


Figure 2.19: TriageTrainer

2.4.5 Other Medical Areas

The Virtual Dental Implant Training Simulation Program [20] was designed by Medical College of Georgia School of Dentistry faculty and students and BreakAway and is target at dental students. The game provides a virtual environment where the player can train three main aspects of doing a dental procedure, namely diagnostics, decision making and treatment protocol. It also includes multiple patients to allow the player to with a high number of differentiate conditions. A part from current health condition, patients also simulate different personalities which requires the player to adapt the interaction according to patient type.

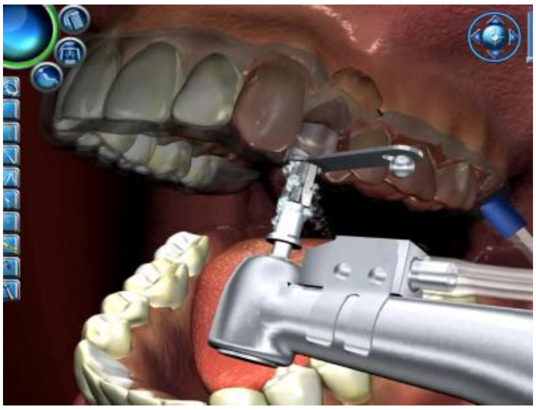
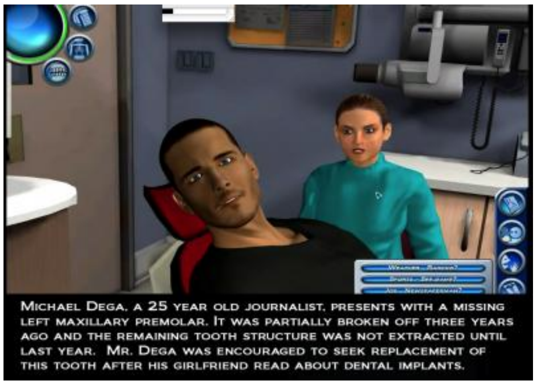



Figure 2.20: Virtual Dental Implant Training Simulation

RescueSim[21] is a training software for emergency crews to experience and train how to assess and choose the best response strategy in an emergency situation. These emergency situations range from small scale incidents like a residential fire to a full-scale high rise fire, riot response, rail road collision, port incidents, air plane accidents or industrial disasters.

[20] http://www.sciencedaily.com/releases/2009/06/090611084130.htm
[21] http://www.rescuesim.com/

Figure 2.21: RescueSim

Zero Hour: America's Medic[22] is another game developed for emergency crews. This game was developed on top of Unreal Engine 3 and is targeted at providing a virtual environment for paramedics to train how to handle mass casualty incidents such as earthquakes and terrorist attacks. Apart from training purposes it is also used as a recruiting tool. The objective is to assess the problem and save as many lives as possible while interacting with patients.

Figure 2.22: Zero Hour; America's Medic

[22]http://www.humansim.com/projects/zero-hour

3

Designing Serious Games for Clinical Education: Case Studies

This chapter describes the cases studies that were conducted in order to investigate how game attributes can be transformed and integrated in game mechanics in order to build effective games for clinical education. Clinical education is a vast field and encompasses different areas, each with its own particularities. In the context of this thesis we focused on Emergency Medicine which is a medical branch "based on the knowledge and skills required for the prevention, diagnosis and management of the acute and urgent aspects of illness and injury affecting patients of all age groups with a full spectrum of undifferentiated physical and behavioural disorders" [Fatovich, 2002]. It is also a speciality in which time is critical, where there is a high level of mobility between medical staff and where the levels of professional exhaustion are very high. Due to these characteristics, it is an area of clinical education where Serious Games could have a great impact as they can be adapted to different learners profiles and education contexts and can be played anytime-anywhere.

We start by presenting the pedagogical considerations that were taken into account in the development of our case studies. These considerations consist of an aggregation of both the knowledge provided by previous proposed Serious Games design models as well as design frameworks. Then, taking these issues into consideration, we describe the development of two Serious Games targeted at clinical education. These Serious Games were chosen together with healthcare professionals in order to traverse different medical procedures and target users with different levels of expertise. These games place the user in the role of a healthcare professional that has to examine the clinical condition of a patient and by exploring the virtual environment decide the best course of action.

We also present some details regarding the design and development of each serious game. Regarding the design, which design approach was used, the stakeholders involved and respective roles. Regarding the development, GUI, scenario and game mechanics.

3.1 Pedagogical Considerations

The main goal of clinical education is to prepare students to became competent healthcare professionals. The theoretical knowledge that is taught through the medical curriculum is very important in achieving this goal but equally important, and critical in continuing clinical education, is the ability to practice in order to evolve from novice to expert [Duvivier et al., 2011].

The ability to practice as process of improving ones cognitive or psycomotor skills reflects the underlying principle of experience learning, as described by Kolb [Kolb and Kolb, 2008]. Specifically, Kolb's states that learning by experience occurs when individuals have the ability to actively experiment in the context of a concrete experience and also by reflecting on the results of this experience in order to abstract the knowledge gain to be used in new experiences. This same principles have been integrated in game design models such as the experiential gaming model [Kiili, 2005] and the exploratory learning model [de Freitas and Neumann, 2009].

Nevertheless, experience by itself or unguided reflection is not sufficient to generate knowledge. In order to have the desired effect, which is to allow the student/person to enhance her/his current skills, this has to be both contextualized and structured according to the target skills. In clinical education, it is particularly important to foster healthcare professionals that are good problem-solvers. Meaning, that they have the ability, in the face of a problem, to strategically align known and unknown knowledge in order to solve it successfully. This is the underlying principle of problem-based learning (PBL) [Kilroy, 2004,Wood, 2008], which is a learning approach that was originated in medical education.

These same principles have been applied to Serious Game design, through the work developed by Kiili. Kiili has proposed the Problem-based Gaming model (PBG) [Kiili, 2007] which is based on problem-based learning and presupposes three main phases: strategy; experimentation; and a reflection. In the strategy phase the player decides appropriate strategies based on her/his current knowledge. In the experimentation phase the player tests her/his strategy in the game world and perceives the consequence of her/his actions. The strategy and experimentation phase are related with single-loop learning. Through in-game feedback the player learns which is the best strategy for each challenge. The reflection phase promotes double-loop learning which leads to a deeper understanding of the output of all considered strategies and how these can be used to effectively solve problems. de Freitas and Oliver [de Freitas and Oliver, 2006] proposed the Four Dimensional Framework (4-DF) and it has been argued that having into consideration these four main dimensions contributes to the development of efficient Serious Games [Bellotti et al., 2011].

In the design and implementation of our case studies we took into account the principles proposed in these frameworks and models. Namely, we used the 4-DF to drive the interviews and discussion before the implementation phase and the experiential and problem-based model to guide the integration of pedagogical constructs and game mechanics in order to create a meaningful gameplay that allows players to achieve the pedagogical objectives of the Serious Game.

3.2 Pedagogical and Game Constructs

”In order to bridge the gap between the learning outcomes and engaging game content it is essential to define the appropriate mechanisms to promote both learning and game play” [Arnab et al., 2013]. Balancing these two aspects of Serious Games involves relating game attributes with learning outcomes. As described previously, several researchers have tried to establish this connection by proposing either a game design model, an evaluation framework or categories of aggregated attributes. Nevertheless, game attributes are high-level concepts that provide us just a raw idea of how they can be represented within Serious Games. Therefore, it is still not clear how these attributes can be combined in order to provide a meaningful gameplay experience that conveys the pedagogical goals of Serious Games.

Salen & Zimmerman have argued that the ”gameplay produced by digital games is not directly attributable to the fantasy context of a game but the mechanism through which players make meaningful choices and arrive at a meaningful play experience” [Salen and Zimmerman, 2004, p. 317]. These mechanisms are commonly referred to by game developers as the game mechanics [Habgood and Overmars, 2006].

Lundgern and Björk [Lundgren and Björk, 2003] have defined game mechanics as ”simply any part of the rule system of a game that covers one, and only one, possible kind of interaction that takes place during the game, be it general or specific”. A game can be composed of one or more game mechanics and these can be shared among different games. How and when a mechanics is used during a game is defined by the rules of each game using the mechanics. Habgood while investigating the impacts of intrinsic and extrinsic fantasy on learning has defined a game mechanics as ”the procedural mechanisms of a game that provide the essential interactions required to create a meaningful gaming activity” [Habgood, 2007].

Dormans, the creator of the Machinations Framework [Dormans, 2012] has discussed the concept of game mechanics. The author stated that within the game design community game mechanics is often used as a synonym for rules which are closer to the implementation of the game. Meaning that mechanics need to be accurate enough for game programmers to turn them into code without confusion or for board game players to execute them without failure. McGuire & Jenkins state that ”Mechanics are the mathematical machines that give rise to gameplay; they create the abstract game” [McGuire and Jenkins, 2009]. Based on this statement, [Dormans, 2012] pointed ”out that mechanics are media-independent: they are amongst those parts of games that are separable from images and sounds and might actually be transposed from one medium to another: a board game might be recreated as a computer game with different art and a different theme without altering the mechanics”. Finally, other authors have also highlighted the designation of ”core mechanics” as the mechanics with which the player interacts more often and have the biggest impact on the gameplay [Adams and Rollings, 2007, McGuire and Jenkins, 2009].

Although the concept of game mechanics is well-known in the context of entertainment game design, there isn't a clear definition nor an agreement of what are their core features nor how they should be combine to create a meaningful gameplay experience. Moreover, when designing Serious Games other aspects such as the achievement of pedagogical goals also have to be taken into account, for each the proposed definitions offer no clear guidance. Therefore, understanding what are the core features of game mechanics for Serious Games, presents an opportunity to take the design of Serious Games a step forward. Particularly, it would help pedagogues, game designers and developers to better communicate, because it could be used as a semi-formal language to specify how pedagogical goals can be achieve through specific mechanics. Also, it could help provide evidence of Serious Game efficiency by relating game mechanics and objective measures (composed of valid performance measures) that could be collected and analysed using both qualitative and quantitative methods.

3.3 Critical Transport

The transport of critically ill patients is potentially harmful. These patients' condition may deteriorate by being mobilized or they may need sophisticated treatment such as advanced life support during transportation. Therefore, there must be an important reason for their transport, i.e. a clinically relevant necessity/ advantage as for instance a heart catheter in a patient with an acute myocardial infarction. The clinical risk of transportation must be quantified and qualified so that a decision can be made regarding what kind of resources - material and human - are needed for a safe intra- or inter-hospital transport. The Portuguese Society of Intensive Care (Sociedade Portuguesa de Cuidados Intensivos)

Score	Level	Vehicle	Team	Monitoring	Equipment
0-2 (only with O2 and iv line)	A	Normal Ambulance	Paramedic	None	AMS standard
3-6 (without any item that scores 2)	B	Normal Ambulance	Paramedic, Nurse	Pulsoximetry, ECG, Non-invasive blood pressure	The above + Monitor Iv medication and fluids
> 7 or < 7 if any item sores 2	C	Ambulance with advanced equipment	Paramedic, Nurse, Physician	Pulsoximetry, ECG, Non-invasive blood pressure, Capnography if needed	The above + defibrillator with external pacemaker, ventilator; material for tracheal intubation; perfusion pumps

Table 3.1: Correspondence between patient evaluation score and team, monitoring and equipment

and the Portuguese Medical Board (Ordem dos Médicos) released recommendations for the transport of critically ill patients in 2008 [de Cuidados Intensivos and dos Médicos, 2008]. These recommendations establish objective criteria, such as respiratory rate or degree of consciousness, for the evaluation of the patient that lead to a ”risk and needs score”. Three categories of material and human resources are defined and should be available during the transport of each patient according to his/her individual score (Table 3.1). With this clinical decision tool the responsible physician has an important support for the clinical management of the patient who needs transportation.

3.3.1 Context and Learners

Before the development of the game it was necessary to understand how these recommendations should be covered, whom they should be aimed at and what they should be like. For that purpose several unstructured interviews [Cohen et al., 2007] took place at an academic hospital which involved a number of major stakeholders, namely, two physicians and one nurse.

After this initial discussion it was decided that the Critical Transport serious game would be a scenario-based game with two main parts. Part one focused on evaluating the criteria directly related to the patients' condition while part two was related to deciding what was the right crew and equipment to transport the patient.

During these interviews it was also decided that the Critical Transport serious game was targeted at 4th year medical students. The rationale of this choice was related to two main conditions. The first was related to the familiarity of students with the hospital environment, which in the case of 4th year students is almost none because it is during this academic year that they have their first contact with a real hospital environment. The second was related to the level of familiarity with the pedagogical content. Most medical concepts involved in the recommendations are familiar to the students, nevertheless evaluating each of the listed criteria requires the student to relate different information, for example the student must collect information from various sources such as the ECG monitor and the perfusion pump to do a proper evaluation of the hemodynamic state, and also locate and understand the data provided by medical equipment. Therefore, the main aim of the game was to provide the student with an immersive scenario were they could safely have their first contact with a real world situation.

Finally, it was decided that the Critical Transport would be used in a formal setting, a workshop class at the academic hospital. The summary description of the outcome of the interviews and discussions following the 4-DF are presented in Table 3.1.

Context	Learner Specifics	Pedagogical Considerations	Representation
The serious game will be integrated as part of a formal class in the academic hospital aimed at teaching the recommendations for the transport of critically ill patients as described in [de Cuidados Intensivos and dos Médicos, 2008].	The serious game will be used by 4th year medical students. The serious game will be used by learners working singly	Kolb's experiential learning and problem-based learning. Learning activities: solving clinical cases. Learning outcomes: knowing patient condition criteria that needs to be evaluated; the appropriate team and equipment of the ambulance that will transport the patient.	The recommendations for the transport of critically ill patients will have a medium level of fidelity, including 3D animated non-player characters (the nurse and the patient). The learning activities and outcomes will be accomplished by implementing different clinical cases with increase level of difficulty.

Figure 3.1: Four-Dimensional Framework applied to Critical Transport serious game

3.3.2 Learning Objectives and Game Mechanics

The main objective of the Critical Transport serious game is to teach students the recommendations for the transportation of critically ill patient. The document describing the recommendations was analysed by the physicians responsible for teaching the workshop class and it was decided that the game should comprise five main learning objectives: (1) Identify hospital material (e.g. Guedel airway tube); (2) Relate patient condition and hospital equipment data (e.g. hemodynamic state); (3) learn which are the criteria that should be observed in order to decide in which conditions the patient should be transported (e.g. arrhythmia risk, respiratory rate); (4) Be able to decide which is the appropriate team to accompany the patient (e.g. paramedic, nurse); and (5) Be able to decide the appropriate equipment for the ambulance transporting the patient (e.g. ventilator; material for tracheal intubation);

In order to integrate these learning objectives into the gameplay, nine main game mechanics were proposed for the Critical Transport serious game (see Table 3.2). These game mechanics incorporate possible kinds of interactions that take place during the game, be it general or specific [Salen and Zimmerman, 2004] and establish how the game progress, and what are the winning and losing conditions [Dormans, 2012]. The game mechanics are described as an input-process-output model. The player does an action within the game which results in changes in the state of the game which allows the player to have more knowledge about the game itself as well as how successful is her/his current strategy (how well she/he is doing). Next we describe each of these mechanics and relate them to the pedagogical objectives of the serious game.

The *Examine Patient* game mechanics (Fig. 3.2) describes what is the game process when the player clicks on the avatar representing the patient. This action initiates a camera zoom to the part of the body of the patient that the player wishes to examine, namely arm, chest and face allowing her/him to check for peripheral central venous accesses, artificial airways and respiratory support.

The next three mechanics are quite similar in terms on functioning as they all express an interaction between the player and medical equipment, specifically an ECG monitor (Fig. 3.3), saline flow meter (Fig. 3.4) and syringe pump (Fig. 3.5). In the case of the *ECG Monitor* game mechanics, it allows the player to check the patient heart rate, respiratory rate, O2 saturation and Blood Pressure (Sys, Dia).

Examining the saline flow meter provides the player with the current information

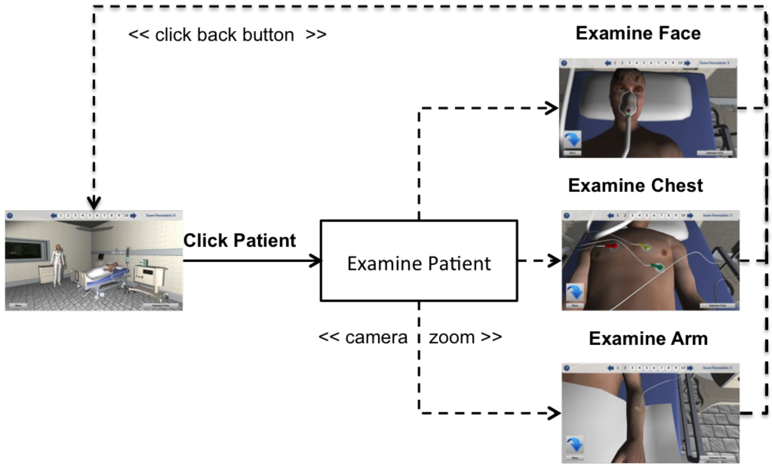


Figure 3.2: Examine Patient Game Mechanics (GM1)

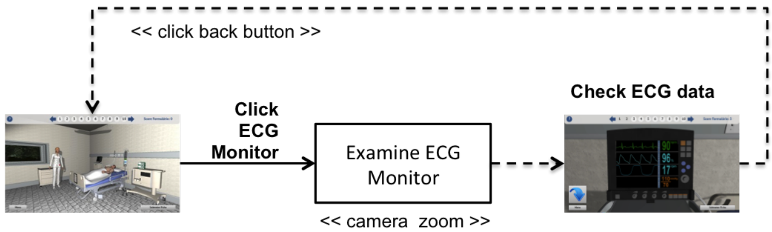


Figure 3.3: Examine ECG Game Mechanics (GM2)

about the current flow of saline being administrated to the patient. The syringe pump

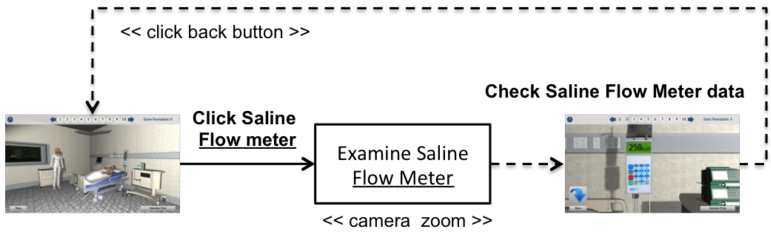


Figure 3.4: Examine Saline Flow Meter Game Mechanics (GM3)

shows all the information related to the medication currently being administered to the patient. The *Examine Patient Chart* game mechanics has all the relevant information regarding the clinical case and patient data, such as name, age, previous clinical conditions and also a description of what was the situation that caused the patient to be in the hospital. The *Examine Glasgow Scale* game mechanics (Fig. 3.7) allows the player to ask the nurse for information. In the context of Critical Transport, the information the player

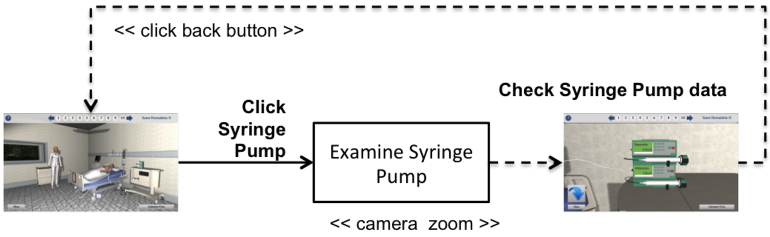


Figure 3.5: Examine Syringe Pump Game Mechanics (GM4)

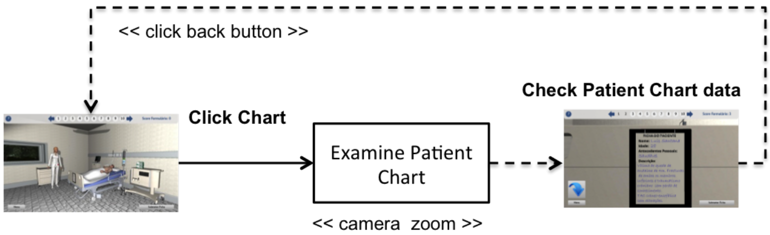


Figure 3.6: Examine Patient Chart Game Mechanics (GM5)

can ask is related to the patient's Glasgow coma scale, specifically eye, verbal and motion response. In the real environment a physician has to examine and evaluate all the previous

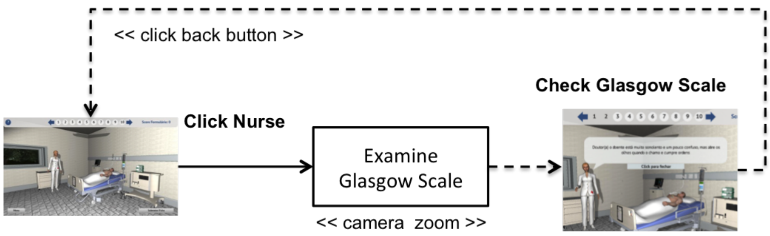


Figure 3.7: Examine Glasgow Scale Game Mechanics (GM6)

criteria and fill out a ten item form. This form was integrated in the game and its visual aspect is very close to how it looks in the real environment. In this manner it will be easier for the player to translate the familiarity gained by playing the game to her/his work practices. The only concern was that it would not obstruct or somehow block any relevant part of the 3-D environment. Every question has an associated score which is updated every time the player fills out one of the questions in the form. This behaviour is encapsulated in the *Fill Out Questionnaire* game mechanics. The next two game mechanics are related to the team and equipment of the ambulance responsible for transporting the patient. The

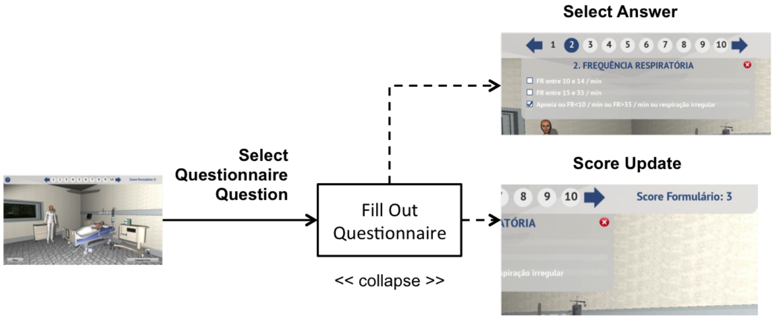


Figure 3.8: Fill Out Questionnaire Game Mechanics (GM7)

Choose Team game mechanics allows the player to choose the proper team having into account the patient's condition. The team can be composed of a combination of the following healthcare professionals: paramedic, nurse and physician. Regarding the *Choose*

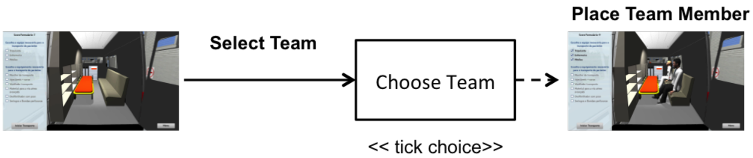


Figure 3.9: Choose Team Game Mechanics (GM8)

Equipment game mechanics, it allows the player to choose to take in the ambulance an ECG monitor, a ventilator and defibrillator among other things.

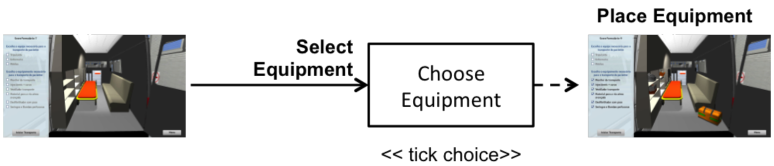


Figure 3.10: Choose Equipment Game Mechanics (GM9)

In Table 3.2 is summarized the correspondence between learning objectives and game mechanics.

Learning Objectives	Game Mechanics
Identify hospital material	GM1, GM2, GM3, GM4, GM5
Relate patient condition and hospital equipment data	GM1, GM2, GM3, GM4, GM5, GM6
Criteria for the transport	GM1, GM2, GM3, GM4, GM6
Transport team	GM8
Transport equipment	GM9

Table 3.2: Learning Objectives and Game Mechanics

3.3.3 Representation

The Representation dimension of the 4-DF is concerned with ”how interactive the learning experience needs to be, what levels of fidelity are required and how immersive the experience needs to be” [de Freitas and Oliver, 2006]. In the following sub-sections it is described how the environment and every relevant element was represented and how the interactivity and immersion was integrated in Critical Transport.

3.3.3.1 Representation and Immersion

The main goal of Critical Transport is to teach students the recommendations for the transportation for the transport of critically ill patients, which involves, as explained previously, evaluating the criteria directly related to the patients’ condition and deciding what is the right crew and equipment to transport the patient.

Evaluating the patients’ current condition takes place in a hospital environment and involves the interaction between the physician and the patient, the physician and a nurse and the physician and hospital equipment. Therefore, the representation of the environment was modelled as close as possible to the real environment, specifically a hospital room. For this reason, software developers and the 3D artist spent several mornings or afternoons in the Emergency Department where rooms, material and every relevant element of the environment were documented photographically. Also, it was possible to observe how things were done in a real situation/environment.

The representation of the virtual hospital room can be depicted in figure 3.11. The yellow circled areas are clickable interaction spots, namely, a nurse which informs the player about the patient's neurological status (help regarding Glasgow coma analysis) (1), zoom to patient's chart (2), zoom to vital signs monitor (3), zoom to patient (check IV lines and intubation/ventilation) (4), perfusion pump (5), and drugs infusion pump (6). When doing the evaluation the physician has to fill out a form with specific information for each of the criteria. This form was incorporated in the virtual environment and includes buttons to open the form's questions (b), the interface to answer the form's questions (c), the form's score (d) and the submit button (f) which can only be used when the form is completed.

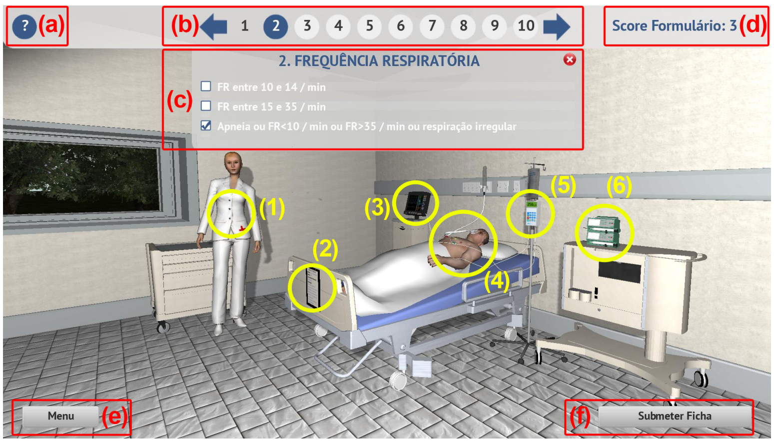


Figure 3.11: Evaluation Phase Representation

The Critical Transport includes four different clinical cases. Each clinical case includes a patient with a different clinical condition. The goal of including different clinical cases was to allow the player to be able to learn to recognize different medical equipment (e.g. oxygen therapy, mechanical ventilation) and related different medical data (e.g. systolic blood pressure and Glasgow coma scale). The different avatar representations are depicted in Figure 3.12.

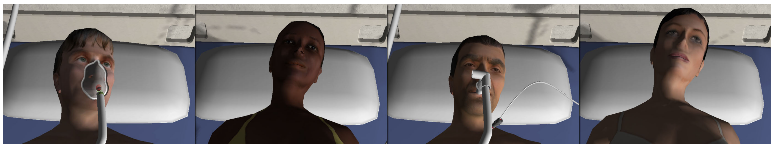


Figure 3.12: Patient Avatar Representation

In a real situation the physician doesn't have to choose the crew and equipment per se. Instead, the score that results from evaluating the criteria regarding the patients' condition already indicate which is the type of ambulance adequate to perform the transport. Nevertheless, two of the pedagogical goals of the Critical Transport include teaching the students to be able to choose the appropriate ambulance crew and equipment. These two pedagogical goals were included in the second scenario of the game and include the form's score (a) to support the user's choices, check-boxes to choose the team (b), the equipment (c), a button to submit the choices and start the patient's transport, an ambulance 3D scenario where the selected items will appear (e), and a menu button (f).

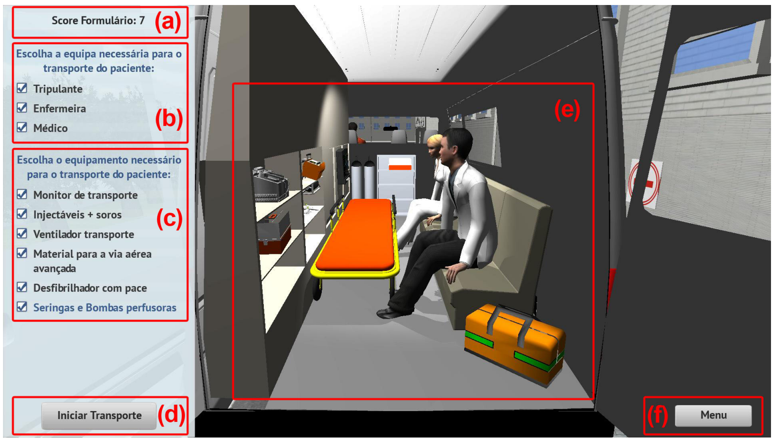


Figure 3.13: Team and Equipment Choice Representation

To enhance player immersion, all the realistic visual effects were achieved using unity3D shaders and custom scripts were developed to load and display models, set camera positions and control poses and animations. Poses and animations can be mixed and blended as well as played back at the desired speed. Sound support was also added to the game in order to have a more engaging and realistic environment.

3.3.3.2 Interactivity and UI

The Critical Transport is targeted at medical students which may not be 'gamers' in general. Therefore, the interface was created with the goal of making the player's interaction as simple and efficient as possible. With that purpose in mind several principles were taken into account.

Firstly, in the initial prototype tests we noticed that some students and most of the physicians had some difficult in navigating in a 3D environment. In order to solve that problem, the navigation was based on point-and-click. This greatly facilitates the navigation inside the virtual world for players that are not used to playing games or navigating inside 3D environments.

Secondly, it was important to avoid long training times. For this reason, we based many aspects of the user interface on well-known 2D interface principles. Among the elements used are conventional buttons, boxes and windows, all of which are used in software programs (e.g. Word, email) familiar to most medical students. Also, a help screen was integrated in the game to help students to rapidly be familiarized with the game environment (Fig. 3.14).

Finally, it was important to make the game extensible to other languages and possible alterations of the pedagogical content. Hence, every string used for button labels, message

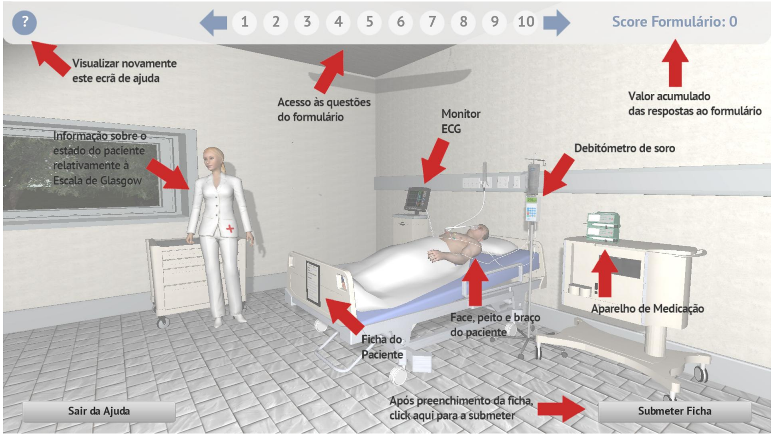


Figure 3.14: Help Screen

boxes, form items, are defined in XML files in order to ease the game translation and to improve its extensibility. Also, this further prevents the game from being obsolete in case the recommendations change and a different form must be filled out during patient evaluation.

3.4 Sepsis Fast Track

Severe sepsis and septic septic shock refers to a hole body infection that causes, among other things, organ malfunction leading to failure and in many cases premature death. Therefore, this health condition is considered a priority as it affects millions of people all over the world. In order to guarantee that patients are identified and treated in time a protocol based on evidence has been proposed [Dellinger et al., 2013].

3.4.1 Context and Learners

The Sepsis Fast Track serious game integrates the current version of the sepsis protocol (see Appendix B). The main goal of developing a Serious Game to teach the sepsis fast track protocol was to provide a tool that help healthcare professionals to learn or refresh four main aspects of the protocol: medical acts sequence, the appropriate therapeutics that should be applied and when; the interactions between physician-nurse and physician-patient; and fill out the sepsis fast track form on the IT system. Also, because time is a critical factor for sepsis patients, these four aspects would have to be done in a timely manner.

The methodology as well as the pedagogical considerations and game constructs used to develop this case study were similar to the ones described in the previous case study. The dimensions where these two case studies differ are specifically the context, learner specifics and pedagogical content. The Sepsis Fast Track serious game is targeted at healthcare professionals (triage nurses, interns and attending physicians), the learning content is the sepsis fast track protocol and the serious game would be integrated on-the-job-training. The summary of applying the 4-DF to the Sepsis Fast Track serious game is depicted in Table 3.15.

Context	**Learner Specifics**	**Pedagogical Considerations**	**Representation**
The serious game will be used both to train and refresh the sepsis fast track protocol as described in [commitee, 2012] as a on-the-job-training tool at the academic hospital.	The serious game will be used by triage nurses, interns and attending physicians. The serious game can be used by learners working singly and in groups (nurses and physicians).	Kolb's experiential learning and problem-based learning. Learning activities: solving clinical cases both positive and false positive. Learning outcomes: knowing the protocol sequence; the appropriate therapeutics in each protocol step; how to interact with the nurse and when and how to use the IT system.	The sepsis fast track will have a medium level of fidelity, including 3D animated non-player characters (the nurse and the patient). The learning activities and outcomes will be accomplished by implementing different clinical cases with increase level of difficulty.

Figure 3.15: Four-Dimensional Framework applied to Sepsis Fast Track serious game

3.4.2 Scenarios

As in the previous case study the main idea underlying each scenario was to place the player in a real-world situation but in this case it involved identifying a patient with sepsis. Therefore, the main element of each scenario was also a clinical case. Nevertheless, certain pedagogical as well as game design considerations had to be taken into account. Namely, the sepsis protocol is quite more complex than the recommendations for the transport of critically ill patients and the serious game is targeted at both triage nurses, interns and attending physicians.

Based on the results of applying the 4-DF it was decided that the game would be composed of two main parts. The first would be played by the triage nurse which involved executing all the necessary steps to identify a potential case of sepsis. The second would be played by a physician which would then do all the necessary steps to confirm and if necessary treat a sepsis case.

Regarding pedagogy, to correctly evaluate a sepsis clinical case more information is needed regarding patient clinical history and current condition, among other things. Also, in order for the player to fulfil the pedagogical objectives of the game it is also necessary that she/he treats the patient until a stable condition is reached. This means that all the information has to be coherent with the therapeutics administered to the patient and the time it was given. This information had to be integrated with and all the necessary actions in order for the player to follow the protocol as she/he would do in a real-world situation. Next a description of the clinical cases both for the nurse and for the physician are described.

Nurse scenarios

The scenarios for the nurse were mainly concerned with performing the triage of a patient that just arrived at the emergency department. In particular, the nurse should ask the patient her/his current complaints, take her/his temperature, heart rate and respiratory rate and based on this information decide if it is a possible sepsis case or not. If it is, the nurse is also responsible for activating the sepsis fast track and call the attending doctor to assist the patient as soon as possible. Disregarding if it is a sepsis case or not the nurse has also to register all the relevant information regarding the patient current condition in the hospital IT System. These activities and which conditions identify a possible sepsis case are described in the first step of the sepsis fast track protocol (see Appendix B). In Figure 3.16 two different clinical cases are presented. The remaining clinical cases that were implemented can be consulted in Appendix A.

ID	1
Sepsis Positive Identification	True
Sepsis Positive Confirmation	True
Patient Personal Details	
Name	Luis Santana
Age	52
Weight	70
Birth Date	06/02/1961
Genre	Masculino
Patient Details	
Clinical Process ID	123456789
Complaints	Ando há 3 dias com tosse, deito expectoração escura que é difícil de soltar e canso-me muito, às vezes sinto que o ar não entra. Hoje então nem consegui ir trabalhar.
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]
Temperature	38.7
Heart Rate	110
Respiratory Rate	24

Figure 3.16: Nurse: Clinical Case Example

Physician scenarios

The sepsis fast track protocol for the physician involves three main steps. The first involves confirming that it is in fact a sepsis case. There are many medical conditions that have similar symptoms and giving the specific therapeutics to the patient without sepsis, as is the case of the antibiotherapy, may result in his premature death. The same happens in a reverse situation. This requires examining the patient, for example checking the ECG monitor and doing a arterial blood gas. The second step involves requesting complementary exams, doing a fluid challenge and antibiotherapy, among other things. Finally, the third step involves continuing to diagnose and apply therapeutics until the patient is stable to be transferred to the intensive care unit. Another important requirement is that the physician register all the relevant data in the IT system. This is important both for patient care quality as well as hospital management.

This implies that there is an order that has to be respected when executing the sepsis fast track protocol. But it is not just the order that we wanted the learner to retain. It is also very important that she/he is able to properly judge the situation (what exams to order, the amount of fluids to give, etc.) while treating the patient. In order to accomplish these goals it was necessary to allow the learner to interact with a range of different situations, namely different patient conditions.

Also, each scenario was divided in three different moments that encompass a two hour period (1h, 1:30h and 2h). Twelve different clinical cases were developed with the healthcare professionals that included both positive and negative sepsis cases as well as different combinations of protocol steps. In Figure 3.17 an example of a clinical case is provided. The remaining clinical cases are in Appendix A.

ID	1			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	True			
Patient Personal Details				
Name	Luis Santana			
Age	52			
Weight	70			
Birth Date	06/02/1961			
Genre	Masculino			
Patient Details				
Clinical Process ID	123456789			
Complaints	Ando há 3 dias com tosse, deito expectoração escura que é difícil de soltar e canso-me muito, às vezes sinto que o ar não entra. Hoje então nem consegui ir trabalhar.			
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]			
Temperature	38.7			
Heart Rate	110			
Respiratory Rate	24			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	90	80	88	120
Diastolic Blood Pressure	50	46	52	60
Urine Flow Rate	0	15	25	200
Central Venous Pressure	6	6	12	12
Exclusions	-			
Clinical History	Fumador			
	00h00	**01h00**	**01h30**	**02h00**
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.
Physical Exam	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sem sinais de má perfusão periférica. Eupneico, sem tiragem. Auscultação pulmonar com fervores na base direita.
Lactate	5	6	4	3
Complementary Exams	RX Tórax			
Exams Results				
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.35	7.38	7.39	7.39
pC02	32	33	35	35
p02	61	65	74	74
ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	90%	91%	94%	94%
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random

Figure 3.17: Physician: Clinical Case Example

3.4.3 Learning Objectives and Game Mechanics

In order to define which game mechanics would create a gameplay where the player could interact with a sepsis case and correctly learn the respective protocol it was first important to define what were the learning objectives. During several meetings in the hospital with the team involved (both nurses and physicians) it was decided that the serious game would have three main learning objectives for the nurses and eleven main objectives for the physicians for which appropriate game mechanics were proposed. Next we describe the main game mechanics developed in order to integrate the learning objectives in the Sepsis Fast Track gameplay.

Nurse Mechanics

Taking into account the triage nurse responsibilities in the real environment it was decided that the main pedagogical objectives that had to be fulfilled were: identify the criteria for suspected infection, know the criteria for the Systemic Inflammatory Response Syndrome (SIRS) [Dellinger et al., 2013] and register data and activate sepsis fast track in the IT System. In order to do so, the player, playing as a nurse, had to be able to interact with a patient, with the IT system, and with the physician in charge. Each of these interactions were defined according to the following mechanics.

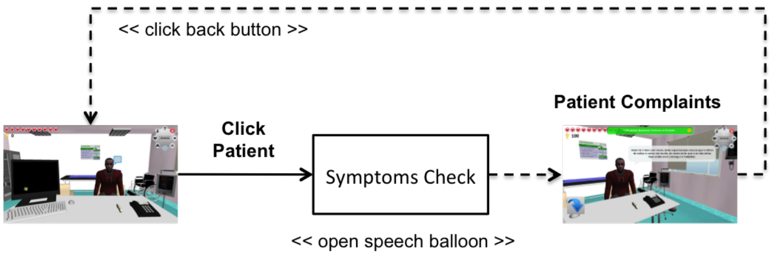


Figure 3.18: Symptoms Game Mechanics (GM1)

The *Symptoms Check* game mechanics (Fig. 3.18) allows the player to ask which are the complaints that motivated the patient to visit an Emergency Department. Based on this information, the presence of a suspected infection can start to be analysed.

There are three main diagnosis game mechanics available to the nurse, namely the *Ex-*

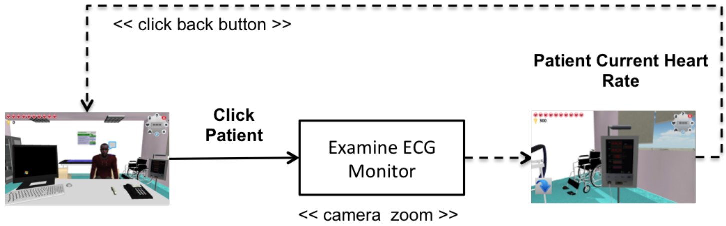


Figure 3.19: Examine ECG Game Mechanics (GM2)

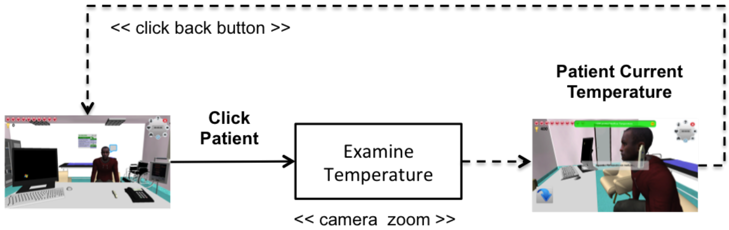


Figure 3.20: Examine Temperature Game Mechanics (GM3)

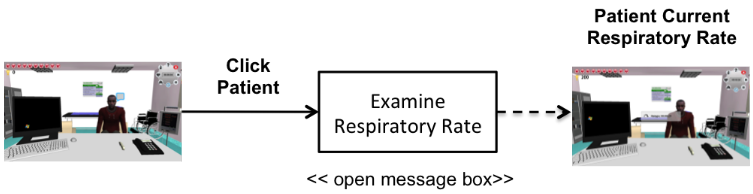


Figure 3.21: Examine Respiratory Rate Game Mechanics (GM4)

amine ECG Monitor, *Examine Temperature* and *Examine Respiratory Rate* game mechanics. All these mechanics are non-invasive and are all used when collecting information to support a diagnosis. They correspond to the evaluation of the Systemic Inflammatory Response Syndrome (SIRS) that ”is an inflammatory state affecting the whole body, frequently a response of the immune system to an infection” [Dellinger et al., 2013]. If two individual criteria are met for SIRS the sepsis fast track must be activated.

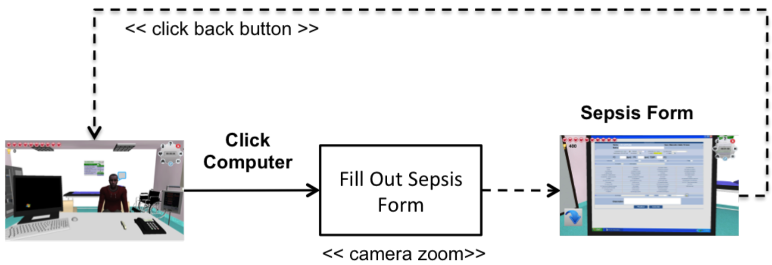


Figure 3.22: Fill Out Sepsis Form Game Mechanics (GM5)

The IT System represents the hospital's information system where all the information regarding the patients' medical acts, among other data are recorded and managed. The Sepsis Fast Track serious game IT system is based on the academic hospital where the case studies were performed and captures the part of the IT system relevant for the sepsis fast track protocol. Namely, the relevant patient data, options, and screens. It was developed using the screenshots of the real system and by watching real professionals using it, simulating a real sepsis case. Using this game mechanics the nurse can register the patients' current heart rate, temperature, respiratory rate and activate (or not) the sepsis fast track.

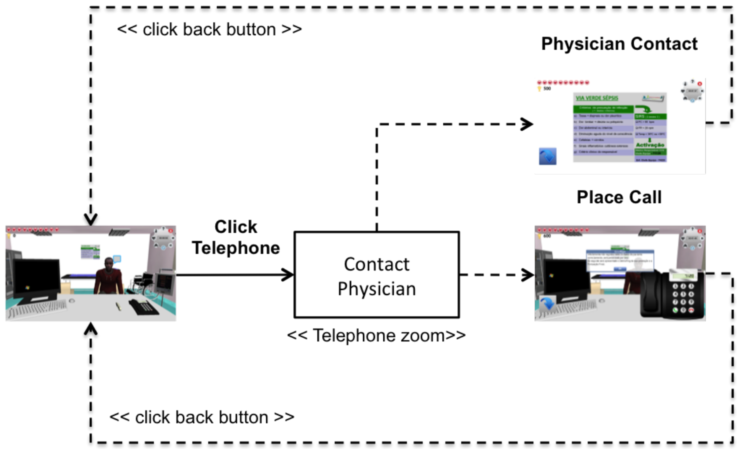


Figure 3.23: Contact Physician Game Mechanics (GM6)

The *Contact Physician* game mechanics allow the nurse to consult and contact the physician in charge. The physician is then responsible for continuing to execute the sepsis fast track protocol until the patient condition is stable.

The *Send to Waiting Room* game mechanics, as the name suggests, allows the player to send the patient to the waiting room. This mechanics should be used if the patient's evaluation concludes that it hasn't a suspect sepsis infection.

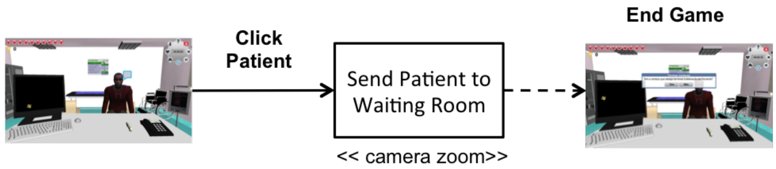


Figure 3.24: Send Patient to Waiting Room Game Mechanics (GM7)

The relationship between learning objectives and game mechanics is described in Table 3.3.

Learning Objectives	**Game Mechanics**
Criteria for Suspected Infection	GM1
Criteria for SIRS	GM2, GM3, GM4
Register data and activate sepsis fast track in the IT System	GM5, GM6, GM7

Table 3.3: Learning Objectives and Game Mechanics

Physician Mechanics

In this phase, the player assumes the role of a physician and her/his goal is to confirm if the patient is or not a case of sepsis. If a case of sepsis is identified the physician is also responsible for administering the necessary therapeutics until the patient current condition is stable and no longer in a life threatening situation. To do so, the player needs to interact with the nurse, the patient and the IT system. The game mechanics that represent these interactions are described next.

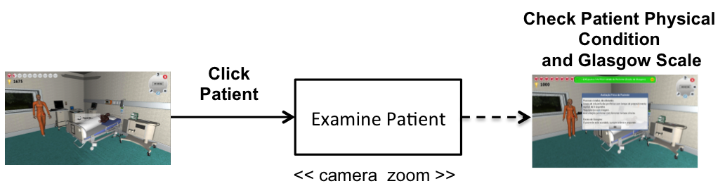


Figure 3.25: Examine Patient Game Mechanics (GM1)

The *Examine Patient* game mechanics (Fig. 3.25) allows the player to perform a physical exam to the patient and also to evaluate his neurological state. To trigger this mechanics, the player must click on the patient and then choose an option from the patient's menu. The outcome of this mechanics is a pop-up message with all the information needed for an accurate patient evaluation.

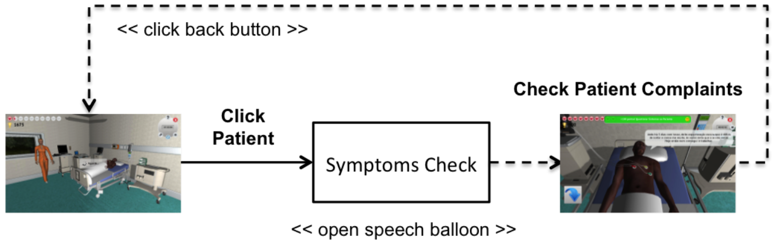


Figure 3.26: Symptoms Check Game Mechanics (GM2)

Additionally to doing a physical exam and evaluating the patients' neurological state, a physician should also ask the patient what are her/his current complaints. The information is available through the *Symptoms Check* game mechanics (Fig. 3.26) which allows the player to interact with the patient and request information regarding her/his current condition. The patient's complaints are presented in a speech balloon and are explained as are usually said by a common person, so the player must interpret them.

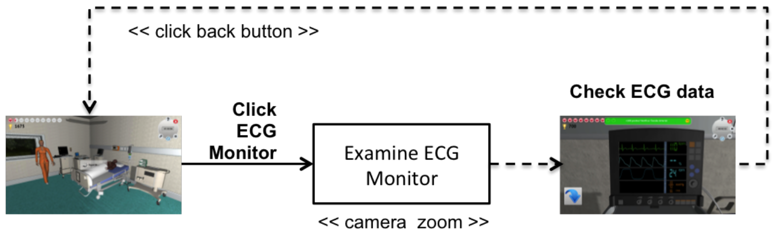


Figure 3.27: Examine ECG Game Mechanics (GM3)

The *Check ECG Monitor* game mechanics (Fig. 3.27) allows measuring the patients' heart rate, respiratory rate, and blood pressure (systolic, diastolic and mean). To trigger this mechanics, the player must click on the ECG Monitor available in the examination room. Evaluating the systolic blood pressure allows the player to evaluate the patient's state of hypoperfusion, which is a condition for confirming the sepsis case. There is a sign of hypoperfusion if the systolic blood pressure is less than 90mmHg.

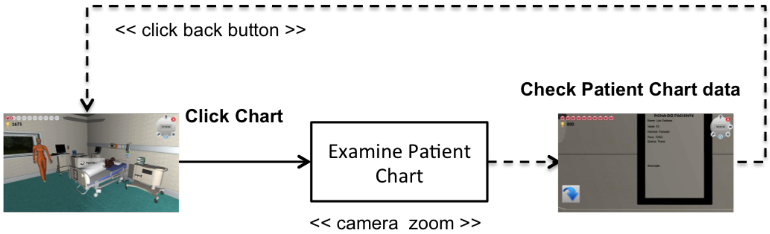


Figure 3.28: Examine Patient Chart Game Mechanics (GM4)

The *Check Patient's Chart* game mechanics (Fig. 3.28) allows the player to check the patient's personal and medical information, such as, name, age, complaints registered during the triage, habits and medical history. With the information available in the patients' chart, the player can decide if the patient has any exclusion criteria. Even if a patient has a confirmed sepsis infection and hypoperfusion, if he has any exclusion criteria the antibiotherapy cannot be administered. Therefore, the sepsis fast track must not be validated and the evaluation must end. The patients' chart is represented by a clipboard on the patient's bed.

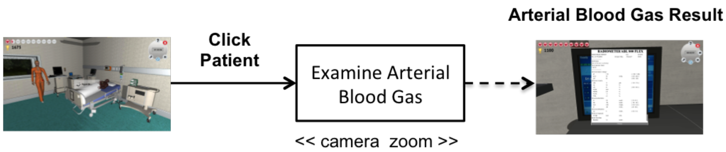


Figure 3.29: Examine Arterial Blood Gas Game Mechanics (GM5)

The *Arterial Blood Gas* game mechanics (Fig. 3.29) allows the player to perform a blood gas exam. The Arterial blood gas is a blood test that in the sepsis evaluation is used to analyse the blood lactate. If a patient has a lactate value of less than 4mmol/L, it is an indication of a possible sepsis case. To use this game mechanics the player has to click the patient avatar and then choose the Blood Gas option from the patients' menu. This action starts an animation representing the blood gas exam, which ends with a report created by the blood gas analyser. The blood gas report has the same layout and information as the one used in the real environment.

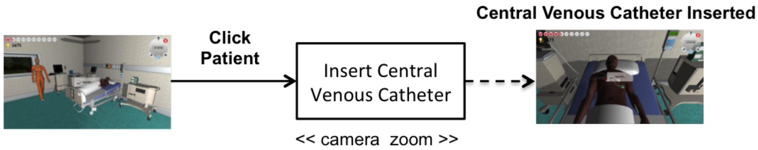


Figure 3.30: Insert Central Venous Catheter Game Mechanics (GM6)

The *Central Venous Catheterization* (Fig. 3.30) allows the player to apply a central venous catheter to the patient. This must be done on Step 4 of the sepsis fast track protocol. To trigger this game mechanics the player has to click the patient avatar and then choose the central venous catheter option from the patient's menu. This action shows an animation representing the central venous catheter application, the fluidtherapy and antibioteraphy tubes, that were connected to a peripheral catheter, are connected to the central catheter. Afterwards, it is possible to check what is the patients' current central venous pressure.

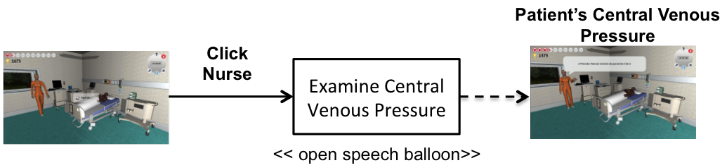


Figure 3.31: Examine Central Venous Pressure Game Mechanics (GM7)

The current value of the central venous pressure is accessible through the nurse interaction menu. Therefore, to examine this value the player has to interact with the nurse and request this information by choosing the appropriate option of the interaction menu. This gameplay functionality is provided by the *Examine Central Venous Pressure* game mechanics (Fig. 3.31).

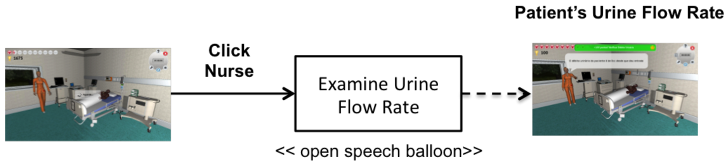


Figure 3.32: Examine Urine Flow Rate Game Mechanics (GM8)

Another criteria that gives a strong indication regarding the patient current condition is the urine flow rate. Specifically, it indicates if the current fluid therapy is having the desired impact. For the player to access this information she/he has to interact with the nurse, in the same manner as in the previous mechanics as it can be depicted on Figure 3.32.

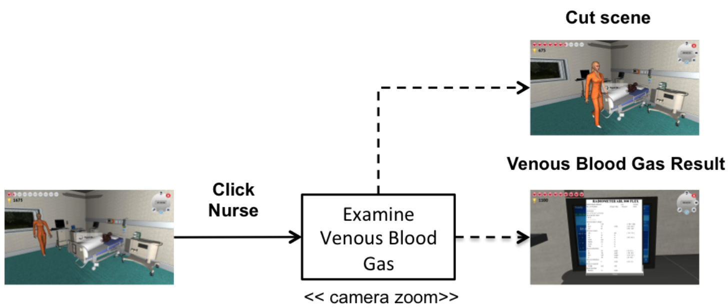


Figure 3.33: Examine Venous Blood Gas Game Mechanics (GM9)

The *Examine Venous Blood Gas* game mechanics (Fig. 3.33) allow the player to monitor the patients' current central venous pressure. This information is provided by the nurse and is presented in a speech balloon.

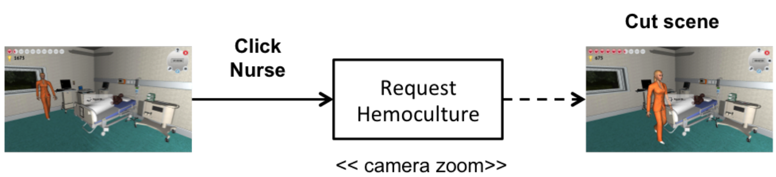


Figure 3.34: Request Hemoculture Game Mechanics (GM10)

”Almost all kinds of micro organisms from blood can be isolated by hemoculture” [Stojanovic et al., 2006]. Despite ”its limiting factors (time of sampling, duration of incubation, possible contamination of samples, number of hemocultures), hemoculture is the only method by which the causes of bacteria and sepsis can be isolated” [Stojanovic et al., 2006]. Therefore, it is very important that the physician in charge do this request in a timely manner, which is available through the *Request Hemoculture* game mechanics (Fig. 3.34).

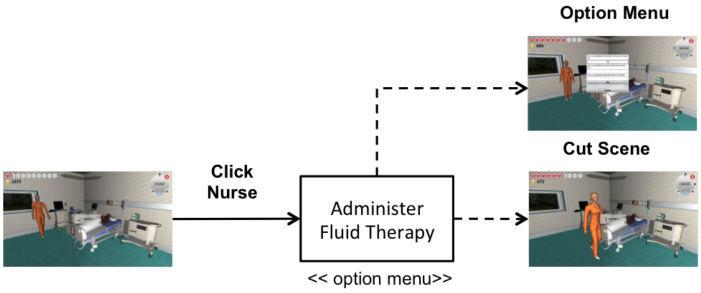


Figure 3.35: Administer Fluid Therapy Game Mechanics (GM11)

The *Fluid Therapy* game mechanics allows the player to initiate fluid therapy (fluid challenge) ”in patients with sepsis-induced tissue hypoperfusion and suspicion of hypovolemia to achieve a minimum of 30 mL/kg of crystalloids (more rapid administration and greater amounts of fluid may be needed in some patients)” [Dellinger et al., 2013]. However, this game mechanics should be used throughout the gameplay as well as hemodynamic improvement, as based on either dynamic or static variables. Therefore, is very important that the physician continually reassesses the patient current condition.

Once a suspected sepsis case is confirmed, the most important action a physician should do is to administer antibiotic therapy. Therefore, the *Antibiotic Therapy* game mechanics is the most important game mechanics of Sepsis Fast Track serious game. It

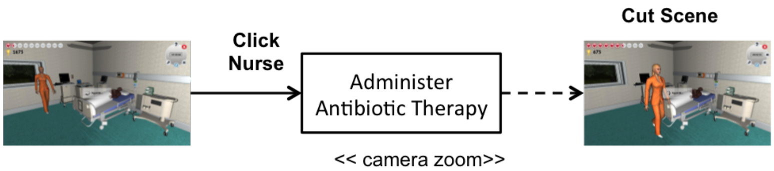


Figure 3.36: Administer Antibiotic therapy Game Mechanics (GM12)

allows the administration of an antibiotic to the patient, which must be made within one hour, since the patient's admission in the Emergency Department. This is critical and if it is not done in time, the patient dies, resulting in a game-over situation.

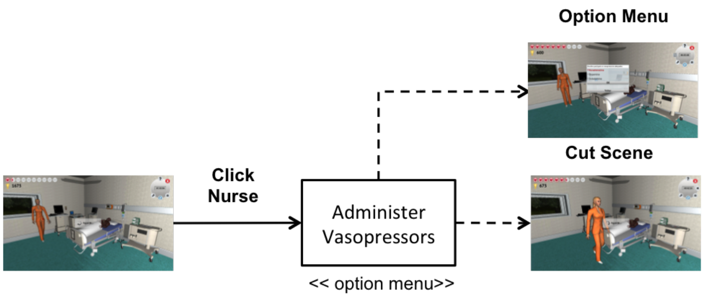


Figure 3.37: Administer Vasopressors Game Mechanics (GM13)

If fluid replacement is not sufficient to maintain blood pressure, vasopressors can be used. This therapeutic is available through the *Administer Vasopressors* game mechanics (Fig. 3.37). When triggered, the player must choose the appropriate vasopressor agent to be administered to the patient. This action starts a real-time cut scene that portrays the nurse administering the chosen vasopressor to the patient.

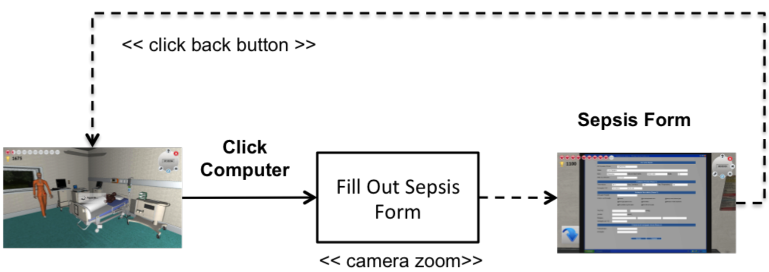


Figure 3.38: Fill Out Sepsis Form Game Mechanics (GM14)

The sepsis fast track form is composed of three main parts. The first is concerned with the systemic inflammatory response syndrome criteria, which are the body temperature, heart rate, and respiratory rate and is filled out by the triage nurse. The second part is where the information about the confirmation, or not, of the sepsis case suspicion is registered. It includes the registration of the arterial blood pressure, checked using the game mechanics *Examine ECG Monitor*, the exclusion criteria, checked using the game mechanics *Examine Patient Chart*, the Glasgow coma scale, checked using the game mechanics *Examine Patient*, and the lactate value, checked using the game mechanics *Examine Arterial Blood Gas*. In this part it is also registered the validation, or not, of the sepsis fast track. Finally, the third part of form is concerned with the information about the therapy administered to the patient. This should only be used if a sepsis case is confirmed and validated. Also, the time when when the patient had the therapy (hemocultures, antibiotherapy and fluid therapy) should be registered.

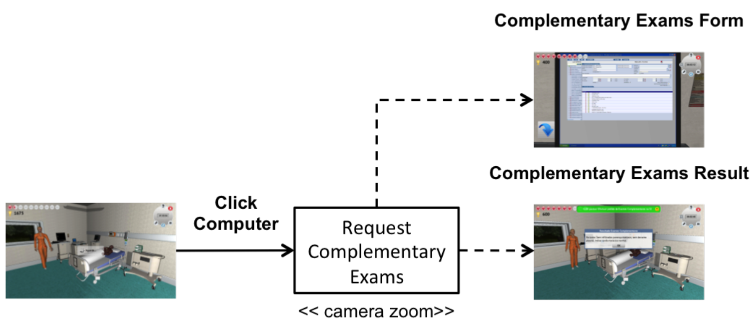


Figure 3.39: Request Complementary Exams Game Mechanics (GM15)

The cause of an infection can't always be confirmed by a blood test. Therefore, to do a proper diagnosis and clearly identify the cause of the infection it is necessary to request complementary exams, such as X-ray, CT scan, or ultrasound. The *Request Complementary Exams* game mechanics allows to the player to access the IT system and request all the necessary exams. After the request is placed the nurse informs the player of the results for all the requested exams.

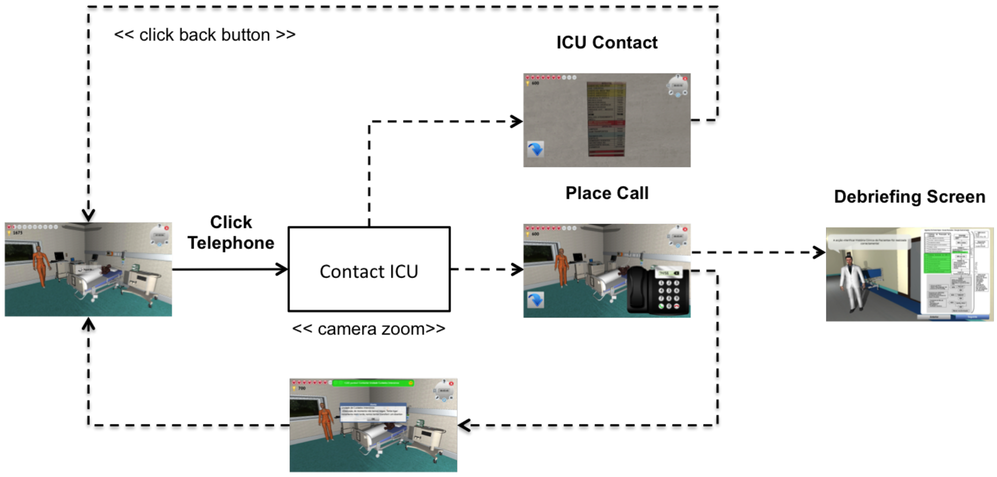


Figure 3.40: Contact Intensive Care Unit Game Mechanics (GM16)

Patients with a suspicion of sepsis are in a critical condition and must be monitored during 24h after they were diagnosed during triage. Once the patient is given the initial therapeutics (antibiotic, fluid therapy) she/he should be transferred to the intensive care unit where she/he is constantly monitored and attended in order to guarantee that her/his health condition doesn't deteriorate. This would be the ideal scenario but the intensive care unit is an area of the emergency department that has allocation problem due to crowding. Therefore, transferring a patient is always a difficult task. We have introduced this situation in the gameplay through the *Contact Intensive Care Unit* game mechanics. The player should contact the intensive care unit between each protocol step in order to successfully transfer the patient.

The relationship between learning objectives and game mechanics is described in Table 3.4.

Learning Objectives	Game Mechanics
0 hour	
Confirm suspicion	GM1, GM2, GM3, GM4, GM5
Administer initial therapeutics	GM12, GM13
Register clinical case in the IT System	GM14
Request and interpret the appropriate complementary exams	GM5, GM7, GM8, GM9, GM10, GM15
Transfer patient to the ICU	GM16
After 1 hour	
Reassess patient condition	GM1, GM2, GM3, GM5, GM7, GM8
Perform appropriate therapeutics acts to keep CVP > 8	GM6, GM7, GM11
Transfer patient to the ICU	GM16
After 1 hour and 30 m	
Reassess patient condition	GM1, GM2, GM3, GM5, GM7, GM8
Perform appropriate therapeutics acts to keep MAP > 65	GM3, GM13
Transfer patient to the ICU	GM16
After 2 hour	
Reassess patient condition	GM1, GM2, GM3, GM5, GM7, GM8
Perform appropriate therapeutics acts to keep $S_cVO_2 > 70\%$	GM7, GM9
Transfer patient to the ICU	GM16

Table 3.4: Learning Objectives and Game Mechanics

3.4.4 Representation

As described previously, the Representation dimension of the 4-DF is concerned with ”how interactive the learning experience needs to be, what levels of fidelity are required and how immersive the learning experience needs to be” [de Freitas and Oliver, 2006]. In the following sub-sections it is described how the environment and every relevant element were represented and how the interactivity and immersion were integrated in Sepsis Fast Track serious game.

3.4.4.1 Representation and Immersion

In the following sub-sections is described how the virtual environment, the hospital IT system, Avatars and interactivity are represented in the sepsis fast track serious game.

Environment

The first person to have contact with a possible sepsis case is the nurse(s) responsible for triaging patients in the Emergency Department. A part of executing the Manchester triage protocol, the nurse has to evaluate the SIRS criteria in order to clearly diagnose if it is a possible sepsis case or not. This means that the nurse has to be able to measure the temperature, heart rate and respiratory rate and relate this information with the current patient's complaints. Therefore, these elements had to be integrated in the virtual environment.

The triage takes place in a dedicated place in the hospital and as in the previous case study its representation in the virtual environment is as similar as possible to the real environment. The underlying idea was to both facilitate the player's interactions within the virtual environment and also to ease transferring the knowledge gain in the serious game to work practices. In order to do so the triage room in the hospital facilities was photographed and several nurses were observed while triaging patients in the real environment.

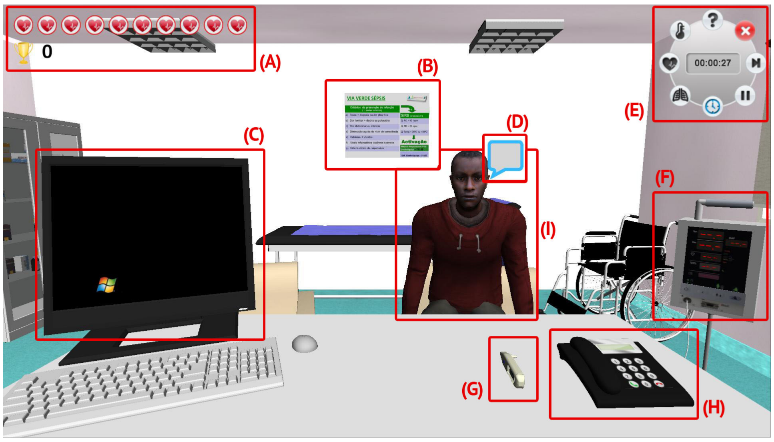


Figure 3.41: Hospital Triage Room Representation

In Figure 3.41 the elements available to the player playing the nurse scenario is presented. The following list described each element in more detail:

(B) Sepsis Poster contains the sepsis fast track procedures and is a replica of the poster that exists in the triage room at the Emergency Department.

(C) Computer Allows the player to access and register patient's data in the hospital IT system. Also, it allows the player to activate the sepsis fast track. The IT system is described in more detail below.

(F) ECG Monitor Allows the measurement of the patient's heart rate.

(G) Thermometer Allows the measurement of the patient's temperature.

(H) Phone Allows the contact of sepsis fast track responsible physician, in order to refer the patient as a possible sepsis case. When the player makes the call, this game's phase ends.

(I) Patient Avatar represents a possible sepsis patient.

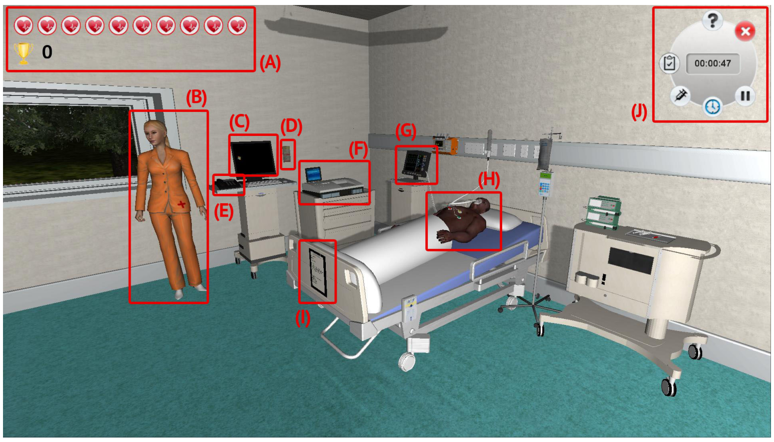


Figure 3.42: Hospital Room Representation

The hospital room representation used in the physician scenario is similar to the one described in the previous case study, except it includes more medical equipment (e.g. Blood Gas Analyser) which were modelled to match the look and feel of their real counterparts.

As in the nurse scenario, the realistic representation of both the environment and interactions with environment elements is related, potentially easing the transfer of knowledge gain in the serious game to work practices. Therefore, a similar (photography and observation) methodology was used to model the physician environment. The complete list of elements that composed the physician scenario can be depicted in Figure 3.42 and includes:

(B) Nurse Avatar Allows the player to ask the nurse information regarding patient medical condition and to perform medical acts.

(C) Computer Allows the player to access and register patient information in the hospital IT system. Moreover, it allows the player to request complementary exams and fill out the sepsis fast track form. The IT system user interface is presented in more detail below.

(D) Phone Book Allows the player to consult hospital internal contacts, namely the phone number of the intensive care unit.

(E) Phone Allows the player to contact the intensive care unit.

(F) Blood Gas Analyser Allows the player to view the arterial or venous blood gas report. This report is only available after the player performed a blood gas exam.

(G) ECG Monitor Allows the player to check the patient's vital signs, namely blood pressure, oxygen saturation, and heart rate.

(H) Patient Avatar Prompts the possible interactions with the patient, namely, ask for symptoms, perform a physical exam, and execute a blood gas exam.

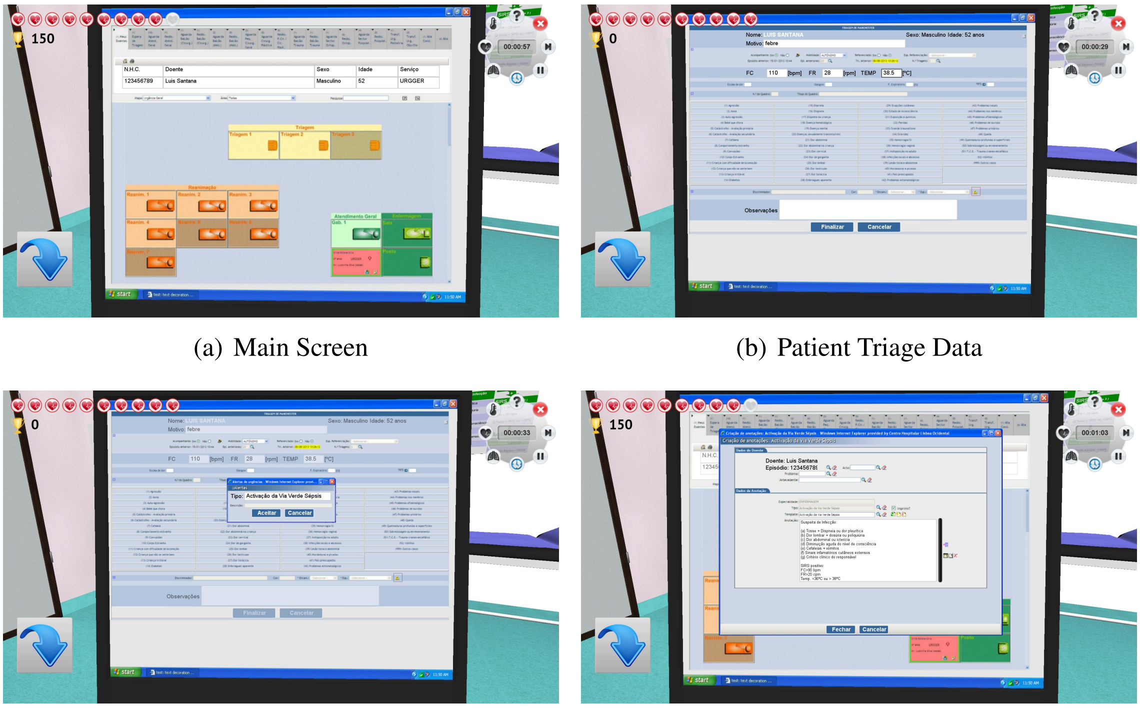
(I) Patient's chart Shows the medical and personal information about the patient, such as, name, age, medical history, among others.

Hospital IT System

The sepsis fast track protocol includes both guidelines for patients diagnose and treatment but it also established the kind of information that has to be registered for each patient in the hospital IT system. This is both relevant for better patient care as well as for improving hospital management. Therefore, one of the goals of the Sepsis Fast Track serious game, as described in Section 3.4.3, was to increase the usage of the current IT system when registering sepsis clinical cases, both by nurses and physicians. Although there are patients that are identified and confirmed, most of the times the healthcare professionals do not register all the medical acts that were made. Therefore, in most cases it is not possible to know what actually happened to the patient. In order to increase the compliance regarding IT system usage by healthcare professionals, every element of the real IT system relevant to the sepsis fast track was integrated in the game.

The development of the in-game IT system is made using screenshots of the real IT system, which facilitated the identification of several elements. Namely buttons, dynamic text boxes, editable text boxes, drop-down menus, among others. This development, based on the real IT system, allows the players to know exactly where the needed options are and learn and train how to fill in and register the needed data into sepsis fast track form.

In the case of the nurse, he/she has access to the patient triage data (Fig. 3.43 (b)) through the main screen (Fig. 3.43 (a)). This is the screen where the values for the SIRS criteria are registered and the sepsis fast track can be activated (Fig. 3.43 (c)). Finally, he/she can also annotate any relevant information regarding the patient clinical condition (Fig. 3.43 (d)).



(a) Main Screen

(b) Patient Triage Data

(c) Sepsis Fast Track Alert

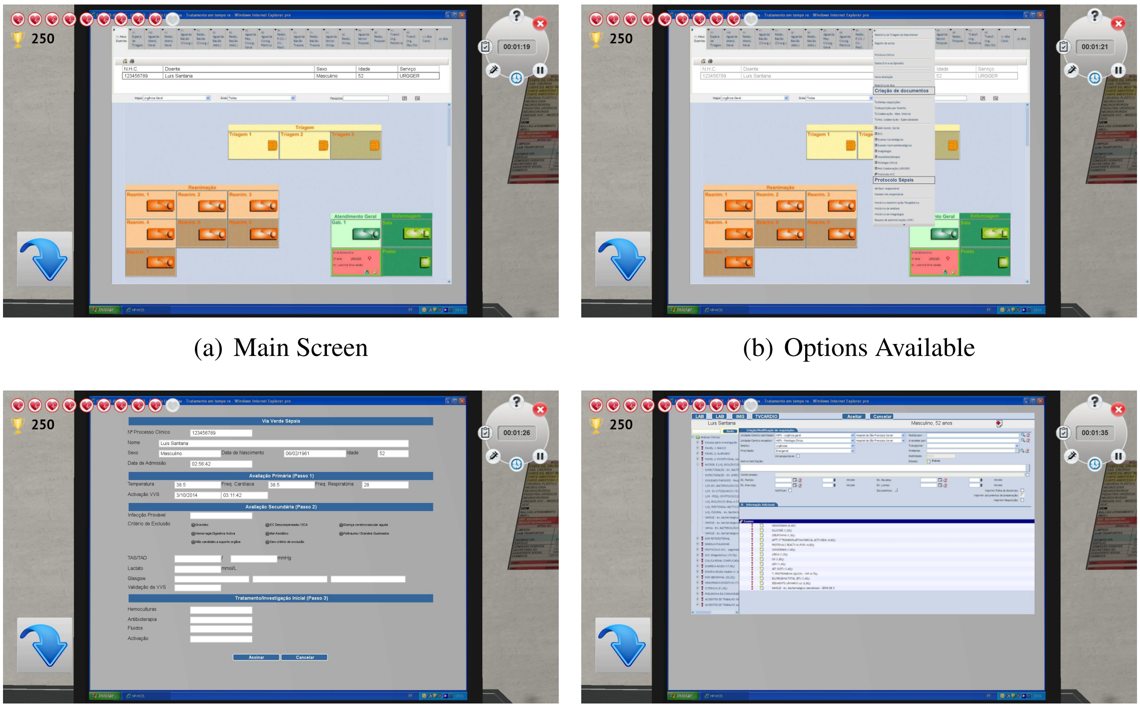
(d) Sepsis Fast Track Annotation

Figure 3.43: Hospital IT System

In the case of the physician, he/she has access to the sepsis fast track form (Fig. 3.44 (c), choosing the appropriate option (Fig. 3.44 (b)) in the menu available in the main screen (Fig. 3.44 (a)). Finally, he/she can also request all the necessary complementary exams (Fig. 3.44 (d)) to clearly diagnose the patient current condition.

Avatars

As described in Section 3.4.2, there are nine different clinical cases in the Sepsis Fast Track serious game. Each of these clinical cases describes a patient with different characteristics, both clinical and personal (e.g. gender, name, age). The avatars used to



(a) Main Screen

(b) Options Available

(c) Sepsis Fast Track Form

(d) Complementary Exams Request

Figure 3.44: IT System of Sepsis Case Confirmation and Therapy game's phase.

represent each patient are the same in the nurse and physician scenario, but in the nurse scenario the patient is dressed and sitting and in the physician scenario the patient is undressed and lying down in a hospital bed. Six different avatars representation can be depicted in Figure 3.45.

Figure 3.45: Patient Avatar Representation

3.4.4.2 Interactivity and UI

Although the target users in this case study were healthcare professionals and nurses instead of students we observed the same difficulties during the first user tests as described in Section 3.3.3.2. Therefore, the same principles used in the development of Critical Transport were applied to the Sepsis Fast Track serious game. Specifically, the player interaction with all the environment elements is done using point-and-click interaction which greatly facilitates navigating in the 3-D environment. Moreover, the use of mouse buttons when interacting with the IT system is exactly the same as in the real environment.

In the case of the sepsis fast track there is a lot more information with which the physician needs to interact. In the real environment, every physician has a notebook where she/he keeps notes regarding relevant patient information. Also, the gameplay is longer than in the case of the Critical Transport and the game was divided into two different scenarios targeted at different healthcare professionals. Therefore, we have added to the head-up-display a UI widget where some useful options and information are available to the player. A more detailed description of the head-up-display per scenario is presented next. Finally, in the sepsis game we have included a score and lives with increase or decrease according to the decisions the nurse/physician does while playing the game (Fig. 3.42 and 3.41 (A)).

Nurse UI Widget

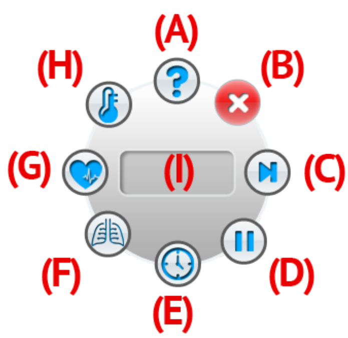


Figure 3.46: Nurse Scenario UI Widget

The UI widget (Fig. 3.46) in the nurse scenario is composed of eight buttons that have the following functionalities:

(A) Help Opens the Help (Fig. 3.45) dialogue.

(B) Exit The player is prompted with a pop-up that allows him/her to quit the game.

(C) Skip Nurse Scenario It allows the player to to skip the nurse scenario and go directly to the physician scenario. This option is only available if the player chose to play both as a nurse and a physician in the Login screen.

(D) Pause Allows the player to pause the game. This prevents time from advancing which is an important aspect of the sepsis fast track protocol.

(E) Clock This option shows the clock, a time counter, in the Information Panel (I).

(F) Respiratory Rate This option shows the patient's respiratory rate in the Information Panel (I). This information is only visible after the player examines the patient's current respiratory rate.

(G) Heart Rate This option shows the patient's heart rate in the Information Panel (I). This information is only visible after the player examines the patient's current heart rate.

(H) Temperature This option shows the patient's temperature in the Information Panel (I). This information is only visible after the player examines the patient's current temperature.

(I) Information Panel Displays information to the player, such as, time passed since the beginning of the game, patient's temperature, respiratory rate, and heart rate.

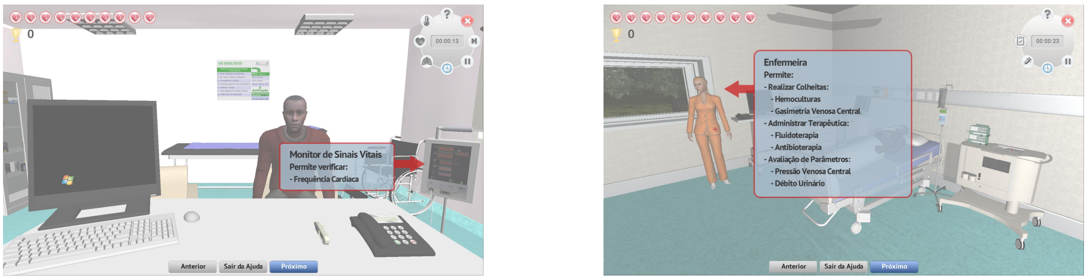


Figure 3.47: Nurse Help Screen (Right) and Physician Help Screen (Left)

Physician UI Widget

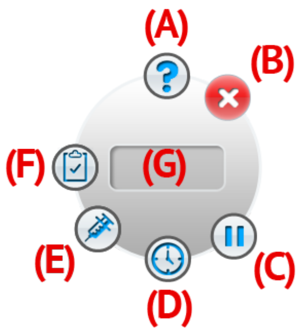


Figure 3.48: Physician Scenario UI Widget

The UI widget (Fig. 3.48) in the physician scenario is composed of six buttons that have the following functionalities:

(A) Help Opens the Help (Fig. 3.45) dialogue.

(B) Exit The player is prompted with a pop-up, allowing him/her to quit the game.

(C) Pause Allows the player to pause the game. This prevents time from advancing which is an important aspect of the sepsis fast track protocol.

(D) Clock This option shows the clock, a time counter, in the Information Panel (I).

(E) Blood Gas Report Shows the patient's arterial or venous blood gas report. This report is only available after the player performed a blood gas exam.

(F) Previous Acts This option shows the previous medical acts performed by the player.

(G) Information Panel Displays the time passed since the beginning of the game

4

Experimental Studies

In the following sections is described the experimental studies conducted to evaluate the efficacy of the Serious Games developed in knowledge gain, retention and impact on work practices of healthcare professionals. Moreover, several unstructured interviews were conducted with medical students, interns and attending physicians in order to identify which were the game attributes that had a greater impact on their learning experience with the serious games.

4.1 Evaluating Learning

In the next sub-sections is the described the experimental study conducted to evaluate the efficacy of the critical transport serious game in teaching medical students the recommendations for the transport of critically ill patients.

4.1.1 Methods and Materials

The objective of this study was to determine if the Critical Transport serious game, is an effective educational and training tool for training fourth year medical students on the recommendations for the transport of critically ill patients. The study was conducted in three different formal classes at the academic hospital that took place between October 2012 and June 2013.

4.1.1.1 Participants

Critical Transport was integrated in the learning curriculum of fourth year medical students during their practice in an Emergency Department (ED) of the academic hospital. During the three classes, 25 students used Critical Transport in a class room setting that took place at the hospital. Before each class the students were informed about the study and its respective objectives and were asked if they would freely agree to participate.

4.1.1.2 Procedures

Prior to the beginning of the class, each computer was tested to ensure that the serious game was working properly (sound, colors, playing different clinical cases) and also if the on-line questionnaire was accessible. At the beginning of each class, students were randomly assigned to a computer and given an initial oral presentation of around 10 minutes about the topic that was going to be taught and how the structure of the class was organized. This presentation was performed by the facilitator which is a teaching physician at the ED. After this initial explanation, the students were asked to answer an entry questionnaire (pre-test) for which they had around 5 minutes to submit their answers. Once all students finished the questionnaire, an additional 5 minutes were given for them to be familiarized with the game. To facilitate this task a help screen was provided which explains every functionality of the game (Figure 3.14). The students were also able to ask for assistance if required.

This was followed by asking each student to solve the first two clinical cases of the serious game. For this task they were given approximately 20 minutes. The description of the clinical cases is presented in Table 4.1. Upon completing the clinical cases and debriefing, the students were asked to answer an exit questionnaire (post-test).

The pre/post-test questions were a mixture of general questions regarding the transport of critically ill patients as well as more specific questions such as, which of these criteria should be evaluated or what is the right crew from a specific type of ambulance.

After conducting the first study [Ribeiro et al., 2013] we realized that it would be interesting and would also help to strength and enrich the analysis of our data if we collected in-game data. After discussing with the physician involved in the project it was decided that for each clinical case all the data regarding student choices, both in criteria evaluation as well as team and equipment choice, would be logged per student. Therefore, the analysis of in-game data included only the students that participate in the second and third workshop class in the academic hospital.

At the end of their practice in the ED students were asked to answer a questionnaire regarding their perception of the serious game efficacy as learning and training tool in comparison to the traditional methods. They were asked if they would like to see serious games integrated into their curricula. Demographic data, as well as data regarding gaming habits were also collected. This questionnaire was anonymous in order to reduce the probability of biased answers.

4.1.1.3 Statistics

This study used a combination of qualitative (focus group) and quantitative (questionnaire) data, therefore both descriptive and inferential statistics were used to analyse the data. Regarding inferential statistics the tests used were specifically: to verify if the difference between the pre-test and post-test followed a normal distribution a Shapiro-Wilk

Clinic Case	Description	Monitoring Parameters	Transport Type
1	• 28 year old male • Fell from a scaffolding from a height of 4 meters: Fractured both lower limbs; Head trauma without loss of consciousness • Cranial CT scan unremarkable • Medical history: unremarkable	• Heart rate: (90/min) • Blood pressure: (110/70 mmHg) • Respiratory rate: 17/min • O2 Saturation: 96%	B
2	• 65 year old female • Acute myocardial infarction (onset 6h ago) • Must be taken to the cath lab which is located in another facility in order to get timely coronary re-perfusion • Medical history: Type 2 Diabetes; High blood pressure	• Heart rate: (65/min) • Blood pressure: (130/80 mmHg) • Respiratory rate: 17/min • O2 Saturation: 96%	C

Table 4.1: Clinical Case 1 and 2 description

test with Lilliefors significance correction [Sheskin, 2011] was used; to test if the results of the post-test were correlated with the pre-test we used a Wilcoxon Signed Ranks test [Sheskin, 2011]. Descriptive and correlation analysis were performed using SPSS 21.0. Significance was set at the $p < 0.05$ level.

4.1.2 Results

In the following sub-sections a description of the results obtained are presented. First the sample used in the study is characterized, then the results of pre-test and post-test are compared and finally the in-game log data is analysed.

4.1.2.1 Participants Demographics

The group of 25 medical students was composed of 17 females and 8 males with an average age of 22,28 years old. Regarding student game habits and perceptions, 39% were usual gamers and 39% had previous experience with learning by a serious game in a context different from medical education. 4% of the students had previous training on the learning topic. 64% considered that serious games allow to acquire more, 24% an equal amount and 12% less knowledge than traditional teaching methods (class, lecture or reading). 76% stated that the knowledge would last longer when acquired by a serious game, 20% that it would last an equal amount of time and 4% less time. 92% considered that serious games allowed a better training of skills. All agreed that learning by serious games was more interesting. 80% would like to see serious games to be part of their learning and training curriculum, 12% were indifferent and 8% would rather not have them integrated in the curriculum.

4.1.2.2 Pre-test and Post-test

The pre-test measures the knowledge related to the recommendations of the transport of critically ill patients that students had prior to engaging with the serious game. The 25 students had a mean value of 31% of wrong answers. This lack of knowledge referred mostly to the question related to which physiological parameters should be monitored during transport and which should be evaluated to calculate the risk score during patient evaluation.

Regarding the post-test results, the 25 students had a mean value of 20% of wrong answers. This represent an improvement of 11% when comparing to the pre-test. A graphical comparison of the number of correct answers between pre-test and post-test is depicted in Figure 4.1. Nevertheless, and because the wrong answers were mostly

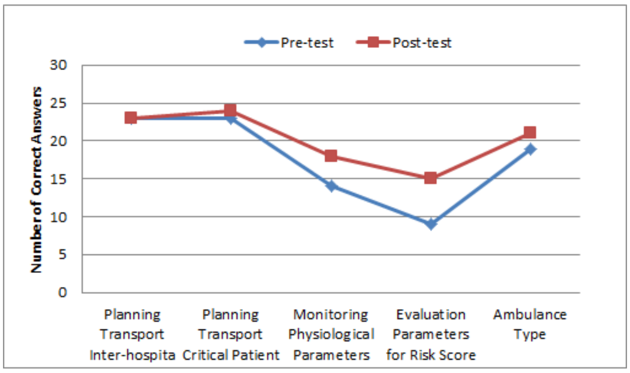


Figure 4.1: Comparison between Pre-test and Post-test.

concentrated in two questions, we analysed the responses of the students and calculated the improvements in the post-test both per question and per student. By conducting this analysis we wanted to track the evolution of correct answers between pre-test and post-test and also understand if the generality of students improved or if it was just some particular cases. The results of this analysis are expressed in Figure 4.2 and Figure 4.3.

In terms of improvements in the post-test per question we observe that in the question related to which physiological parameters should be monitored during transport there was an average improvement of 20%. Meaning that half of the students that didn't know the answer to this question in the pre-test were able to answer it correctly in the post-test. Regarding the question related to which parameters should be evaluated to calculate the

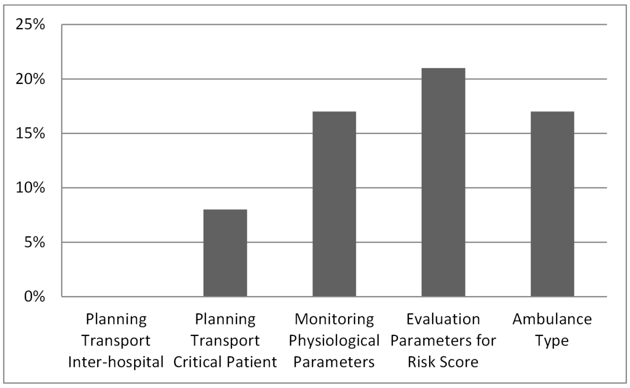


Figure 4.2: Improvements in Post-test per Question.

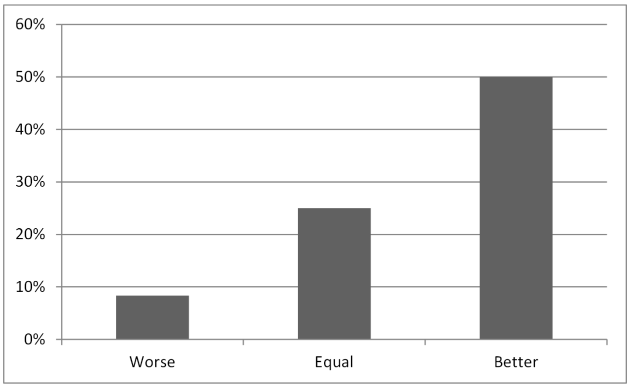


Figure 4.3: Improvements in Post-test per Student.

risk score during patient evaluation we observed an improvement of 25%, which also represents an improvement on average of half of the students in comparison to the pre-test. In planning transport inter-hospital there were no improvements because most of the students had answered it correctly in the pre-test.

Regarding the overall improvement of students in terms of the total number of correct answers in the post-test, we observe that 50% of students had a higher number of correct answers, 25% had an equal number of correct answers and only 8% had a worse result.

For these results to be meaningful we had to understand if the ability of students to answer the post-test increased after using the Critical Transport. Undergoing this analysis involved a number of steps in order to choose the most appropriate test for our study.

First we conducted a normality test on the difference between the pre-test and post-test. Because our sample is smaller than 30 we used the Shapiro-Wilk (SW) test instead of the Kolmogorov-Smirnov test [Sheskin, 2011]. The SW test confirmed that our data set doesn't follow a normal distribution (*sig. = 0.006*), therefore we couldn't use the *Student's t-test* and instead used a Wilcoxon Signed Ranks test (z = *-2.543* e p = *0.011*). These results show that there is a statistically significant difference ($p < 0.05$) in the ability of students answering the post-test. Therefore, we are led to believe that the serious game did have a positive impact on student prior knowledge. In order to be able to better support these findings we conducted a focus group whose results are explained next.

4.1.2.3 In-Game Data Analysis

The pre/post-test questionnaire allowed us to test and measure the knowledge gain regarding both general and specific questions related to the pedagogical content. The in-game data collected just specific information about the recommendations for the transport of the critically ill patients. This information was aggregated into three different groups, namely the in-game questionnaire which covered the criteria that should be evaluated regarding the patient condition, the ambulance team and ambulance equipment. Data was collected from both clinical cases played by the students and the results of comparing these data can be depicted in Figures 4.4 and 4.5.

Analysing each specific group shows that students perform better in the second clinical case when evaluating the criteria. In the other two groups of questions, namely team and equipment the improvement was not clearly observed. In some choices students did perform better in the second clinical case but there were others where they performed worse. This same trend was also observed in the post-test data. In the discussion section

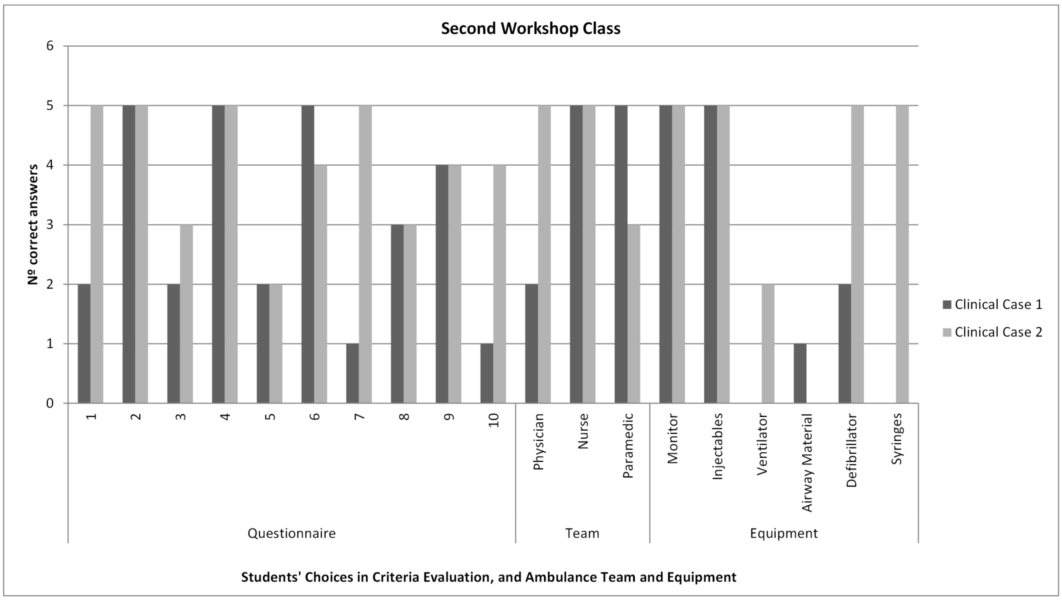


Figure 4.4: Comparison of In-Game Performance: Second Group

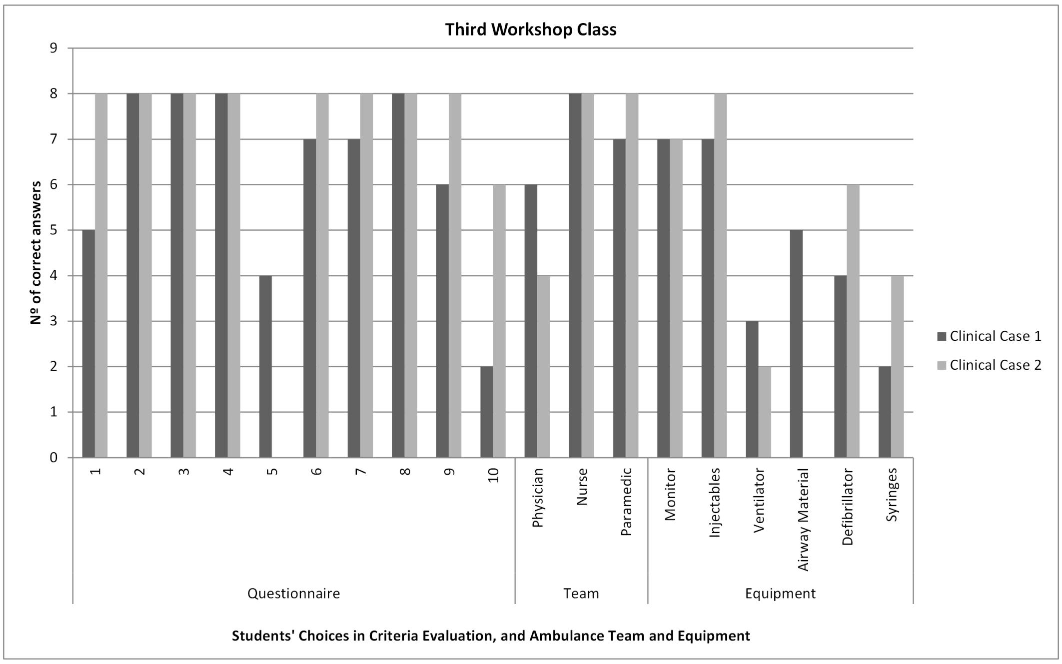


Figure 4.5: Comparison of In-Game Performance: Third Group

we provide possible explanations that might have motivated the discrepancy in improvement when considering different question groups.

4.1.3 Discussion

This study has shown that in general students had a higher ability to answer questions about the recommendations for the transport of critically ill patients both in the post-test as well as while playing the second clinical case. Nevertheless, in the specific questions regarding ambulance team and equipment this positive trend wasn't verified. The biggest difference between the two parts of the serious game is that in the first part (related to criteria evaluation) the students had access to a score that provided feedback about their current choices while in the second part (related to choosing ambulance team and equipment) this is not the case. Therefore, there might be a relation between student performance and in-game feedback. In any case, in-game feedback needs to be carefully balanced because the goal is that the player learns by establishing cognitive links between what she/he currently knows and the information that is available in the 3-D environment and not learned by trial and error or mimicry. Also, the debriefing provided to the students was mainly a monologue just stating what they did well and what did wrong. Due to these results we were also inclined to think that a more carefully designed debriefing, one that better contextualized and related the student decisions and the recommendation would probably help the students to reflect and better understand what and why they did wrong. Therefore, game attributes such as progress and assessment are core attributes in serious games for medical education and their integration in the gameplay has to balance the previous knowledge of the players and its presentation needs to be contextualized, meaning it should clearly connect player actions and pedagogical content.

From all the discussions and during the game design process, it was observed that realism was also a very important factor. Specifically, the level of realism representing the virtual environment (look and feel of medical equipment and location), and also all the data provided. Physicians seemed particularly sensible when certain values (e.g. ECG monitor data) were not coherent with patient data (e.g. medical condition, age) and also the terms used to describe the clinical cases.

Pedagogical approaches, game mechanics and game attributes are the three pillar stones of serious games. Pedagogical approaches define how the pedagogical content should be expressed in terms of tasks and activities while game mechanics and game attributes determine how they are integrated in a meaningful gameplay. Moreover, clearly defining game mechanics and linking them to pedagogical objectives provides the means to define concrete measures of player performance, in this case, if there was knowledge gain and if so how it came about. The process of designing this serious game resulted in a set of game mechanics that tried to mimic what a physician would have to do in a similar situation in a real environment. Analysing these mechanics we can see that they could be grouped by: mechanics that described the interaction between physician and patient, mechanics that described the interaction between physician and hospital equipment; and mechanics that described the interaction between the physician and another healthcare professional. It would be interesting to verify if these game mechanics would be useful to describe other medical procedures. If this was the case, it could potentially be possible to develop a game mechanics library for serious games targeted at medical education that could be used interchangeably in different serious games. Also, it would be very useful to integrate in the mechanics the description of learning analytics that could be collected during gameplay to analyse how effective the game mechanics were attaining a certain learning objective. This not only allows to compare serious games but also student performance between different academic institutions as well as different cultures.

Another important factor observed by us was the importance of the facilitator role both during the design phase as well as during the classes. As argued by Iverson [Michael and Chen, 2006], "serious games offer a paradigm shift in training as it changes the role of the trainee from passive to active and the role of the trainer changes from just delivering material to being a facilitator". Diehl et al. has also argued that the "role of the teacher becomes central as the facilitator of balancing the educational game experiences to other practices and in design terms, he or she must be involved in the game experience itself, either participating in the game or as a close observer" [Diehl et al., 2011]. Also, after the students interact with the serious game the facilitator should be responsible for helping the students to establish a link between the pedagogical content and what the students learned and experienced during gameplay.

Among the things we observed while the students were playing the game was the high level of enjoyment and engagement. This is corroborated by the students' general agreement of having serious games introduced in the classes and that playing the serious game was fun.

Although this is an encouraging finding, further research is needed to determine the most efficient way to utilise gaming technology in medical education. The proximity of the training to the assessment exercise (post-test) may lead to an increased level of performance for the overall students. Therefore, to strengthen our finding it would be necessary to conduct a study that also includes a knowledge retention-test to evaluate if and what is the level of the knowledge retained by students.

Providing evidence of these results has also other important related aspects. Because games can be played anytime-anywhere, application of gaming technology to medical education could promote remote and independent learning. This could be particularly interesting and important for refresher courses. Another use could be as a lower-cost substitute to clinical algorithm simulators. Although the cost of developing a simulator can be similar to a serious game, serious games support virtually an unlimited number of students training at the same time. Therefore, the ratio of facilitator versus students is substantially greater which increases cost and time for training a large number of students when using a simulator. Also, ”mannequin-based simulators have limits with respect to the types of symptoms that are supported (e.g. skin changes)” [von Zadow et al., 2013].

4.2 Evaluating Knowledge Retention: Comparing Blended Learning and Traditional Learning

In the next sub-sections is the described the experimental study conducted to evaluate the level of knowledge retention comparing a face-to-face course with two models of blended learning (face-to-face and serious game with face-to-face with video).

4.2.1 Aims

The aim of this study was to compare the educational effectiveness between a face-to-face class and two models of blended course (combined video and serious game). Student perceptions and opinions regarding the use and efficacy of serious games for medical education were also registered.

4.2.2 Methods and Materials

The subjects in this study were forty-two 4th year medical students currently doing workshop classes and practical work in an Emergency Department (ED) of an academic hospital. Before the experiment, the students were informed about the purpose of the study and asked their consent to participate voluntarily.

The main goal of the course was to teach the recommendation for the transportation of the critically ill patients. The content of the course, as described in the PowerPoint presentations, included (1) identification of critically ill patients (2) the initial cares that should be provided to these patients, and (3) the initial therapeutic attitudes of the physician in charge of the patient.

The serious game is a video game specifically developed to practice the recommendations for the transport of critically ill patients. It was developed by a multidisciplinary team composed of physician, software developers and a designer and previous to this study it was evaluated during formal classes in the academic hospital. The details of both the design considerations and initial evaluation were described in [Ribeiro et al., 2013]. An extended version of this paper, which includes the complete evaluation, results and discussion was selected to be published in the Special issue from VS-Games 2013 conference, IGI's International Journal of Game-Based Learning.

The design of the study was according to similar studies comparing face-to-face courses with on-line courses or blended learning models [Kavadella et al., 2012,Makhdoom et al., 2013]. Every subject in our study attended a conventional class of 45 minutes led by an instructor and supported by PowerPoint presentations. During the class the students were invited to participate by both answering questions as well as clarifying any questionable or difficult issue about the topic being taught. After the conventional class the students were randomly divided in three groups (see Fig. 4.6). The first group, was dismissed and allowed to go home. The second group was directed to another room where they played the serious game Critical Transport [Ribeiro et al., 2013] during 15 minutes. During this time interval the students played the first two clinical cases of the serious game (see Table 4.2). The two clinical cases both refer to patients in need to be transported to a different institution due to their critical condition but differ in difficulty, specifically understanding and relating information regarding patient clinical history and current condition.

The third group stayed in the room and watched a video during 15 minutes. The video showed two game sessions, one of the first clinical case and another of the second clinical case narrated by one the of the responsible physicians responsible for teaching the workshop.

In addition all the students filled out three different questionnaires: (a) before starting the face-to-face class all groups completed a (i) knowledge test (pre-test) to identify their current knowledge level and (ii) a questionnaire of demographic information, expectations and attitudes regarding serious games; (b) After one month, and without previous notice, the students were administered a mandatory knowledge test (retention-test) at the academic hospital after the students morning classes. Knowledge tests contained right/wrong, multiple choice questions about the recommendations for the transport of the critically ill patient and were devised by the physicians responsible for administering the conventional class, which were also involved in the design of the serious game. The ques-

Clinic Case	**Description**	**Monitoring Parameters**	**Transport Type**
1	• 28 year old male • Fell from a scaffolding from a height of 4 meters: Fractured both lower limbs; Head trauma without loss of consciousness • Cranial CT scan unremarkable • Medical history: unremarkable	• Heart rate: (90/min) • Blood pressure: (110/70 mmHg) • Respiratory rate: 17/min • O2 Saturation: 96%	B
2	• 65 year old female • Acute myocardial infarction (onset 6h ago) • Must be taken to the cath lab which is located in another facility in order to get timely coronary re-perfusion • Medical history: Type 2 Diabetes; High blood pressure	• Heart rate: (65/min) • Blood pressure: (130/80 mmHg) • Respiratory rate: 17/min • O2 Saturation: 96%	C

Table 4.2: Clinical Case 1 and 2 description

tionnaire aimed at eliciting students' perceptions, expectations and satisfaction regarding serious games was composed of three yes/no questions, one multiple choice question, four three-point Likert-scale and one open question. This questionnaire was only answered by the group of students that attended the game session.

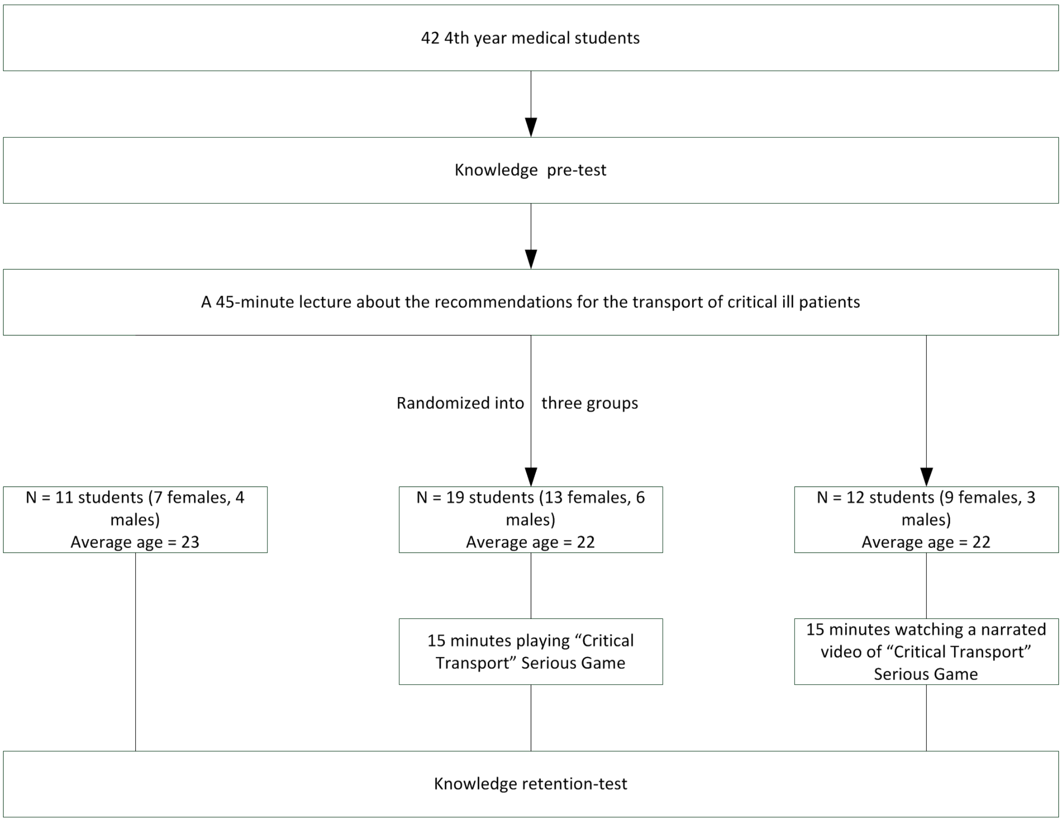


Figure 4.6: Research flowchart

Statistics

This study used both descriptive and inferential statistics to analyse the data. Regarding inferential statistics the tests used were namely: to verify if the difference between the pre-test and retention-test were correlated we used a Wilcoxon Signed Ranks test [Sheskin, 2011]; to compare the differences between group we used the Kuskal Wallis non-parametric test. These tests were chosen because our sample did not follow a normal distribution. Descriptive and correlation analysis were performed using R Studio. Significance was set at the $p < 0.05$ level.

4.2.3 Results

The group of 42 medical students was composed of 29 females and 13 males with an average age of 23 years old. All the students were currently in the 4th year of medicine degree and from the same university.

Descriptive analysis of the student's scores obtained in the knowledge assessment according to the group and point of assessment are presented in Table 4.3 and Figure 4.7.

Descriptive Statistics					
	Teaching method	N	Mean	Std deviation	Std error mean
Knowledge pre-test	conventional	11	4.55	1.21	0.37
	blended (game)	19	4.63	0.90	0.21
	blended (video)	12	4.50	0.80	0.23
Knowledge retention-test	conventional	11	5.73	1.27	0.38
	blended (game)	19	5.95	1.03	0.24
	blended (video)	12	6.25	0.75	0.22

Table 4.3: Mean grade of the students in the knowledge tests

According to pre-test scores we can observe that there were no significant differences on students previous knowledge of the recommendations for the transportation of critically ill patients and we have also verified this same conclusion doing a Kruskal-Wallis test on pre-test scores ($p > 0.87$).

Regarding retention-test results both blended learning models have achieved a slightly higher level of knowledge retention and in particular the group that watched the video have all in general scored higher in the retention test than the group in the face-to-face class and face-to-face game session.

Nevertheless, doing a between group analysis, no statistically significant difference ($p = 0.5$) was observed for groups when comparing results obtained in the two points of assessment and teaching method (see Table 4.4). However, it was also important to

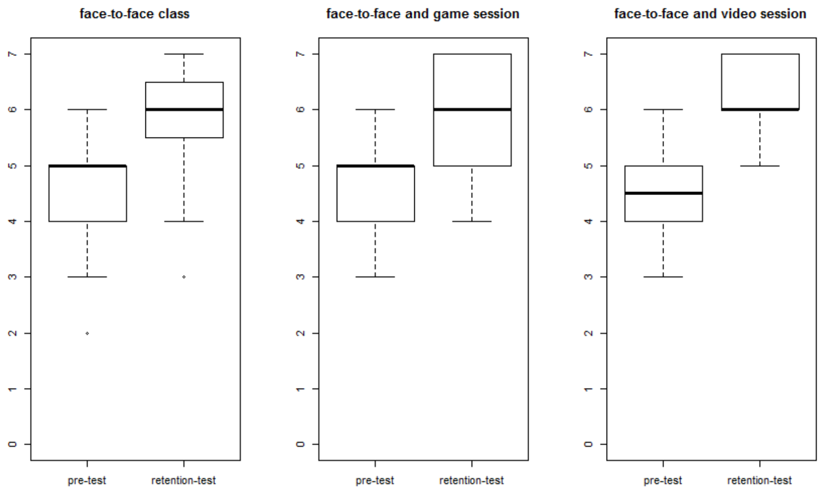


Figure 4.7: Pre/Retention-test Results

analyse the results within group in order to try to establish a casual relationship between retention-test results and the teaching method. For this purpose the Wilcoxon signed rank test was used to verify the correlation between knowledge test scores in each of the teaching methods used. The summary of these results is also presented in Table 4.4. These results show that there is a statistical significance when comparing the difference between pre/retention-test results for the blended learning models, while this was not verified for the conventional class ($p > 0.06$).

Inferential Statistics			
Kruskal-Wallis	chi-squared = 1.3478	df = 2	p-value = 0.5097

	Conventional	blended (game)	blended (video)
Wilcoxon signed rank test	p-value = 0.069	p-value = 0.001	p-value = 0.002

Table 4.4: Comparison between groups (teaching method) and within groups (difference between pre/retention-test)

We have also analysed the improvement of student's performance per question comparing pre-test and retention-test (Fig. 4.8). The questions where the students had more difficulties in the pre-test were *Q1*, *Q6* and *Q7*. Regarding the retention-test, in the face-

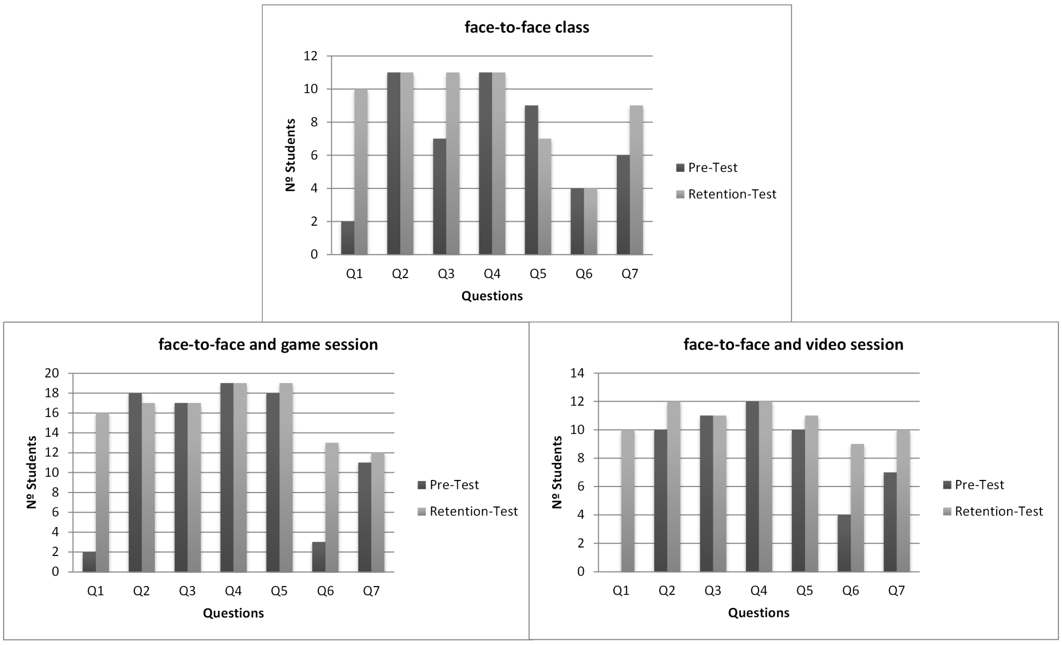


Figure 4.8: Pre/Retention-Test Results per Question

to-face students had difficulties in *Q5* and *Q6*, in the face-to-face and video session in *Q6* and *Q7* and in the face-to-face and game session more than half of the classes had every question correct. This means that, in general, all the students had difficulties identifying initial medical approach (e.g. ABCDE), knowing what are the patient evaluation criteria and appropriate transport type. Nevertheless, it was in this group of questions where there were the highest improvements, specially for the blended learning models.

4.2.3.1 In-Game Log Analysis

The pre/post-test questionnaire allowed us to test and measure the knowledge gain regarding both general and specific questions related to the pedagogical content. The in-game data collected just specific information about the recommendations for the transport of the critically ill patients. This information was aggregated into three different groups, namely the in-game questionnaire which covered the criteria that should be evaluated regarding the patient condition, the ambulance team and ambulance equipment. Data was collected from both clinical cases played by the students and the results of comparing this data are depicted in Figure 4.9.

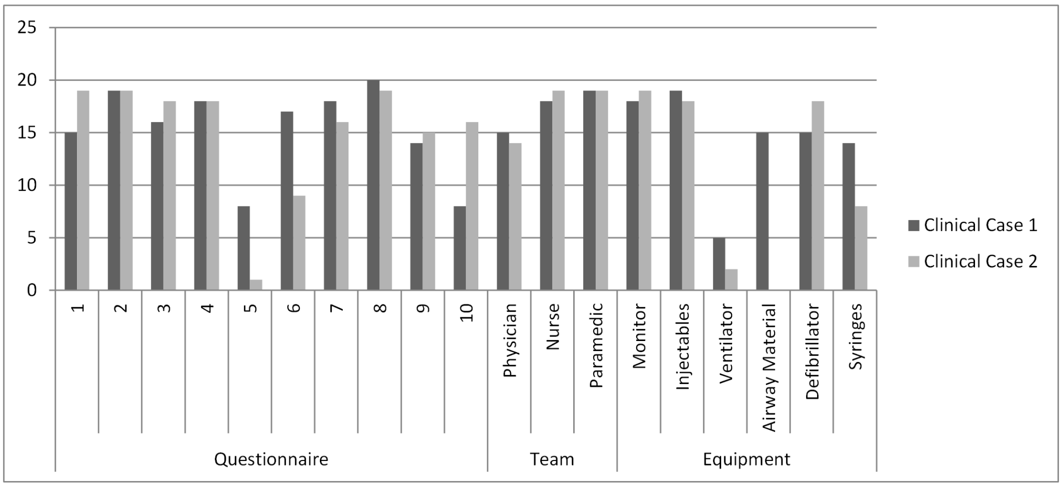


Figure 4.9: Comparison of In-Game Performance

Analysing results between the two clinical cases show that students are erratic in terms of improvement, both regarding the questions about evaluation criteria, as well as team and equipment. There are actually some examples where in some choices students did perform better in the second clinical case but there were others where they performed worse. In the discussion section we provide possible explanations that might have motivated the discrepancy in improvement when considering different question groups.

4.2.3.2 Perceptions and Satisfaction Questionnaire Results

Regarding student game habits and perceptions, 39% were usual gamers and 39% had previous experience with learning by a serious game in a context different from medical education. 4% of the students had previous training on the learning topic. 64% considered that serious games allow to acquire more, 24% an equal amount and 12% less knowledge than traditional teaching methods (class, lecture or reading). 76% regarded that the knowledge would last longer when acquired by a serious game, 20% that it would last an equal amount of time and 4% less time. 92% considered that serious games allowed a better training of skills. All agreed that learning by serious games was more interesting. 80% would like to see serious games to be part of their learning and training curriculum, 12% were indifferent and 8% would rather not have them integrated in the curriculum.

This questionnaire also included an open question in case students wanted to write a commentary regarding Critical Transport and the experience of using it. Next is a transcription of some of the commentaries left by the students and were relevant for our study:

> *"Although the discussion of results and errors is very limited, learning with the serious games is more interactive."*

> *"Conducting a proper discussion of the clinical cases prior to playing the serious game could help consolidate the knowledge gain."*

> *"This teaching method should be applied to other medical areas, involving diverse clinical cases, not just about the recommendation for the transport of the critically ill patient."*

> *"Although i know it was a matter of lack of time, i think that it would have been important in terms of learning to have played the four clinical cases available in the game. Therefore, i think that in the future the class should be longer."*

4.2.4 Discussion

Blended learning models that include either computer-based training such as e-learning or serious games for acquiring factual knowledge are gaining popularity in medical education [Kavadella et al., 2012, Makhdoom et al., 2013, Rondon et al., 2013]. Their role and efficacy in teaching emergency medicine skills have only been accessed in very few recent studies [Platz et al., 2011, Petty, 2013, Back et al., 2014]. To our knowledge, this is the first study that compares the level of knowledge retention between face-to-face classes and two different blended learning models.

The results obtained from this experiment show that although there are no statistically significant difference between groups, both in knowledge assessment test and teaching method, there is a statistically significant correlation for the blended learning models when comparing the difference between pre/retention-test scores. These scores indicate that complementing conventional classes with video watching or serious games can have a positive impact on student knowledge retention.

According to experiential learning theory it was expected that the blended learning group that used the serious game had better results than the other two groups, but this was not the case. There are a few explanations for this result. As states by Mayer et al. in [Mayer and Moreno, 2003] ”meaningful learning refers to a deep understanding of the material, which includes attending to important aspects of the presented material, mentally organizing it into a coherent cognitive structure, and integrating it with relevant existing knowledge”. They further explain that ”meaningful learning requires that the learner engage substantial cognitive processing during learning”, but the learner’s capacity for cognitive processing is severely limited. When interacting with a serious game for the first time, the player has to dedicate cognitive processing to understand what are its underlying rules and goals and how she/he can go about to accomplishing it. While watching a video is a passive activity where the viewer can dedicate its full attention to hear and watch what is being shown. This finding is corroborated with the results of the study conducted by Ridgway et al. [Ridgway et al., 2007] which concluded that surgical students had higher performance results when using web-based aural lectures than non-aural lectures. This means, that the learner requires more cognitive processing abilities when playing a game than when watching a video which might result in reduced cognitive resources to process the learning content of the game. Nevertheless, we believe is worth mentioning that this is the case when the game is new to the player. Once she/he masters how the game is played the cognitive resources would be equally free to process other aspects of the game, specifically the pedagogical content.

The serious game has a higher level of interactivity than watching a video but there is a difference that should be noted. During a game session the player explores the virtual environment and by her/himself attempts to overcome the challenges presented by the game. While, during a video session the teacher and students can interact therefore providing a more guided manner to understand and incorporate the pedagogical content. This means that complementing the game session with the presence of a facilitator or integrating in the game an artificial mentor could provide pedagogical advantages. Nevertheless, both of these approaches have their own set of challenges. Namely, the people responsible for teaching at medical universities and in academic hospitals are medical professionals or medical researchers that are not usually very digital skilled. Therefore, it would be necessary to prepare them for their role in supporting students learning with serious games.

Another factor that should be analysed is the type of feedback that is provided by both mediums, in this case, the serious game and the video. The video per se doesn't give any feedback to the viewer since is a non-interactive experience. On the other hand feedback it is central to the design of games including the design of serious games. Regarding serious games, the importance of such feature is connected to the role that feedback plays in pedagogical approaches as described in [Shute, 2008]. Feedback provides the player with information regarding how he is evolving in the game allowing him to improve her/his current strategies and become a better player. In the particular case of Critical Transport the only feedback provided is regarding the patient evaluation criteria and how it impacts the score related to the ambulance type. Therefore it has no relation to the choices of the player itself. Such observation leads us to believe that this type of feedback is not enough for the player to properly understand and learn from the learning experience provided by the serious game as it doesn't give any hint to the player related to what she/he is doing right or wrong and why. However, efficient feedback design in serious games is in itself an open research question: what kind of feedback, how and when it should be given to the player. Therefore further research should be carried out to verify if changing the type of feedback would have substantial impacts on the levels of knowledge retention.

The participants did enjoy playing Critical Transport and their general opinion was that serious games would allow them to learn more effectively and therefore they would like to see this kind of medium integrated in their formal studies. This is a positive insight since facilitating enjoyment and engagement and learning has been argued to benefit learning.

4.3 Evaluating Impact on Work Practices

In the next sub-sections is the described the study conducted to evaluate if the sepsis fast track would have an impact of healthcare professionals work practices.

4.3.1 Aims

The main purpose of this study was to evaluate the impact of the sepsis serious game on the work practices of both physicians and triage nurses when identifying and treating a possible sepsis patient. In the case of the triage nurses this involves evaluating knowledge and work practices regarding three main aspects of the sepsis fast track protocol, specifically criteria for suspected infection, criteria for SIRS and register data and activate sepsis fast track in the IT system. For the physicians (both interns and attending physicians) involves evaluating knowledge and work practices with respect to four main aspects of the sepsis fast track protocol, namely medical acts sequence, the appropriate therapeutics that should be administered and when; the interactions between physician-nurse and physician-patient; and filling out the sepsis fast track form on the IT system. Also, we want to analyse if there were differences in both attitudes and knowledge gain in retention when comparing interns and attending physicians.

4.3.2 Methods and Materials

This study was divided into two phases. The first consisted in training the attending physicians that form the fixed team of the emergency department. The fixed team is composed by 17 attending physicians of which 11 were included in this study (6 were either in sick leave or on holidays) and they work in the emergency department Monday to Friday from 8h to 20h. During our study we also trained 4 interns, which usually are not part of the hospital staff and only come to this emergency department to do the night and weekend shifts.

Before we started the study we asked the physician to fill out a questionnaires regarding demographic information, her/his gaming habits, previous knowledge regarding the sepsis fast track protocol and experience with serious games. Next they played two clinical cases, one positive and one negative, where they where ask to think out loud. Also in between and at the end of the game session several questions were asked regarding their perceptions, expectations and satisfaction regarding the Sepsis Fast Track serious game. These questions include importance of certain game attributes for learning as well as the suitability of the game to teach this medical procedure both to interns and attending physicians. After one month data were retrieved from the hospital IT system containing information about, number of sepsis fast track activations per year and month and also the the data filled out for each sepsis case in the sepsis fast track form. This data comprises the time interval between January 2011 to February 2014. The research flow chart of this study is depicted in Figure 4.10.

The second phase of this study consisted in training all the triage nurses working in the emergency department. The triage nurses are the first persons to have contact with a possible sepsis case that enters the emergency department. Therefore, it is critical that they are updated and aware of the current sepsis fast track protocol and how it was implemented in the Emergency department. Our study started with a video session, that was specially prepared to help nurses to be aware of the importance of this protocol. Then, they all fill out a questionnaire regarding demographic information, her/his gaming habits, previous knowledge regarding the sepsis fast track protocol and experience with

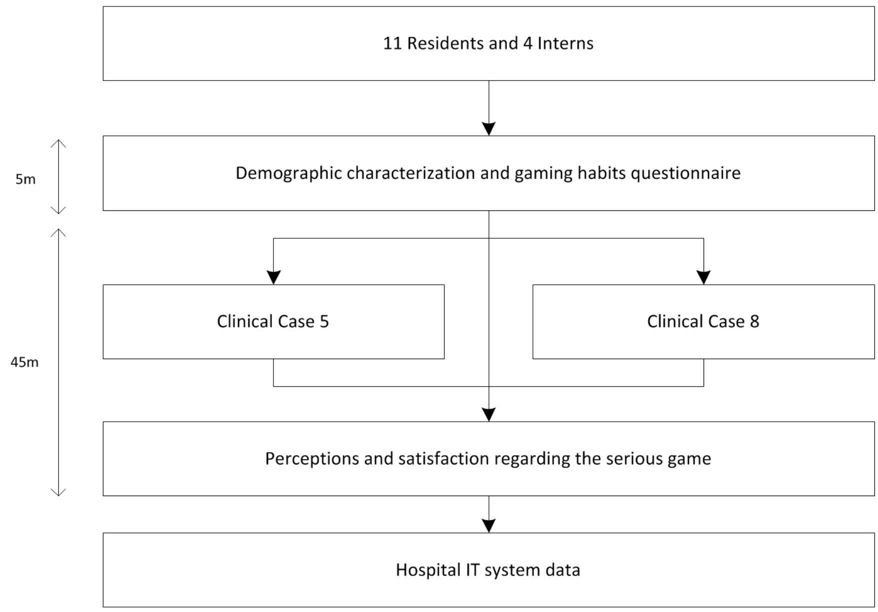


Figure 4.10: Research flowchart: Interns and Attending Physicians

serious games. This was exactly the same questionnaire administered to the physicians. Due to logistic limitations, they were randomly assigned to a computer in groups of two and played four clinical cases, two positive and two negative. After one month data were retrieved from the hospital IT system containing information about the number of sepsis fast track activations per year and month and also the the data filled out for each sepsis case in the sepsis fast track form. This data comprise the time interval between January 2011 to February 2014. The research flow chart of this study is depicted in Figure 4.11.

4.3.3 Results

The physicians participating in this study was composed of 11 females and 4 males with an average age of 37 (sd $\approx$ 11.09) years old and 6 years (sd $\approx$ 6.59) of previous experience working in an emergency department. Regarding game habits and previous experience with serious games, 50% indicated that they never played games and the other 50% rarely played games (mostly casual games). 56% had previous experience with

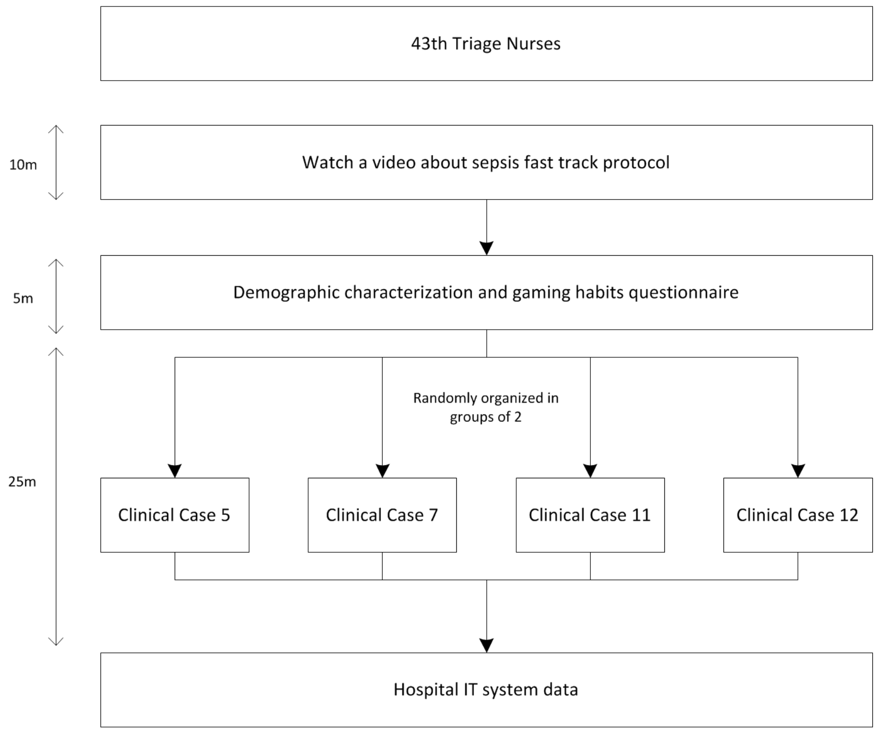


Figure 4.11: Research flowchart: Triage Nurses

simulators in medical education (Resuscitation) and 69% of them had previous training on the sepsis fast track protocol in a face-to-face class.

The group of 43 triage nurses was composed of 26 females and 17 males with an average age of 35.07 (sd $\approx$ 6.63) years old and 12 years (sd $\approx$ 6.61) of previous experience working in an emergency department. Regarding game habits and previous experience with serious games or simulators, 30% stated to occasionally play games (mostly strategy and fight games) and 12% had previous experience with learning by simulators (ACLS Trainer and Resuscitation). 81% of the nurses had previous training on the sepsis fast track protocol in a face-to-face class.

4.3.3.1 In-Game Log Analysis

One of the main goals of our serious game was to evaluate the level of knowledge that both interns and attending physicians had regarding the sepsis fast track protocol medical acts sequence and appropriate therapeutics that should be administered and when. In order to collect this information a module was implemented in the game that collects chronological logging data about the decisions made by the physicians in each step of the sepsis fast track protocol while playing the clinical cases. A summary of the decisions made by both interns and attending physicians while playing clinical case 8 (Appendix A) is presented in Figure 4.12.

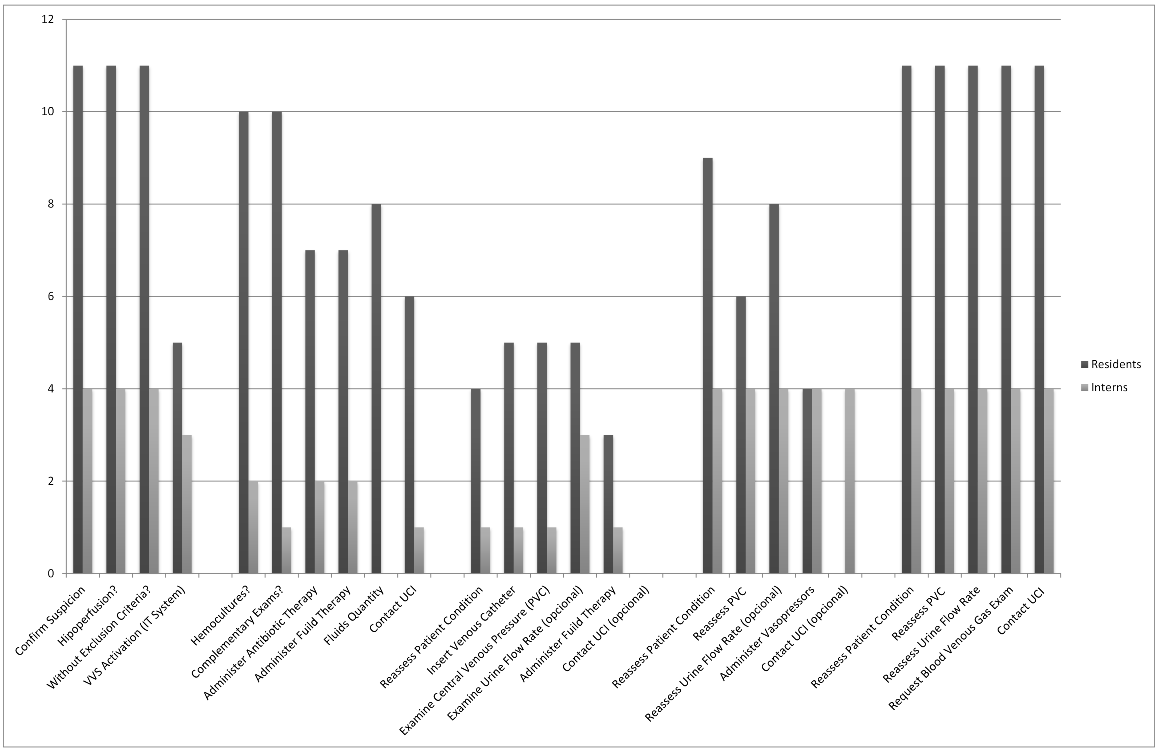


Figure 4.12: Physicians: Clinical Case 8 Log Analysis

In the first step of the fast track protocol the physician has to confirm if it is or not a sepsis patient. This involves confirming if exist an infection suspicion exists, the existence of hipoperfusion and if the patient doesn't have any exclusion criteria (e.g. pregnancy). Once a decision is made the appropriate data should be registered in the hospital IT system which included confirming the activation of the sepsis fast track. As shown in Figure 4.12 both interns and attending physicians have correctly evaluated the existence of an infection. Nevertheless, less than half of the attending physicians started to execute the procedures of the next protocol step without filling out and confirming the activation of the sepsis fast track in the hospital IT system.

The next step of the protocol involves administering the initial therapeutics to the patient, namely fluid therapy and antibiotic therapy and requesting complementary exams to both monitor how the patient's condition is progressing and to clearly identify the origin of the infection. Also, it is at this time that the ICU unit should be contacted in order to transfer the patient as soon as possible. This action is both important and critical because the ICU unit has very few resources and transferring a patient might not be possible and if this is the case then it will be necessary to transfer to an ICU unit that has availability in a different hospital. This takes time and resources which can have very negative impacts in critical patients as is the case of sepsis patients. The log data of the game showed that most physicians were unaware of the recommended amount of fluids that should be given in the first hour nor gave priority to administer antibiotic and fluid therapy which are the two therapeutics that can potentially save a patient if administered in a timely manner.

After this initial treatment, the protocol states that the central venous pressure (CVP), mean arterial pressure (MAP) and S_cVO_2 values should be above certain recommended values (see annex y). To monitor and regulate the CVP the physician has to apply a central venous catheter and according to the CVP value reinforce the amount of fluids currently given to the patient. Checking the urine flow rate is another relevant measure to verify if the fluid therapy is having the desired effect on the patient and although it is not specifically recommended by the protocol we have captured if and when the physicians checked this value. In this particular protocol step the physicians did in general poorly as shown in Figure 4.12. Most of them didn't reassess the patient condition before deciding what to do next and tried to measure the CVP without applying a catheter to the patient or administer fluids without knowing the CVP value.

Monitoring and assessing the MAP current value involves checking the ECG monitor and according to its value and current patient condition decide if it is necessary to administer vasopressors. In this step most physicians reassessed the patient's current condition before deciding what to do next but in most cases didn't check the current CVP value and as in the previous step tried to contact the ICU unit to check if there was an opening to transfer the patient.

In the last step of the protocol, which consisted in assessing and monitoring the S_cVO_2 current value, every physician correctly executed the protocol procedures.

Comparing the performance between attending physicians and interns we notice that initially they had more difficulties both in the sequence of medical acts as well as choosing the right therapeutics but they showed an improvement towards the end of the protocol, specifically in the two final steps.

4.3.3.2 Hospital Data Analysis

Another important goal of our serious game was to influence the current medical professionals' work practices, namely correctly activating (triage nurse), confirming and executing (physician) the sepsis fast track protocol. In order to verify if the serious game had an impact on work practices we have collected the number of sepsis track activations and form completion between January 2011 and February 2014.

The sepsis fast track protocol was implemented in the academic hospital in 2011.

This included both procedures and the integration of the sepsis fast track form in the hospital IT system. Since then, both nurses and physicians have attended mandatory workshop classes where physicians that are experts in the sepsis fast track protocol teach the guidelines through clinical case analysis. These mandatory classes have occurred both at the end of 2011 and 2012. In Figure 4.13 the number of activations per year is presented. After these workshop classes we can see a positive trend in the number of activations (December - April).

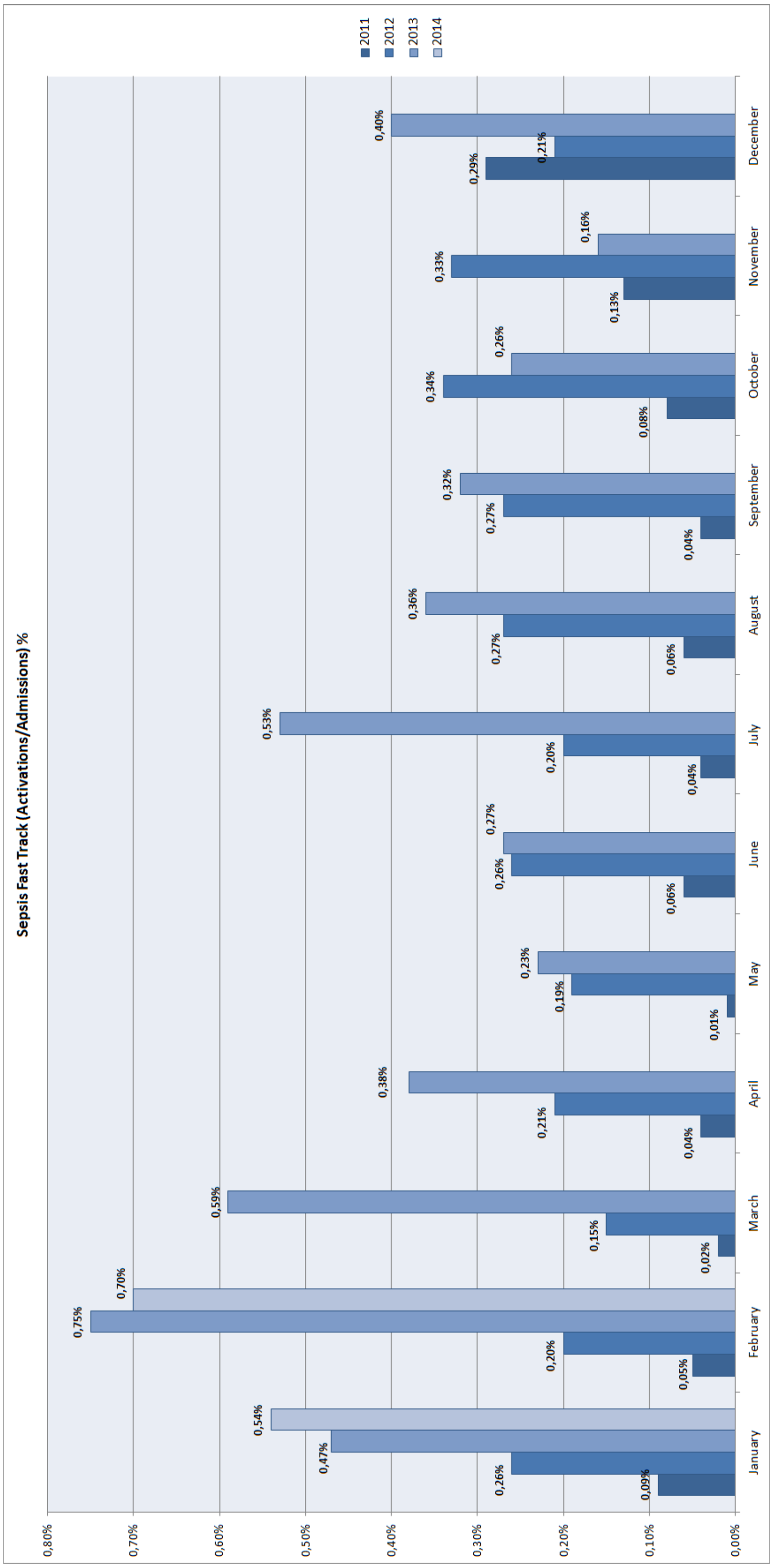


Figure 4.13: Number of Sepsis Fast Track Activations

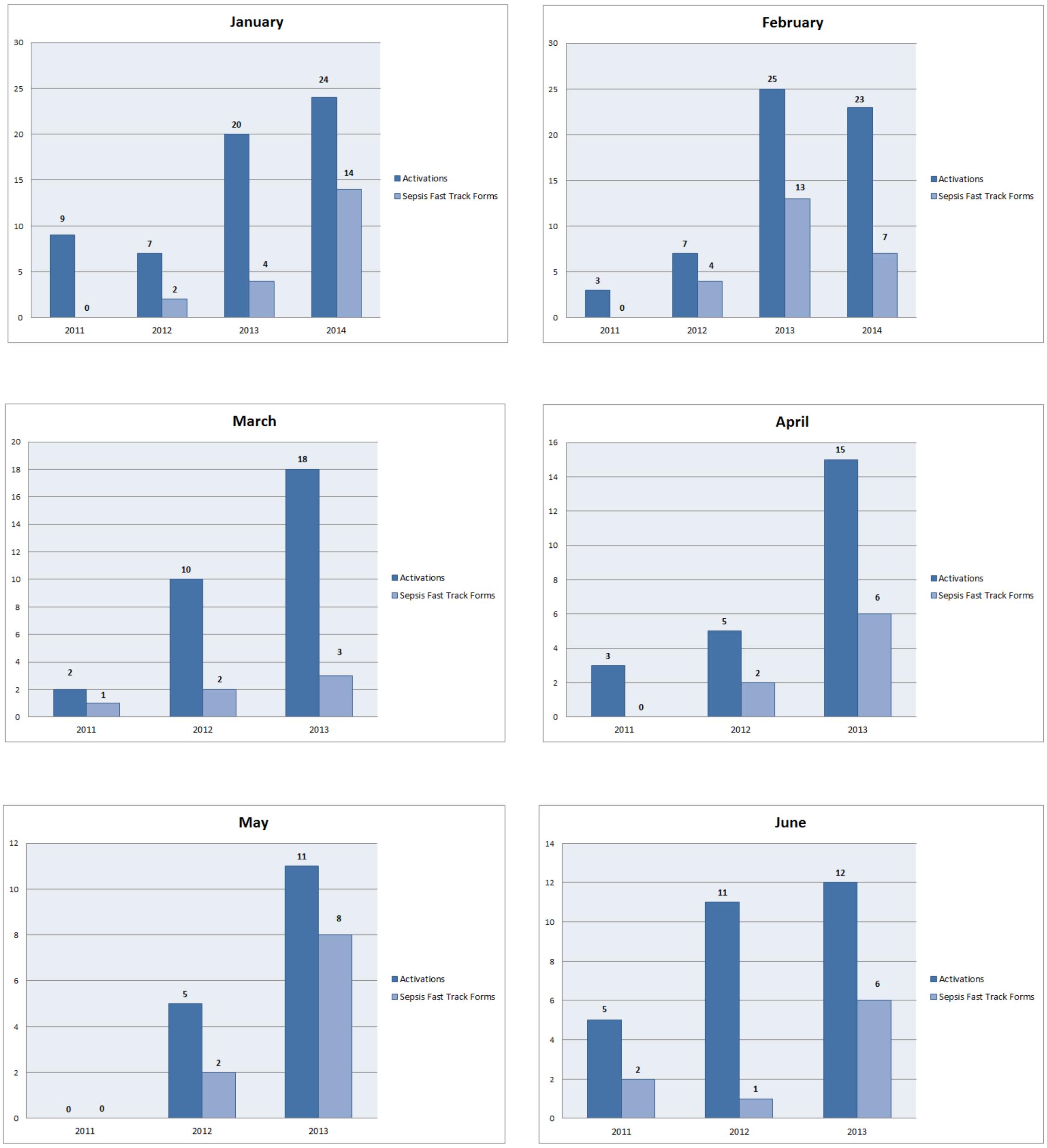


Figure 4.14: Number of Sepsis Fast Track Activated by the Nurses and Number of Form Completion by Physicians (January - May)

4.3.3.3 Interview Results

The context where the Sepsis Fast Track serious game was intended to be used was on-the-job-training, therefore all the game sessions occurred during working hours. A

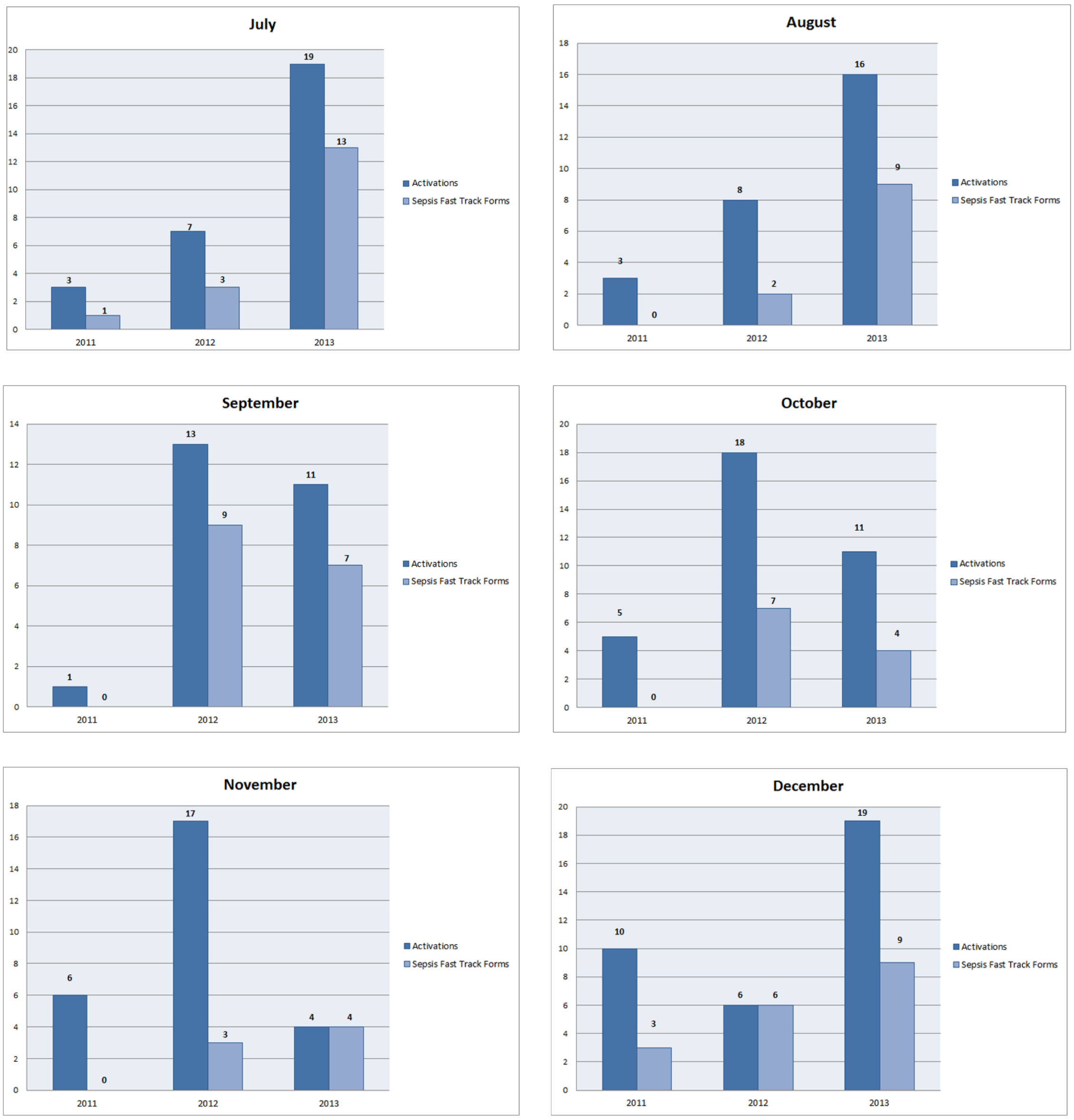


Figure 4.15: Number of Sepsis Fast Track Activated by the Nurses and Number of Form Completion by Physicians (June - December)

computer was setup with an installation of the game in a room where each physician could play the game in a quiet environment and the only people present in this room were the people responsible for developing the game which both helped the physicians during game play and collected information before the game session and conducted the

Did you agree that the game helps you understand the importance of the sepsis fast track protocol?
Did the feedback given during the game help you understand what you had to do next and learn during the game?
What are your impressions about how the debriefing is structured and the information that is shown? Do you think it help you understand what you did wrong and why?
Did you feel that the game helps you to systematize the protocol steps (medical acts and therapeutics)?
Did you fell in the role of a physician?
Did you think the game is intuitive? Is it easy to understand what you have to do and how you have to do it?
Did you like playing the game? Do you think it is useful?

Table 4.5: Examples of Questions That Guide the Interviews

interview during and after the game session. The questions used to guide the interviews are described in Table 4.5.

Attending Physicians

The attending physicians that participated in this study had already had previous contact with the pedagogical content in a workshop class and in attending sepsis patients while working in the emergency department. Therefore, they were all aware of the importance and goal of the sepsis fast track protocol.

In general all the attending physicians showed very little tolerance in losing lives and points during the game. In fact, some were so upset that they actually screamed and hit their hands on the table:

> "*I didn't register the lactate value?? Yes, I did!!*"

> "*Why did I lost points?? This is not how it's done in real life!!*"

In this respect the feedback, served both to help them understand what to do next but also to bridge the gap between what they do in the real environment and what they are expected to do inside the virtual environment:

> "*I'm always confused what to do first in the game because usually we do everything at the same time. But yes i understand the feedback and it is correct. This is how things should be done.*"

> "*It is different to be in a multitasking environment, which we don't have here in the game. Theoretically the protocol has an order that should be respected, but in real life we do everything at the same time. Because we have that habit in real life we try to do the same in the game.*"

The opinions about the debriefing diverge among attending physicians. Some felt that it was very long and what we observed was that they didn't pay much attention to the information being shown. They were more in a hurry to finish and go back to work. Others agreed that it was very well structured and did help them understand why they were penalized in some of their decisions and also help them remember some particularities about the protocol (e.g. which is the recommended vasopressor, the recommended value for the TAM, etc.).

In general all the attending physicians agreed that the game was suitable to teach and refresh the sepsis fast track protocol. In particular some of them said that it help to systematize the protocol sequence. Nevertheless, the attending physicians that had more professional experience all expressed that they feel that the game is more suited for interns and not for them which already have a vast practical experience in diagnosing and treating sepsis patient:

> "*Yes, I agree that this game is suitable to teach and refresh the sepsis fast track protocol. It seems very effective to systematize the things we have to do which I find very important.*"

> "*Playing the game is a good training. It helps people to get their ideas in order about the protocol.*"

> "*Yes, I liked to play the game. But for us (attending physicians) that already have the protocol systematized seems a bit trivial. On the other hand, interns could benefit very much by training with this game.*"

When asked if they felt in the role of a physician while playing the game most of them said that they didn't feel and in fact during game several attending physicians forgot what they had already done and sometimes repeated certain actions (e.g. give antibiotic or vasopressors twice) and in this situations they always said *"oh, it's okay. It is just a game."*.

They all like to play the game but when asked if they would play it voluntarily, most of them said no, that they didn't have time and when they did have time they think it would better to rest and dedicate it to their personal things.

Finally, the comment that was common to all the attending physicians had to do with the way they had to examine the patient in the virtual environment. In the serious game they have to click the respective medical equipment (e.g. ECG monitor) or patient and nurse to have access to the information needed to make a decision. They thought this was not intuitive because when they are treating a patient they are used to having all the information accessible around them. While they are administering a therapeutic or observing a patient they can also see the ECG monitor values, the amount of fluids currently being given to the patient among other relevant information.

Interns

The interns that participated in this study all have very little experience working in an emergency department and all came from different hospitals. They all had some contact with the pedagogical content but always from a theoretical point of view, none had experienced attending a sepsis patient. In this regard all of them agreed that the game helped them having a more clearer idea of what the protocol was about, its respective importance in patient care quality and how it has been implemented in that particular hospital.

In general, the interns were a lot more tolerant when they did errors in virtual environment and more comfortable to ask for help instead of starting to question what and why certain information was shown and a particular decision should have been made. In general when they received a negative feedback all took a little time to understand why that was the case. They all agreed that the feedback was very important because it helped them to understand what to do next, what they did wrong and right:

> ”*ok, i didn’t know we had to do this first. I never had to do this with a real patient. When something like this happens we always call a more experience physician.*”

The opinion expressed regarding the ability of the serious game to help them systematize the protocol steps (medical acts and therapeutics), was that they felt it help very much, specifically when combining the information given during gameplay (in-game feedback) and during the debriefing phase. Both during gameplay and in the debriefing phase the interns took notes in their personal notebooks about the sepsis fast track protocol and also tried to discuss what they did versus what they should have actually done:

> ”*yes, i think the game helps to systematize the protocol steps, specially because it gives feedback during the game and we can study the sepsis fast track protocol during the debriefing phase.*”

Finally, in general they all thought the game was intuitive and were very happy to have the opportunity to play the game. They also showed an interest to play more clinical cases and if it would be possible to have the game available to play at home:

> ”*I really liked to playing the game but i would have liked to play more clinical cases. Can we play this game at home?*”

4.3.4 Discussion

The main goal of our study was to evaluate the impact of our serious game on the work practices of both physicians and triage nurses when identifying and treating a possible sepsis patient. Also, we have collected information about perceptions and satisfaction with our serious game in order to understand if the physicians are willing to adopt this training method.

To evaluate the impact of our serious game in work practices we collected both in-game log data and data from the hospital IT system. The in-game log data consisted in the timestamp and decision that the physicians and nurses made while playing each clinical case of the Sepsis Fast Track serious game, both right and wrong decisions. From the hospital system we collected the number of sepsis fast track activations and sepsis fast track forms submitted since January 2011.

From our in-log analysis we have observed that although attending physicians have a had previous training in the sepsis fast track protocol and also practical experience in diagnosing and treating sepsis patients their performance wasn't in general superior to the interns. From the analysis of the interviews we believe that this result is connected to several factors. One is that in general attending physicians already have a way to do things which was the result of many years diagnosing and treating patients in the emergency department and which in many situations is different from what was proposed in medical treatment protocols as is the case of sepsis fast track protocol. One of the differences that was stated by most attending physicians was the inability to do multitasking while playing the serious game. We also noticed that where they make more mistakes is when reassessing the patient current condition. As described in (Section 4.3.3) in the real environment they are used to have all the relevant information visible and easily accessible. Therefore, having to specifically interact with medical equipment and characters in the virtual environment was not intuitive. This opinion was both shared by attending physicians and interns. Another factor described in Section 4.3.3 was the fact that the physicians didn't really feel in the role of a physician in the virtual environment. We observed in many occasions that they repeated certain decisions (e.g. administering antibiotic) that in a real situation would be very harmful to the patient. There was a certain unaccountability because they knew they were playing a game and whatever they did wouldn't have an effect on the real world. Because the goal of the Sepsis Fast Track is to teach a medical protocol, being aware that they are in a "world with no consequences" might have a negative impact on learning.

All of these factors are directly related to the representation dimension of the 4-DF, namely how interactive, what levels of fidelity are required and how immersive the experience needs to be [de Freitas and Oliver, 2006]. From these results we believe that regarding fidelity, clinical case data and patient condition has to evolve as close as possible to how it would be in real life if the same procedures have been done. In terms of interactivity, the physicians need to interact with the environment around them more closely to what they are used to do. Unnecessary actions (e.g. clicking objects) don't seem to be relevant to them because it is not how the real environment works. As stated by Held and Hein, "action is a necessary component of perception" [Held and Hein, 1963]. A similar point was made by Varela [Varela, 1991] "objects are not seen by the visual extraction of features, but rather by the visual guidance of action". Therefore, our understanding is that interactivity and fidelity are critical factors when designing serious games for medical education. Specifically, these factors need to be very well balanced in order to create an immersive virtual environment adapted to the physicians expectations where they can learn from experience as they do in the real world. We believe that this would help increase their willingness to accept these training methods and also help facilitate transferring the knowledge gain from playing the serious game to the real world environment (work practices).

The in-game feedback and the debriefing phase of the game were also mentioned several times during the interviews as important game attributes for an effective learning experience with the serious game. The importance of feedback and assessment in learning processes have already been stressed by many theories of learning. Nevertheless, implementing effective feedback is still a challenge in the context of serious games. This difficulty arises as a consequence of the need to provide feedback seamlessly alongside an engaging gameplay experience, and balancing these two factors is a considerable design challenge. From the experience derived from this study and also with the Critical Transport serious game, both feedback and assessment have to take into account both the pedagogical content being taught as well as to whom it is being taught. In-game feedback has to provide information both to help the player to improve his current strategy (single-loop learning versus double-loop learning) as well as motivate him to continually being engaged in the game activity. Combining these two effects during game play helps increase the probability of learning to occur. With this aim in mind we have derived, together with physicians, a list of minor and major errors from the sepsis fast track protocol (section nurses and physicians). By providing these two levels of feedback we have create a certain level of flexibility for both physicians and triage nurses to try different strategies and also define different feedback frequencies. Major errors are very severe for the current condition of the patient, while minor errors constitute less danger to the patient. When a major error occurs the player is always warned via a pop-up message as well as decreased in available lives and current score. In the case of minor errors, how the in-game feedback is given depends on the current number of minors errors and the step of the protocol. Moreover, whenever there is a major or minor error there is also visual feedback associated through the deterioration of patient condition and cues provided by the nurse in the virtual environment. Therefore, the in-game feedback was both evaluative (measure variables) and interpretive (measure variables and model their relationships) [Dunwell et al., 2011]. The assessment provided in the debriefing phase on the other hand was of the type understanding [Dunwell et al., 2011]. It provided the player with a description of the each error made during gameplay with an explanation why it was an error and what would be the correct decision to make in that situation (see fig. debriefing). Moreover, this information is complemented with a visual representation of the sepsis protocol and an indication of in what step of the protocol it has occurred.

After a thorough analysis, we have concluded that the results from the hospital IT system are inconclusive. Therefore, we cannot discuss if the serious game had or not an impact on work practices but we can discuss possible explanations for these results. Attending physicians with prior sepsis fast track training may have incorrectly presumed that they already knew the material being covered and did not pay as close attention to the serious game sessions, as already point out at the beginning of this section. This same phenomenon was also noted on the study reported by Platz et al. [Platz et al., 2011]. Interns with no prior training are more likely to recognize their lack of knowledge and therefore pay closer attention to the material being presented. This same principle can be applied to the triage nurses.

5

The Attribute-Driven Game-Based Framework

In this chapter, we first describe the result of analysing and comparing our two serious games which resulted from our two case studies, namely the Critical Transport serious game and the Sepsis Fast Track serious game. Next we summarize the results of the experimental studies conducted to evaluate the impact of the aforementioned serious games in knowledge gain, knowledge retention and impact on work practices in medical students and healthcare professional (triage nurses, interns and residents) respectively.

Based on these results and past work done on serious game design we propose an empirically Attribute-driven Game-Based framework. The goal was to devise a framework that would propose a relationship between game attributes and game mechanics to guide the design of serious games that could potentially empower medical students and healthcare professionals with the knowledge required to perform better in real clinical settings.

5.1 Case Studies Analysis

The goal of our thesis was to research and propose the most relevant game mechanics when designing serious games in clinical education and understand how game attributes drive the design of these game mechanics. With this aim in mind we conducted two case studies that involved the design and development of two serious games aimed at teaching medical procedures to medical students and healthcare professionals.

These case studies had the involvement of different healthcare professions (triage nurses and physicians) with different backgrounds and responsibilities in the emergency department. Also, the chosen medical procedures are both different in complexity as well as target group. Having these considerations in mind the goal was to have as much information as possible to analyse whether the two serious games would differ or coincide in terms of game mechanics and game attributes.

Analysing game mechanics within case studies, we distinguish three main categories of game mechanics. The first is related to healthcare professionals interaction with the patient. These interactions involve all the necessary actions a healthcare professional needs to do to examine a patient, which includes examining patient clinical history (patient chart), what are her/his current complaints (symptoms check), temperature, heart rate and also performing medical acts such as inserting a venous catheter and doing a arterial blood gas. The list of game mechanics in this category for both cases studies is described in Table 5.1. The second category is related to interactions between a physician and a nurse and vice versa. When treating a patient there are actions that should be performed by a nurse while others should be performed by a physician. For example, the physician is responsible for choosing the proper amount of fluids to give to a patient but it is the nurse that actually carries out this action. Other actions include requesting hemoculture and administering antibiotic therapy, among others. The nurse can also interact with the physician namely to inform him of the results of a specific exam, or a change that occurred related to the condition of the patient. The list of game mechanics in this

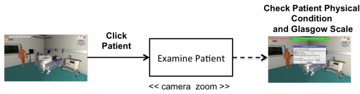
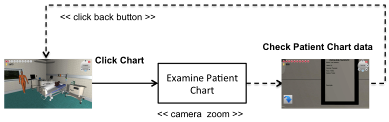
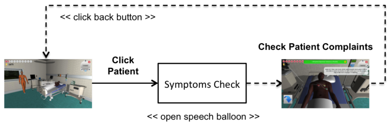
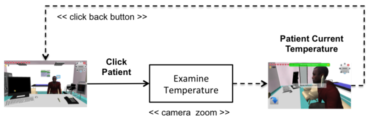
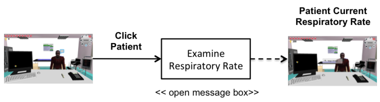
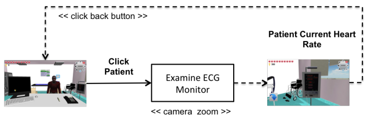
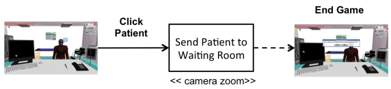
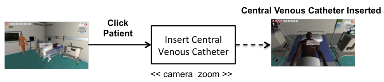
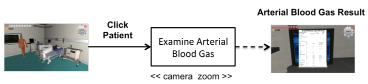
Game Mechanics	Example
Examine Patient	
Examine Patient Chart	
Symptoms Check	
Examine Temperature	
Examine Respiratory Rate	
Examine Heart Rate	
Send Patient to Waiting Room	
Insert Venous Catheter	
Examine Arterial Blood Gas	

Table 5.1: Cross case analysis: Healthcare professional and Patient Interaction Game Mechanics

category for both case studies is described in Table 5.2. The third category is related to the interactions between healthcare professionals and medical equipment as well as the

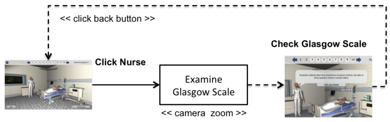
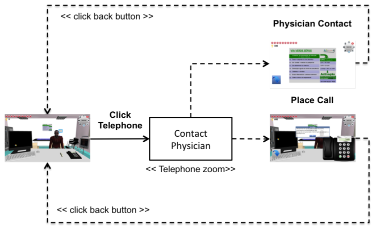
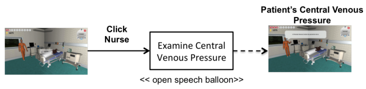
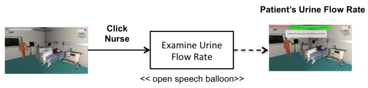
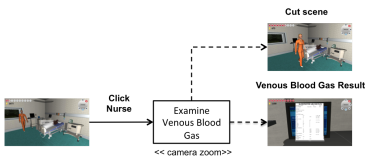
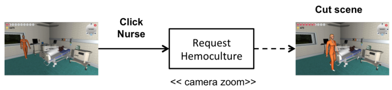
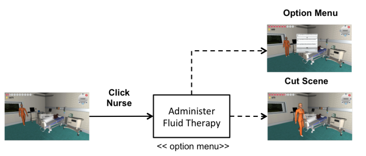
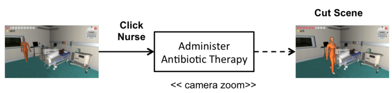
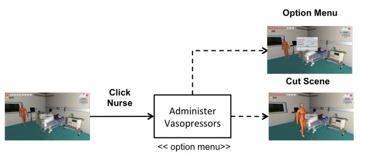
Game Mechanics	**Example**
Examine Glasgow Scale	
Contact Physician	
Examine Central Venous Pressure	
Examine Urine Flow Rate	
Examine Venous Blood Gas	
Request Hemoculture	
Administer Fluid Therapy	
Administer Antibiotic Therapy	
Administer Vasopressors	

Table 5.2: Physician and Nurse Interaction Game Mechanics

hospital IT system. The interactions with medical equipment include checking the ECG monitor, the syringe pump and the saline flow meter. Diagnosing a patient is based on the data on the medical equipments and patient current condition. Therefore, it is critical that this information and/or the ability to obtain it is available in the virtual environment.

The hospital IT System is also an important aspect. Medical procedures require that the responsible healthcare professional register in the respective IT system what were the causes that led to a certain diagnosis as well as the requested exams, among other things. Due to time restrictions this action is often overlooked. Not having such information available also has a negative impact on hospital management decisions as well as in patient care quality. The list of game mechanics in this category for both case studies is described in Table 5.3.

When comparing game mechanics between Critical Transport and Sepsis Fast Track serious games we have observed that categories are overlapping and most mechanics are also common. Moreover, the structure of the serious game is the same. They are both scenario-based games and every level consists of a different clinical case, where each clinical case is composed by a briefing phase, the gameplay and a debriefing phase. The briefing phase is when the clinical case is introduced to the player (includes patient clinical history and what motivated her/his visit to the emergency department). The gameplay is a combination of the game mechanics described in Table 5.1, Table 5.2 and Table 5.3. The debriefing phase is the phase directly related with reflection and promoting deeper understanding of the pedagogical content. Therefore, in this phase the player is presented with a critical overview of her/his performance during gameplay. How this information is displayed should be clear and related to the pedagogical goals of the game. A schematic

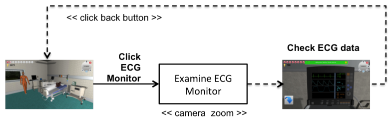
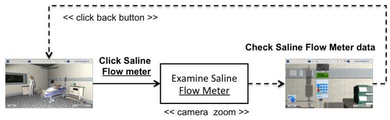
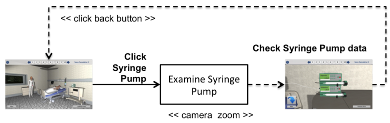
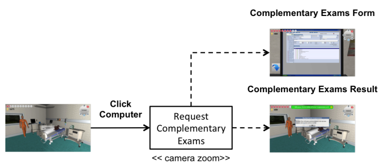
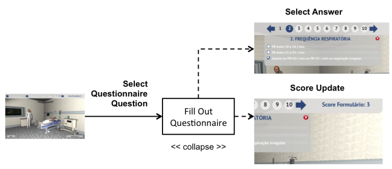
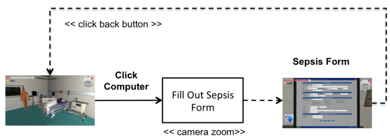
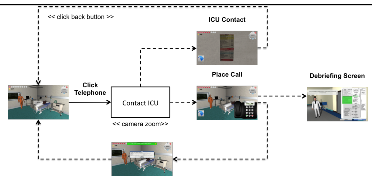
Game Mechanics	Example
Examine ECG Monitor	
Examine Saline Flow Meter	
Examine Syringe Pump	
Request Complementary Exams	
Fill Out Questionnaire	
Fill Out Sepsis Form	
Contact ICU	

Table 5.3: Healthcare Professionals and Medical Equipment/ IT System Interaction Game Mechanics

representation of this structure is depicted in Figure 5.1.

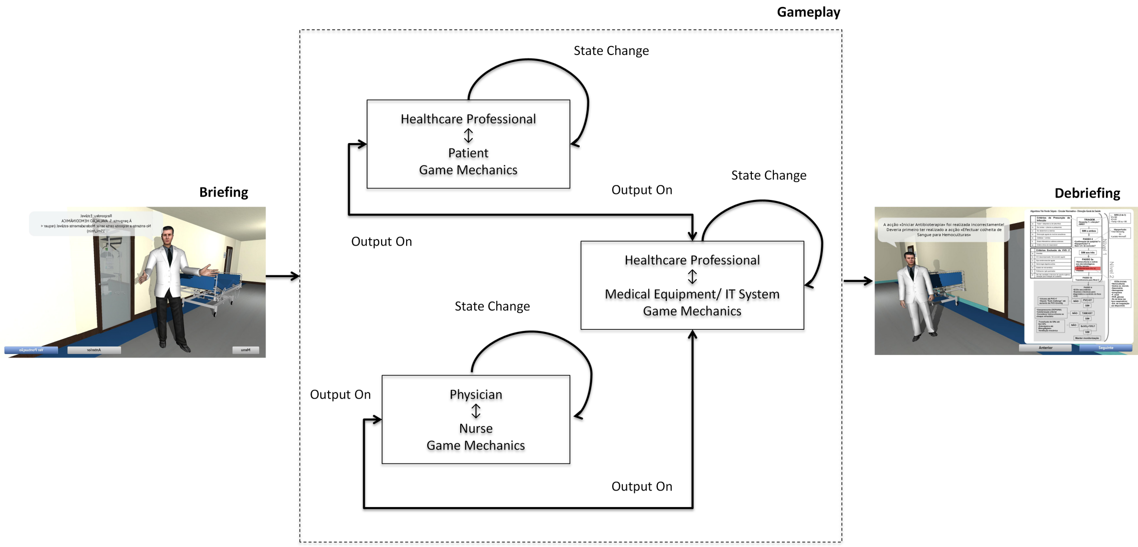


Figure 5.1: Serious Game Structure

5.2 Experimental Studies Analysis

As described previously, another aim that motivated the work of this thesis was to try to understand how game attributes should drive the design of game mechanics for Serious Games in medical education. Although it was not possible to clearly established a relationship, by conducting the experimental studies certain aspects became clear. Namely, both students and medical professionals are very sensitive to the data shown in the virtual environment. Therefore, when structuring clinical cases, that hold patient data, exams data, medical equipment data, etc. it has to be coherent both with the patient condition as well as with medical acts performed during gameplay. Also, the representation of the equipment (e.g ECG monitor curves, data) should be as similar as possible to the medical equipment used in the real environment. Moreover, we have observed during our experimental studies that healthcare professionals are very sensitive to how they interact with objects and characters in the virtual environment. In general they expect that conducting medical procedures (e.g. interacting with a patient and medical equipment) is similar to what they usually do in the virtual environment. This had an effect on how both interns and attending specialists perceived the relevance of the Serious Games.

In the medical domain, the use of language is also a critical factor. The terms used for medical acts, such as invasive and non-invasive, have to conform to the ones that are currently used in clinical practice. Moreover, the sensory stimuli introduced in the virtual environment, such as sounds, visual effects, have to be in accordance with both patient condition and medical equipment. This is the case, because verifying patient respiratory rate and the Glasgow coma scale depends on this kind of visual and sensory cues. Another important factor is concerned with balancing the freedom of actions of the player inside the virtual environment. Although it is important to let the player take her/his own decision and learn from her/his mistakes it is also important to ensure that best practices are also learned. In terms of medical procedures this means that, while letting the player decide what to do, it's very important to provide constant feedback with information relating to what is the best sequence of actions. Providing such feedback allows the player to learn from previous actions and through repetition learn to perform protocol procedures in the order as define by evidence-based medicine.

This repetition should be included by providing several clinical cases, both positive and false-positive with increasing levels of difficulty. The main goal is not to create an environment where the player learns from mimicry, but through understanding the how, what and whys of medical protocols as well as different courses of action inside the same protocol. From the information collected during interviews or questionnaire data it also became clear the importance of the assessment attribute to promote deeper understanding and learning. This was not a common opinion of all the targeted users. Specifically, medical students and interns shared this opinion while attending specialists during the assessment were mostly justifying that the errors made were because of the serious game and not their lack of knowledge.

From these insights we are led to believe that representation, fantasy, sensory stimuli, rules and control are central game attributes that contribute to define the specificities of the game mechanics that make-up the gameplay of the serious game targeted at teaching medical protocols. Goals, adaptation, mystery, challenge and assessment game attributes have a direct impact on how the knowledge is going to be build up incrementally and in between game scenarios.

5.3 The Proposed Framework

The final result of both doing a literature review on game attributes and conducting two case studies is a conceptual framework which proposes a relationship between game attributes and game mechanics to guide the design of serious games in clinical education. The conceptual framework highlights what subject matter experts considered important game attributes and how these impact the design of game mechanics. In particular, from our analysis resulted a separation of game attributes into groups: the mechanics core attributes and the scenario core attributes. The game mechanics are the processes that make-up the gameplay of a serious game. The scenario represents a level in a serious game, which includes a briefing phase, a gameplay phase and a debriefing phase.

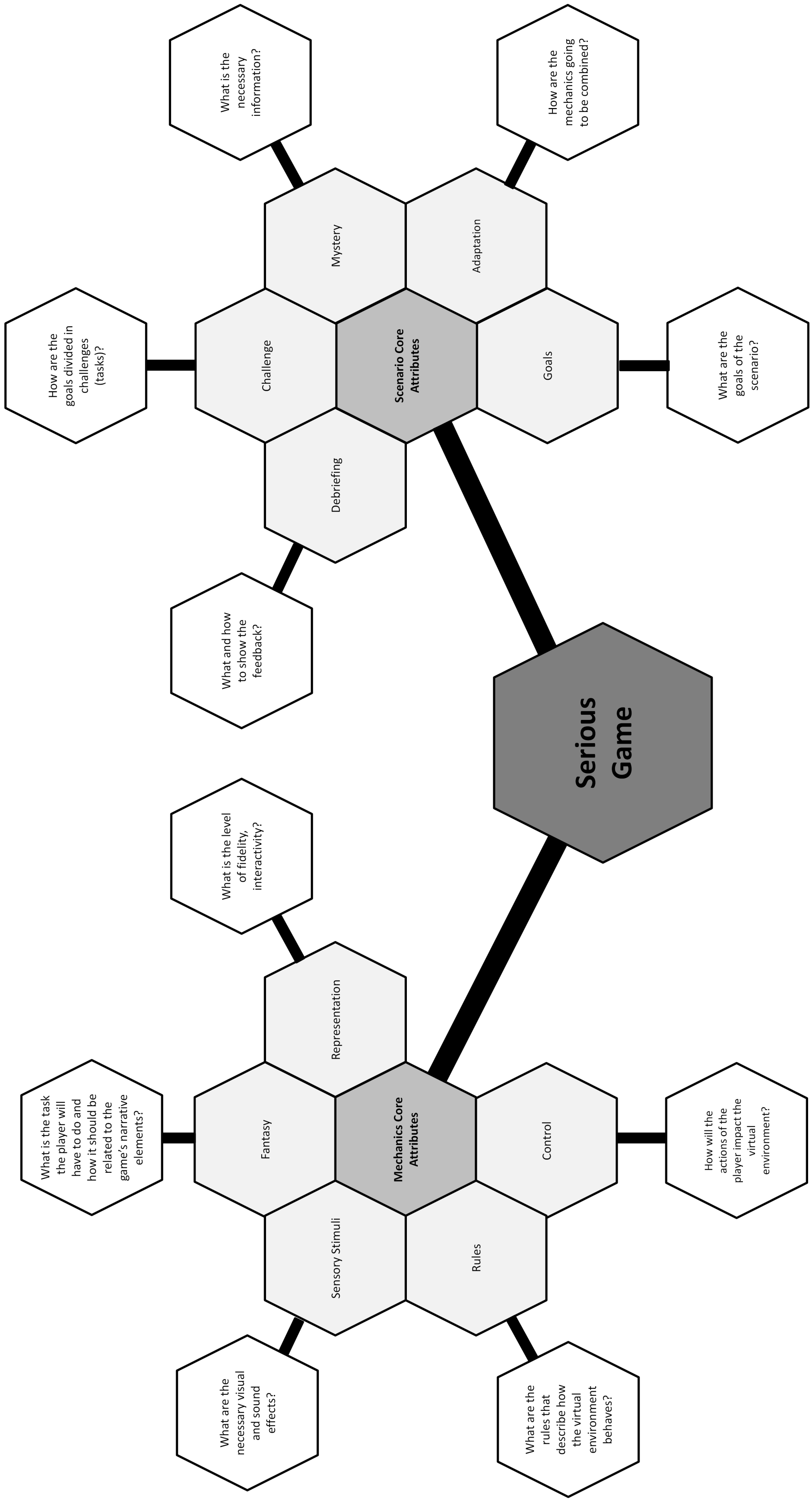


Figure 5.2: Attribute Driven Game-Based Framework

5.3.1 Game Mechanics Core Attributes

In the following sub-sections is described the core attributes that drive the design of the game mechanics following the guidelines of the Attribute-Driven Game-Based Framework.

5.3.1.1 Fantasy

Engaging games, apart from other things, have compelling stories. In the context of serious games this means integrating pedagogical content in contextualized stories that help the player to learn more effectively. This can be accomplished through Interactive Storytelling approaches [Mott et al., 1999] and contextualized tasks (task-based learning) [Willis, 1996, Willis and Willis, 1996, Ellis, 2003]. Using Interactive Storytelling as a support for training and education through the use of serious games has been argued to enable constructive learning and experiential learning by allowing the player to be part of the construction of the game's narrative [Mott et al., 1999]. As argued in Bellotti et al., ”tasks are characterized by an ability to engage the learner's interest, a primary focus on meaning, a need to be completed, and outcome in terms of which the success is judged, and a clear relationship with real-world activities” [Bellotti et al., 2009]. How and which approach is used is described by the fantasy game attribute. This element integrated all the features of the game, such as: environment, levels, player's roles, non-player characters among others. Also, how the aspects are integrated with the learning content can be according to exogenous or endogenous fantasy.

In both of our case studies the learning content is highly related to the game's narrative elements. The player plays the role of a healthcare professional and all the tasks try to mimic what she/he would do in a real environment. Therefore, "the skill being learned and the fantasy depend on each other (endogenous fantasy)" [Malone and Lepper, 1987] and the game narrative is composed by a set of contextualized tasks (task-based learning). This combination of factors contributing to the fantasy attribute of the game has as an underlying principle to attempt to ensure that the player builds knowledge that can be easily transferred to his/her (future) work practices.

5.3.1.2 Representation and Sensory Stimuli

Representation refers to "the player's perception of the game's reality, therefore is a subjective feature that varies according to players expectations and previous experiences" [Crawford, 1984, Bedwell et al., 2012]. Also, the authors state "that a more narrow scope of representation provides a player with focus, while a broader scope provides player with distractions". Although the environment of the serious game is artificial it is important that certain representational aspects are compliant with the real-world environment. These representational aspects should be connected to the pedagogical goals of the game. Relating these two aspects is the underlying rationale to keep the game focus and scope bound to its main goal, allowing the learner to attain certain knowledge. Also, providing the level of consistency creates the ability to sustain suspension of disbelief. The operationalization of this attribute involves not just considering sensory stimuli aspects of the game such as sound (e.g patient breathing) and visual effects (e.g ECG monitor curves or the nurse navigating in the 3-D environment) but it is also related to interaction, how the player navigates and interacts with the objects/players in the virtual environment. This is important because as stated by Kiili [Kiili, 2005] "bad usability decreases the likelihood of experiencing task-based flow because the player has to sacrifice attention and other cognitive resources to inappropriate activity”.

5.3.1.3 Control and Rules

Salen et al. state in [Salen and Zimmerman, 2004], meaningful play is the goal of a successful game design, emerging from ”the relationship between the player action and the system outcome; it is the process by which a player takes action within the designed game and how the game responds to those actions”. They further argue that meaningful play occurs ”when the relationship between actions and outcomes in a game are both discernible and integrated into a larger context of the game” [Salen and Zimmerman, 2004]. The control attribute holds all the actions for each of objects and/or characters in the virtual environment. Therefore, it encapsulates the influence a player can have in the environment and the type of decisions she/he can take during gameplay. These naturally abide by rules which provide two things. Rules hold the win conditions of the game as well as impose limits to player actions which enforces the focus and scope, as explained previously.

5.3.2 Scenario Core Attributes

In the following sub-sections is described the core attributes that drive the design of the game scenarios following the guidelines of the Attribute-Driven Game-Based Framework.

5.3.2.1 Challenge, Mystery and Adaptation

Adaptation refers to the level of difficulty of the game. This can be gradually increased or set in terms of levels or scenarios. Either way, the difficulty should be in accordance with the player skill level. Greitzer et al., has proposed that ”learning scenarios or levels should be presented with the aim to maintain the performance of learners in a ”narrow zone” between too easy and too difficult” [Greitzer et al., 2007, Bellotti et al., 2009]. The term that refers to this idea of ”narrow zone” has been proposed by Vygotsky [Vygotsky, 1976] and is denominated the zone of proximal development . This is accomplished by providing appropriate challenges with the respective amount of mystery, meaning information ambiguity. These are the stepping stones of the flow state.

In both our case studies this was accomplished by integrating in the serious games different clinical cases with increasing level of difficulty. In this manner as the player progresses sequentially through the clinical cases she/he can incrementally increase her/his current knowledge of the pedagogical content.

5.3.2.2 Assessment

Progress refers to the measure of how the player progresses in achieving the goals of the game. Meaning, it establishes how the control of the player affects the evolution of the game. This is then operationalized inside the game through the assessment/feedback attribute. When a player performs an action it impacts both the state of the game (in terms of environment, non-player characters, objects) but also for example, scoring system and hints. In-game assessment/feedback allows the player to learner from previous actions. These corresponds to Schön concept of ”reflection-on-action”, which describe the retrospective thought processes that is usually associated with reflection today e.g. ”reflecting upon your behaviour” [Schön, 1983]. The debriefing /evaluation provides reflection of players’ game performance after the game. Debriefing refers to the information that is shown to the player regarding how he progressed in the game session. The information is displayed according to a structure that facilitates a deeper understanding of how and why certain actions were good while others were poor decisions. These can be presented, for example, by a virtual mentor/tutor in the form of dialogue, or by relating actions and/or physiological data of players with goals in a visual manner. Evaluation refers to an off-game debriefing session, delivered by a facilitator/teacher in the form of a critical discussion with the player(s) about relevant points related to player progress and pedagogical goals.

5.3.2.3 Goals

Clear and specific goals is on of the main factors that motivate players to play games [Locke and Latham, 1990], because it allows the player to perceive how well she/he is currently evolving to achieved a particular goal. Having this unambiguous perception has been argued to increase attention and motivation [Garris et al., 2002]. Also, if the player is goal-driven and is commited to achieve the game goals can lead to ”an increase in effort and performance” as stated by [Kernan and Lord, 1990]. Therefore, in order to promote self-directed and motivated learners games should provided clear and specific goals.

6 Conclusions and Reflections

6.1 Summary

In this research work we have set out to explore what are the game attributes relevant when designing and developing Serious Games for clinical education and how they contribute to the design of game mechanics that produce a positive impact on knowledge gain, knowledge retention and work practices of healthcare professionals. The general literature on this subject is inconclusive on several questions within the contribution of both game attributes and game mechanics in empowering Serious Games with an effective learning process and also there is still very little evidence of the efficacy of using Serious Game in clinical education. Therefore, this research work set out to answer two main research questions:

RQ1: How should the game attributes be realized in the gameplay through game mechanics?

RQ2: What are the advantages and limitations of the Attribute-Driven Game-Based framework?

With the aim to provide answers to these research questions, two case studies were developed with a team of healthcare professionals and their efficacy in knowledge gain, knowledge retention and impact on work practices was evaluated in an academic hospital. The aim of these case studies and experimental studies was to understand the constraints and specificities of clinical education and how these could be effectively integrated in a game environment and gameplay dynamic. With that aim in mind two clinical procedures were selected with a team of healthcare experts. The rationale underlying the choice of procedures was related to several aspects, namely:

- the focus would be the medical procedures and not the physiologic simulation of patient conditions;
- each medical procedure would cover different medical acts, including invasive and non-invasive and therapeutic and diagnostic respectively
- the targeted users should include triage nurses, medical students, interns and attending physicians
- the context of usage should include formal classes and on-the-job training in formal and informal contexts

The result from the first case study was the Critical Transport serious game targeted at 4th year medical students. The serious game was introduced in the formal classes targeted at teaching the recommendations for the transportation of critically ill patients. Four different experimental studies were conducted to understand and measure the efficacy of the serious game in knowledge gain and knowledge retention. In order to evaluate knowledge gain a quasi-experimental study composed of a pre/post-test questionnaire was conducted with twenty-five 4th year medical students from three different classes.

The Critical Transport was also used in a second experimental study concerned with the comparison between blended learning and traditional classes and how these affected the level of knowledge retention of students. This study involved forty-two 4th year students that were randomized in three different groups: the first had a face-to-face class; the second attended a combined face-to-face and serious game session; and the third attended a combined face-to-face and video watching. In order to compare the level of knowledge retention between groups a pre/retention-test experimental study was used.

The second case study involved developing a serious game for triage nurses and both attending physicians and interns to train the sepsis fast track protocol. This serious game was used in on-the-job-training sessions which involved 43 triage nurse, 11 attending physicians and 4 interns. The main purpose of this study was to evaluate the impact of the Sepsis Fast Track serious game on the work practices of both physicians and triage nurses when identifying and treating a possible sepsis patient. For this purpose questionnaire data, in-game log data and hospital IT system data was collected and analysed qualitatively.

In the following section we summarize what were the main findings of our studies and how they contribute to answer our two research questions. We also describe implications derived from our studies for both using serious games in formal medical classes as well on-the-job-training for continuing medical education.

6.2 Main Findings

Next we answer the research questions that motivated the work conducted and reported in this thesis.

Answering research questions RQ1

”Game attributes are those aspects of games which support learning and engagement” [Yusoff et al., 2009]. How they support both of these factors has been the subject of several research works. These works have, in general, treated game attributes as concepts that exist somehow in a separate level where only a conceptual relation can be established between gameplay and game attributes. This presents difficulties when we want understand how each attribute contributes to both learning and engagement in Serious Games.

In order to attempt to overcome these difficulties, in the context of this research work, we have treated game attributes from a different perspective. Instead of abstract concepts that live in the realm of gameplay, we have treated them as requirements that drive the design and specification of game mechanics. Meaning, they help describe both the functionalities (e.g. actions) that a Serious Game must provide as well as the constraints (e.g. interactivity) under which it should operate.

In order to understand how game attributes could work/behave as requirements we have used a bottom-up approach, from game mechanics to game attributes, to understand what were their individual contribution to the design of a game mechanics. This analysis was also motivated by the definitions proposed for each individual game attribute as described in Section 2.2. Combining these two sources of information allows us to derive a group of questions that help guide how game attributes can be realized in the gameplay through game mechanics.

Specifically, the representation attribute influences the fidelity and level of interactivity needed to create a meaningful experience. Therefore, in-game interaction should be carefully designed with and for the target users. Meaning, the focus should be on the interaction with the pedagogical content using graphical representations familiar to the users and not on irrelevant interactions that don't contribute to the objectives of the Serious Game. Also they should take into account how things are done in the real environment in order to promote a more seamless transfer of knowledge attained in the Serious Game to the real-world environment. The fantasy attribute contributes to the definition of a game narrative that translates the pedagogical content into meaningful tasks that when put together make up the underlying learning process of the Serious Game. The sensory stimuli influence how certain visual and sound effects should be integrated in the game mechanics in order to provide immersive experiences. Providing an immersive helps the player to behave in-character which from the results of our case studies could augment the attention attending physicians give to the decisions they make when they are playing the serious game. The rules game attribute is related to how the virtual world should behave.

When the virtual environment doesn't behaves as expected, meaning the output of player actions is not coherent, the player tends to discredit the serious game. We have observed as well as received feedback from attending physicians stating that this interferes with their experience in the virtual environment. It made them disbelief the credibility of the serious game and also feel frustrated because they though it was unfair to lose points or lives in these situations. The control game attribute is directly related to the in-game feedback mechanism of the Serious Game. From the experience derived from our studies in-game feedback should provide information both to help the player to improve his current strategy as well as motivate him to continually being engaged in the game activity. Therefore, it should be a combination of evaluative and interpretive feedback.

The briefing phase is the phase where the problem to be solved is presented to the students, in this context, the clinical case. Therefore, the briefing phase is directly connected to the goal game attribute. There are easier and harder clinical cases and this is influenced by the challenge game attribute. In particular it will constrain the complexity of patient condition which has an impact on the number and level of difficulty of the tasks the player must perform to solve the clinical case successfully. The adaptation influences the level of coverage of the medical protocol introduced in the game level, meaning it can start by devising a scenario that focuses on a particular part of a medical protocol and as the player evolves through the levels it will gradually learn the complete medical protocol. The mystery attribute influences the level of information ambiguity of the clinical case. The assessment game attribute is related with the debriefing phase of the Serious Game. From our experiences both experimental study results as well as healthcare professionals feedback was that a feedback of the type understand helps them to reflect on what was learned during gameplay and in this manner create deeper meaning and understanding of the pedagogical content of the game.

Answering research question RQ2

Our conceptual framework was empirically derived from two case studies conducted at an academic hospital and also from past work on Serious Games as described in Section 2. The main goal of our conceptual framework was to provide guidelines that help drive the design of Serious Games for clinical education. In this respect our conceptual framework can be used as a design aid, as it provides principles and guidelines for educational game design. Educational game designers are free to interpret the framework and adapt it to their own needs with regards to design processes and modelling methods. The conceptual framework can be used as an aid in educational game design, but still leaves practical design decisions up to the game designer; e.g. which genre the game will be, what player perspective will be used.

The serious games that resulted from these case studies were used in several experimental studies where it was assessed their impact on knowledge gain, knowledge retention and also work practices. The results obtained from these experimental studies were encouraging but also showed that our conceptual framework has some limitations.

Namely, every player is different. Players can have different levels of previous knowledge which will influence both the ability of playing the game as well as their interest in the game. Therefore, player modelling should be a central aspect of designing Serious Games. Having this into account we believe that it would strengthen our conceptual framework if we had provided clear guidelines for player modelling and how it will influence the design.

Also, apart from the player, another driving force of Serious Game design are instructional and pedagogical approaches. Due to the context where the concept framework was derived, it is mostly focused on problem-based learning principles, which is a pedagogical approach pioneered in medical education.

Finally, the conceptual framework was derived from the experience of designing Serious Games aimed at teaching medical protocols. Therefore, the focus is on medical procedures and not on cooperation and collaboration between healthcare professionals, which is also a critical factor in clinical education. Therefore, the framework lacks guidelines for multi-player games where other attributes such as pieces/player should be taken into account.

Implication for using Serious Games in medical formal classes

Conducting the first study allowed us to understand some fundamental things about using Serious Games in formal medical education. An important factor observed by us was the importance of the facilitator role both during the design phase as well as during the classes. This finding is corroborated with both [Michael and Chen, 2006, Diehl et al., 2011] which has stated respectively: ”Serious Games offer a paradigm shift in training as they change the role of the trainee from passive to active” and ”they also change the role of the trainer from just delivering material to being a facilitator”.

Blended learning models that include Serious Games can potentially be very effective in medical education but players need to have prior experience with the Serious Game in order to guarantee that learning how to play the game doesn’t affect the level of cognitive processing available for learning the pedagogical content of the game.

Implication for using Serious Games for on-the-job-training

Providing evidence of these results has also other important related aspects. Because games can be played anytime-anywhere, application of gaming technology to clinical education could promote remote and independent learning. This could be particularly interesting and important for refresher courses. Another use could be as a lower-cost substitute to clinical algorithm simulators. Although the cost of developing a simulator can be similar to a Serious Game, Serious Games support virtually an unlimited number of students training at the same time. Therefore, the ratio of facilitator versus students is substantially greater which increases cost and time for training a large number of students when using a simulator. Also, ”mannequin-based simulators have limits with respect to the types of symptoms that are supported (e.g. skin changes)” [von Zadow et al., 2013].

6.3 Limitations of experimental studies

Conducting experimental studies based on pre and post/retention is a common practice in educational research [Cohen et al., 2007] and also in Serious Games research. Nevertheless, these studies have several limitation such as the possibility of confounding influences (e.g. learner’s prior knowledge, game habits), which are hard to contain and control and can have influence on study results [Cohen et al., 2007].

Recognizing these limitations we have attempted to use in the analysis of our case studies mixed methods, where we combined both quantitative and qualitative analyses. In all of our studies we have collected information about users demographical information, gaming habits and other relevant information as well as the previous professional experience and user perception and satisfaction of our serious game. Moreover, we have also registered in-game data analysis for every game session.

6.4 Future Work

The Attribute-Driven Game-Based framework, that constitutes the basis of our work, although was based in the knowledge of subject matter experts have of medical protocols, it was based in a very limited number of case studies. Thus, there are certain aspects of game attributes that could be further explored. And, in addition, the results of the experiment that we have conducted also suggest some interesting issues for future research.

The following items describe some of the open issues that we believe are relevant and, thus, deserve some attention as future work:

- **Game attributes inter-relationship:** this work did not address the inter-relationship between game attributes and their individual contribution to learning outcomes. It would have been interesting to develop different versions of the same serious game and conduct experimental studies to understand how each individual game attribute contributes to achieving particular learning outcomes. For example, it would be interesting to test what would be the level of knowledge retention of the Sepsis Fast Track serious game if there wasn't in-game feedback.

- **Virtual Reality impacts on learning outcomes:** Virtual Reality technology has the ability to create realistic immersive environments that give the player a sense of presence and also increase the suspension of disbelief. These two factor would increase the probability of the player to feel in the role of the a physician which would probably influence his decisions and attitudes while the playing Serious Games. This change could have positive impacts on learning outcomes and because virtual reality technology is both improving and becoming more cost effective, we believe this would be a interesting research direction to follow.

- **Frequency of playing Serious Games:** Healthcare professionals are responsible for executing a high number of diverse tasks and also dealing with patients with a broad range of clinical conditions. Therefore, the usage of medical protocol is not regular which results in healthcare professionals forgetting particular aspects of protocols with time.. This is why there are mandatory refresher courses in continuing medical education. In this respect, it would be interesting to measure the frequency a Serious Game should be played to guarantee the optimal level of knowledge. This could be done by conducting longitudinal studies spanning several years and which involved healthcare professionals with different level of professional experience.

A

Sepsis Fast Track Serious Game Clinical Cases

Clinical Case 1

ID	1			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	True			
Patient Personal Details				
Name	Luis Santana			
Age	52			
Weight	70			
Birth Date	06/02/1961			
Genre	Masculino			
Patient Details				
Clinical Process ID	123456789			
Complaints	Ando há 3 dias com tosse, deito expectoração escura que é difícil de soltar e canso-me muito, às vezes sinto que o ar não entra. Hoje então nem consegui ir trabalhar.			
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]			
Temperature	38.7			
Heart Rate	110			
Respiratory Rate	24			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	90	80	88	120
Diastolic Blood Pressure	50	46	52	60
Urine Flow Rate	0	15	25	200
Central Venous Pressure	6	6	12	12
Exclusions	-			
Clinical History	Fumador			
	00h00	**01h00**	**01h30**	**02h00**
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.
Physical Exam	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sinais de má perfusão periférica com tempo de preenchimento capilar de 4 segundos. Taquipneico com tiragem. Auscultação pulmonar com fervores na base direita.	Mucosas coradas, desidratadas. Sem sinais de má perfusão periférica. Eupneico, sem tiragem. Auscultação pulmonar com fervores na base direita.
Lactate	5	6	4	3
Complementary Exams	RX Tórax			
Exams Results				
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.35	7.38	7.39	7.39
pC02	32	33	35	35
p02	61	65	74	74

ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	90%	91%	94%	94%
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random
FCOHb	Random	Random	Random	Random
FHHb	Random	Random	Random	Random
K+	Random	Random	Random	Random
Na+	Random	Random	Random	Random
Ca2+	Random	Random	Random	Random
Lac	5	6	4	3
tCO2(B)	Random	Random	Random	Random
Base(Ecf)	Random	Random	Random	Random
HCO3-(P,st)	21	19	21	21
HCO3-(P)	20	22	23	23
AnionGap,K+	Random	Random	Random	Random

Clinical Case 2

ID	2			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	False			
Patient Personal Details				
Name	Mónica Abrantes			
Age	28			
Weight	61			
Birth Date	16/05/1985			
Genre	Feminino			
Patient Details				
Clinical Process ID	241225431			
Complaints	Ando com uma dor nas costas já há 3 dias, ontem comecei com febre e vomito tudo.			
Symptoms	Dor lombar + (disúria ou polaquiúria) [b]			
Temperature	39			
Heart Rate	112			
Respiratory Rate	28			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	88			
Diastolic Blood Pressure	54			
Urine Flow Rate	80			
Central Venous Pressure	9			
Exclusions	Gravidez [a]			
Clinical History	Grávida 28 semanas			
Glasgow Comma Scale	A paciente está acordada, cumpre ordens e responde.			
Physical Exam	Mucosas coradas, desidratadas com prega cutânea.AC sons ritmicos, sem sopros.AP MV mantido bilateralmente sem ruidos adventícios.Murphy renal presente à esquerda.			
	00h00	**01h00**	**01h30**	**02h00**
Lactate	5			
Complementary Exams	Ecografia Renal: rins normodimensionados com normal diferenciação parenquimosinusal, ligeira uretero-hidronefrose esquerda, sem litíase observável. Sem liquido ou colecçoes peri-renais. Bexiga em fraca replecção impedindo avaliação adequada			
Exams Results	Leucócitos 22.000x10e9/L, PCR 31 mg/L, urina II: leucócitos +++ e nitritos +, β-HCG 80000 mIU/mL			
Patient Blood Gas Report				

	00h00	01h00	01h30	02h00
pH	7.33			
pC02	30			
p02	90			
ctHb	Random			
Hct	Random			
sO2	100%			
FO2Hb	Random			
FMetHb	Random			
FCOHb	Random			
FHHb	Random			
K+	Random			
Na+	Random			
Ca2+	Random			
Lac	9			
tCO2(B)	Random			
Base(Ecf)	Random			
HCO3-(P,st)	22			
HCO3-(P)	21			
AnionGap,K+	Random			

Clinical Case 3

ID	3			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	False			
Patient Personal Details				
Name	Fábio Martins			
Age	34			
Weight	75			
Birth Date	06/11/1979			
Genre	Masculino			
Patient Details				
Clinical Process ID	215336478			
Complaints	Há meia-hora atrás, assim de repente, comecei a sentir uma pontada aqui nas costas e desde então falta-me o ar e tenho tosse.			
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]			
Temperature	36.3			
Heart Rate	111			
Respiratory Rate	34			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	100			
Diastolic Blood Pressure	56			
Urine Flow Rate	20			
Central Venous Pressure	9			
Exclusions	-			
Clinical History	Fumador			
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.			
Physical Exam	Mucosas coradas, hidratadas.Taquipneico com tiragem.Menor expansão torácica à direita.Murmúrio vesicular diminuido à direita.			
	00h00	**01h00**	**01h30**	**02h00**
Lactate	2			
Complementary Exams	RX Tórax: pneumotórax à direita			
Exams Results	Leucocitos 16.000x10e9/L			
Patient Blood Gas Report				

	00h00	01h00	01h30	02h00
pH	7.58			
pC02	18			
p02	56			
ctHb	Random			
Hct	Random			
sO2	84%			
FO2Hb	Random			
FMetHb	Random			
FCOHb	Random			
FHHb	Random			
K+	Random			
Na+	Random			
Ca2+	Random			
Lac	2			
tCO2(B)	Random			
Base(Ecf)	Random			
HCO3-(P,st)	22			
HCO3-(P)	21			
AnionGap,K+	Random			

Clinical Case 4

ID	4			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	False ???			
Patient Personal Details				
Name	Nélia Fortes			
Age	44			
Weight	90			
Birth Date	08/07/1979			
Genre	Feminino			
Patient Details				
Clinical Process ID	195523647			
Complaints	Ando com tosse seca e a sentir-me cansada há alguns dias, hoje começou a faltar-me o ar.			
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]			
Temperature	37.3			
Heart Rate	125			
Respiratory Rate	40			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	78			
Diastolic Blood Pressure	44			
Urine Flow Rate	40			
Central Venous Pressure	12			
Exclusions	-			
Clinical History	Insuficiência venosa periférica, Obesidade, Fumadora			
Glasgow Comma Scale	A paciente está acordada, cumpre ordens e responde.			
Physical Exam	Mucosas coradas, hidratadas. Ingurgitamento venoso jugular. Taquipneica com tiragem e cianose.AC sons taquicardicos. AC MV mantido bilateralmente sem ruidos adventícios. Edema do MID.			
	00h00	**01h00**	**01h30**	**02h00**
Lactate	6			
Complementary Exams	Angio-TC pulmonar: documenta-se tromboembolismo pulmonar envolvendo os ramos principais de ambas as artérias pulmonares			

Exams Results	Leucocitos 16.000x10e9/L, D-dimeros >5 mcg/mL			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.58			
pC02	28			
p02	51			
ctHb	Random			
Hct	Random			
sO2	86%			
FO2Hb	Random			
FMetHb	Random			
FCOHb	Random			
FHHb	Random			
K+	Random			
Na+	Random			
Ca2+	Random			
Lac	5			
tCO2(B)	Random			
Base(Ecf)	Random			
HCO3-(P,st)	15			
HCO3-(P)	14			
AnionGap,K+	Random			

Clinical Case 5

ID	5			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	False			
Patient Personal Details				
Name	Maria Conceição			
Age	28			
Weight	58			
Birth Date	05/01/1985			
Genre	Feminino			
Patient Details				
Clinical Process ID	195523647			
Complaints	Doi-me muito a barriga e perdi muito sangue pela vagina. Sinto-me muito fraca, há pouco desmaiei e tudo.			
Symptoms	Dor abdominal ou icterícia [c]			
Temperature	37.3			
Heart Rate	115			
Respiratory Rate	16			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	70			
Diastolic Blood Pressure	38			
Urine Flow Rate	0			
Central Venous Pressure	5			
Exclusions	-			
Clinical History	Saudável			
Glasgow Comma Scale	A paciente está acordada, cumpre ordens e responde.			
Physical Exam	Mucosas coradas, desidratadas.Eupneica.AC sons taquicardicos.AP murmúrio vesicular mantido bilateralmente sem ruidos adventicos.Abdómen pouco depressivel, com defesa generalizada e dor à descompressão.			
	00h00	**01h00**	**01h30**	**02h00**
Lactate	2			
Complementary Exams	Ecografia abdominal e pélvica: massa extra-uterina			

	hiperecogénica compatível com gravidez ectópica			
Exams Results	Hb 6.8 g/dL, leucocitos 18.000x10e9/L, PCR 12 mg/mL, β-HCG 1000 mIU/mL			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.42			
pCO2	37			
p02	90			
ctHb	Random			
Hct	Random			
sO2	98%			
FO2Hb	Random			
FMetHb	Random			
FCOHb	Random			
FHHb	Random			
K+	Random			
Na+	Random			
Ca2+	Random			
Lac	2			
tCO2(B)	Random			
Base(Ecf)	Random			
HCO3-(P,st)	23			
HCO3-(P)	22			
AnionGap,K+	Random			

Clinical Case 6

ID	6			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	True			
Patient Personal Details				
Name	Carlos Mota			
Age	23			
Weight	77			
Birth Date	05/09/1990			
Genre	Masculino			
Patient Details				
Clinical Process ID	195523647			
Complaints	Há 2 dias que me muito a cabeça aqui atrás na nuca e tenho febre, acho que estou cada vez pior.			
Symptoms	Cefaleias + vómitos [e]			
Temperature	39			
Heart Rate	110			
Respiratory Rate	24			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	115	108	110	114
Diastolic Blood Pressure	55	50	52	56
Urine Flow Rate	20	50	80	220
Central Venous Pressure	11	11	10	10
Exclusions	-			
Clinical History	Saudável			
	00h00	**01h00**	**01h30**	**02h00**
	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.
Physical Exam	Mucosas	Mucosas coradas,	Mucosas coradas,	Mucosas coradas,

	coradas, desidratadas. Taquipneico. Auscultação cardio-pulmonar sem alterações. Lesões púrpura nos membros inferiores. Rigidez da nuca.	desidratadas. Taquipneico. Auscultação cardio-pulmonar sem alterações. Lesões púrpura nos membros inferiores. Rigidez da nuca.	desidratadas. Taquipneico. Auscultação cardio-pulmonar sem alterações. Lesões púrpura nos membros inferiores. Rigidez da nuca.	desidratadas. Taquipneico. Auscultação cardio-pulmonar sem alterações. Lesões púrpura nos membros inferiores. Rigidez da nuca.
Lactate	5	4	3	2
Complementary Exams	Punção lombar			
Exams Results	Leucocitos 20.000x10e9/L, plaquetas 110.000x10e9/L, PCR 14.0 mg/dL, punção lombar: turvo, leucócitos 500/mm3 com predomínio Polimorfonucleares, glicose 30 mg/dL, proteínas 100mg/dL			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.46	7.48	7.45	7.44
pC02	33	34	36	35
p02	92	94	92	94
ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	98%	98	97	98
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random
FCOHb	Random	Random	Random	Random
FHHb	Random	Random	Random	Random
K+	Random	Random	Random	Random
Na+	Random	Random	Random	Random
Ca2+	Random	Random	Random	Random
Lac	5	4	3	2
tCO2(B)	Random	Random	Random	Random
Base(Ecf)	Random	Random	Random	Random
HCO3-(P,st)	23	25	24	25
HCO3-(P)	22	21	22	23
AnionGap,K+	Random	Random	Random	Random

Clinical Case 7

ID	7
Sepsis Positive Identification	True
Sepsis Positive Confirmation	True
Patient Personal Details	
Name	Teresa Silva
Age	41
Weight	59
Birth Date	13/10/1972
Genre	Feminino
Patient Details	
Clinical Process ID	125469855
Complaints	Ontem depois do jantar comecei a ter uma dor muito forte na barriga que ainda não passou e vomito tudo, não aguento nada no estômago.
Symptoms	Dor abdominal ou icterícia [c]
Temperature	38.2
Heart Rate	113
Respiratory Rate	24

	00h00	01h00	01h30	02h00
Systolic Blood Pressure	88	98	100	110
Diastolic Blood Pressure	46	50	55	60
Urine Flow Rate	20	20	80	150
Central Venous Pressure	8	9	9	11
Exclusions	-			
Clinical History	Saudável			
	00h00	**01h00**	**01h30**	**02h00**
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.
Physical Exam	Mucosas coradas, desidratadas. Taquipneica sem tiragem ou cianose. AP murmúrio vesicular diminuído na base direita. Abdómen com dor à palpação e defensa no hipocôndrio direito.	Mucosas coradas, desidratadas. Taquipneica sem tiragem ou cianose. AP murmúrio vesicular diminuído na base direita. Abdómen com dor à palpação e defensa no hipocôndrio direito.	Mucosas coradas, desidratadas. Eupneica. AP murmúrio vesicular diminuído na base direita. Abdómen com dor à palpação e defensa no hipocôndrio direito.	Mucosas coradas, desidratadas. Eupneica. AP murmúrio vesicular diminuído na base direita. Abdómen com dor à palpação e defensa no hipocôndrio direito.
Lactate	2	3	1	1
Complementary Exams	Ecografia abdominal distensão da vesícula biliar com espessamento das paredes, líquido perivesicular e cálculos no infundíbulo			
Exams Results	Leucocitos 24.000x10e9/L, PCR 24.0 mg/dL, fosfatase alcalina 460 U/L, GGT 400 U/L			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**
pH	7.31	7.33	7.35	7.36
pC02	32	35	36	40
p02	84	86	85	88
ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	94%	95%	94%	95%
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random
FCOHb	Random	Random	Random	Random
FHHb	Random	Random	Random	Random
K+	Random	Random	Random	Random
Na+	Random	Random	Random	Random
Ca2+	Random	Random	Random	Random
Lac	2	3	1	1
tCO2(B)	Random	Random	Random	Random
Base(Ecf)	Random	Random	Random	Random
HCO3-(P,st)	16	18	19	22
HCO3-(P)	15	19	20	21
AnionGap,K+	Random	Random	Random	Random

Clinical Case 8

ID	8			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	True			
Patient Personal Details				
Name	José Murtosa			
Age	78			
Weight	80			
Birth Date	26/08/1935			
Genre	Masculino			
Patient Details				
Clinical Process ID	225336457			
Complaints	Desde há 3 dias que me dói a barriga e tenho diarreia. Hoje já devo ter tido umas 10 dejecções.			
Symptoms	Dor abdominal ou icterícia [c]			
Temperature	38.2			
Heart Rate	120			
Respiratory Rate	34			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	70	80	90	98
Diastolic Blood Pressure	34	42	48	52
Urine Flow Rate	0	0	30	100
Central Venous Pressure	6	6	9	9
Exclusions	-			
Clinical History	Hipertensão arterial, DPOC tabágica, internamento recente por pneumonia			
	00h00	**01h00**	**01h30**	**02h00**
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.	O paciente está acordado, cumpre ordens e responde.
Physical Exam	Mucosas descoradas, desidratadas. Taquipneico sem tiragem ou cianose. Auscultação cardio-pulmonar sem alterações. Abdómen distendido, doloroso à palpação de forma generalizada.	Mucosas descoradas, desidratadas. Taquipneico sem tiragem ou cianose. Auscultação cardio-pulmonar sem alterações. Abdómen distendido, doloroso à palpação de forma generalizada.	Mucosas descoradas, desidratadas. Taquipneico sem tiragem ou cianose. Auscultação cardio-pulmonar sem alterações. Abdómen distendido, doloroso à palpação de forma generalizada.	Mucosas descoradas, desidratadas. Taquipneico sem tiragem ou cianose. Auscultação cardio-pulmonar sem alterações. Abdómen distendido, doloroso à palpação de forma generalizada.
Lactate	6	5	3	1
Complementary Exams	RX abdomen tangencial: distensão de ansas intestinais com níveis hidro-aéreos			
Exams Results	Leucocitos 30.000x10e9/L, PCR 22.0 mg/dL, creatinina 3,5 mg/dL, Pesquisa toxina de Clostridium *difficile* nas fezes positiva			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**

pH	7.18	7.22	7.28	7.31
pC02	22	22	24	29
p02	68	70	71	74
ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	92%	93%	93%	93%
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random
FCOHb	Random	Random	Random	Random
FHHb	Random	Random	Random	Random
K+	Random	Random	Random	Random
Na+	Random	Random	Random	Random
Ca2+	Random	Random	Random	Random
Lac	6	5	3	1
tCO2(B)	Random	Random	Random	Random
Base(Ecf)	Random	Random	Random	Random
HCO3-(P,st)	8	9	11	14
HCO3-(P)	7	10	12	14
AnionGap,K+	Random	Random	Random	Random

Clinical Case 9

ID	9			
Sepsis Positive Identification	True			
Sepsis Positive Confirmation	false			
Patient Personal Details				
Name	Beatriz Fernandes			
Age	68			
Weight	80			
Birth Date	26/08/1935			
Genre	Feminino			
Patient Details				
Clinical Process ID	265441993			
Complaints	Falta-me muito o ar, o oxigénio já não faz nada e tenho mais tosse, com expectoração verde.			
Symptoms	Tosse + (dispneia ou dor pleurítica) [a]			
Temperature	34.6			
Heart Rate	117			
Respiratory Rate	44			
	00h00	**01h00**	**01h30**	**02h00**
Systolic Blood Pressure	68	72	80	80
Diastolic Blood Pressure	34	38	44	42
Urine Flow Rate	0	0	0	0
Central Venous Pressure	9	9	12	15
Exclusions	Não candidato a técnicas de suporte de orgãos			
Clinical History	Neoplasia do pulmão em estádio IV, DPOC tabágica sob oxigenoterapia domiciliária			
Glasgow Comma Scale	O paciente está acordado, cumpre ordens e responde.			
Physical Exam	Caquéxia. Mucosas descoradas, desidratadas.Taquipneica, com tiragem e cianose.Auscultação pulmonar com diminuição do murmúrio à esquerda.Roncos e sibilos dispersos lateralmente.			
	00h00	**01h00**	**01h30**	**02h00**
Lactate	8	12	>14	>14
Complementary Exams	RX Tórax			
Exams Results	Anemia, leucocitose, pcr elevada, ldh 3000			
Patient Blood Gas Report				
	00h00	**01h00**	**01h30**	**02h00**

pH	7.30			
pC02	74			
p02	58			
ctHb	Random	Random	Random	Random
Hct	Random	Random	Random	Random
sO2	86%			
FO2Hb	Random	Random	Random	Random
FMetHb	Random	Random	Random	Random
FCOHb	Random	Random	Random	Random
FHHb	Random	Random	Random	Random
K+	Random	Random	Random	Random
Na+	Random	Random	Random	Random
Ca2+	Random	Random	Random	Random
Lac	9			
tCO2(B)	Random	Random	Random	Random
Base(Ecf)	Random	Random	Random	Random
HCO3-(P,st)	38			
HCO3-(P)	37			
AnionGap,K+	Random	Random	Random	Random

Clinical Case 10

ID	10
Sepsis Positive Identification	false
Sepsis Positive Confirmation	false
Patient Personal Details	
Name	Vera Santos
Age	34
Weight	
Birth Date	
Genre	Feminino
Patient Details	
Clinical Process ID	
Complaints	-
Symptoms	Doí-me a cabeça e o corpo todo e tenho febre desde ontem.
Temperature	37.8ºC
Heart Rate	92
Respiratory Rate	18

Clinical Case 11

ID	11
Sepsis Positive Identification	false
Sepsis Positive Confirmation	false
Patient Personal Details	
Name	Artur Fontes
Age	27
Weight	
Birth Date	
Genre	Masculino
Patient Details	
Clinical Process ID	
Complaints	-
Symptoms	Estou muito mal, não consigo respirar e doí-me o peito.
Temperature	36.6
Heart Rate	122
Respiratory Rate	38

Clinical Case 12

ID	12
Sepsis Positive Identification	false
Sepsis Positive Confirmation	false
Patient Personal Details	
Name	Célia Pinheiro
Age	58
Weight	
Birth Date	
Genre	Feminino
Patient Details	
Clinical Process ID	
Complaints	-
Symptoms	Estou com uma dor aqui nos rins desde há 2 dias e arde muito quando urino.
Temperature	37.2
Heart Rate	102
Respiratory Rate	18

B
Sepsis Fast Track Protocol

Anexo 2- Algoritmo

	Critérios de Presunção de Infecção
a)	Tosse + (dispneia ou dor pleurítica)
b)	Dor lombar + (disúria ou polaquiúria)
c)	Dor abdominal ou icterícia
d)	Diminuição aguda do nível de consciência
e)	Cefaleias + vómitos
f)	Sinais inflamatórios cutâneos extensos
g)	Critério clínico do responsável

	Critérios Exclusão da VVS (1
a)	Gravidez
b)	ICC descompensada / Sd coronário agudo
c)	Dça cerebrovascular aguda
d)	Hemorragia digestiva activa
e)	Estado de mal asmático
f)	Politrauma / gds queimados
g)	Dte não candidato a técnicas de suporte orgânico (situação para limitação de cuidados)

TRIAGEM
- Suspeita de infecção?
- SIRS?

SIM a ambos

PASSO 2
- Confirmação da suspeita? e
- Hipoperfusão? e
- Sem crit. de exclusão?

SIM aos três

PASSO 3a
- Hemoculturas e outros exs microbiológicos
- ECDs iniciais
- Antibioterapia inicial
- Fluídos

PASSO 3b
Transferencia para Nivel 2

Nível 1

Nível 2

SIRS (2 de 3)
- Fc>90
- Fr>20
- Temp >38 ou <36

Hipoperfusão
- TAS<90mmHg
ou
- Lactato>4mmol/l

ECDs Iniciais
- Hemoculturas
- Outros ex. microb.
- Gasometria
- Hemograma
- Ionograma
- F. renal
- PCR, glicose
- Rx de tórax (se foco respiratório)
- Est. da coagulação (se disponível)

PASSO 4
- ECDs secundários
- Exames e técnicas para diagnóstico e controlo do foco
- CVC

PVC>8?
NÃO →
- Volume até PVC>7
- Depois "fluid challenge" até aumento da PVC>2mmHg

SIM

TAM>65?
NÃO →
- Vasopressores (DOPA/NA)
- Cateterização arterial
- Considerar hidrocortisona se choque refractário

SIM

$ScVO_2$>70%?
NÃO →
- -Transfusão de GRs até htc>30%
- -Dobutamina até 20mcg/Kg/min
- -Ventilação mecânica

SIM

Manter monitorização

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