Sepsis Fast Track: A Simulation Game for Clinical Education based on the Sepsis Fast Track Process

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***Abstract*—Sepsis is a serious medical condition responsible for high levels of in-hospital mortality. It requires fast diagnosis and treatment, since the survival rate decreases 7.6% for each hour without treatment. In order to facilitate this process of diagnosis and medical therapy, the Portuguese Directorate-General of Health issued a document regulating the implementation of a Sepsis Fast Track protocol based on the Surviving Sepsis Campaign guidelines. Therefore, training of emergency department healthcare professionals is essential, and should be attended often in order to refresh knowledge and to be made aware of updates to any changes of the protocol. Currently, this training is conducted through traditional learning methods that are mentioned as outdated for the current generation, the so-called digital natives. Serious games are a recent trend that has been taken into consideration when discussing new tools for teaching and training in several fields, including healthcare. In the last decade, several research works have been developed that studied the impact of the application of such technologies in healthcare, stating that serious games could provide new approaches and opportunities. In this paper, a Sepsis Fast Track serious game is presented, which is a serious game developed to teach and train nurses and physicians working in hospital emergency departments about the Sepsis Fast Track protocol. An evaluation study done with the healthcare professionals will also be presented, the main goal of which was to evaluate the impact of serious games on professional working practices.**

I. Introduction

Sepsis is defined as a whole-body inflammation caused by a severe infection that is responsible for a high level of in-hospital mortality and morbidity. The treatment for this inflammatory condition must be administered in a timely manner, because for each hour that passes without the appropriate antibiotherapy, the survival rate reduces by 7.6%. In 2010, the Portuguese Directorate-General of Health issued a *Circular Normativa* for the implementation of a Sepsis Fast Track program in Portuguese hospitals' emergency departments [1] based on the Surviving Sepsis Campaign guidelines [2]. This Sepsis Fast Track would enable rapid identification of a possible sepsis case in order to begin treatment of a patient in a timely manner. For healthcare professionals to know how the Sepsis Fast Track works, including its procedures and when they have to be performed, professionals are required to have a training session. This training should be given recurrently to the professionals, not only to refresh their knowledge, but also to teach them any changes that may occur in the Sepsis Fast Track protocol. Presently, a Sepsis Fast Track training program uses traditional learning methods.

Serious games are gaining interest as a powerful tool for learning and teaching people [3]. Namely, instead of plain explanations, serious games focus on actions creating motivation and satisfaction. The application of serious games to the healthcare field is also being recognized. Several authors [4], [5], [6] have conducted systematic reviews regarding the usage of serious games for clinical education. Serious games are also expanding; in the last decade, several research works have been developed that studied the impact of the application of such technologies in healthcare, stating that serious games could provide new approaches and opportunities.

This paper describes a serious game developed for teaching and training healthcare professionals, namely nurses and physicians, about the Sepsis Fast Track protocol. We also explain the evaluation study, which included 43 nurses and 15 physicians of a hospital emergency department. It was carried out in order to understand if the application of Sepsis Fast Track serious game has any impact on professional working practices. The remainder of this paper is divided into four sections. In Section II several serious games for clinical education are analysed and several serious game gaming models and frameworks are also explored. Section III describes the Sepsis Fast Track serious game in detail, including the Sepsis Fast Track protocol, the game's stages, environment and GUI, and the implementation details. Section IV presents the serious game evaluation study, which is divided into two parts, one for nurses and another for physicians. Finally, the conclusion of this work and the proposed future work are presented in Section V.

II. Background

A. Serious Games for Medical Education

Serious games for clinical education are a recent trend that is developing significant interest. Some examples of serious games developed for clinical education are presented below.

A Critical Transport serious game was designed to teach healthcare students the recommendations for critically ill patients [7]. It is composed of two main scenes, one where the player must evaluate ten parameters regarding the patient's condition, and another one where the player must choose the correct team and equipment for the transport of the patient. An evaluation study was carried out, resulting in a positive impact on player's knowledge.

3DiTeams is a multiplayer serious game for clinical education and team training [9]. It is a first-person game developed using the Unreal Engine. The training method is based on the DoD Patient Safety Program and Agency for Healthcare Research and Quality's (AHRQ) TeamSTEPPS curriculum.

Pivotal Decision serious game was created for mass casualty triage training [10]. It is a first-person serious game

and takes place in a virtual environment where the player has to navigate through the landscape, locate casualties, and perform triage. Players receive feedback detailing both game achievements and casualty details.

In regard to sepsis, a serious game by Stanford University - School of Medicine was developed in 2011 entitled Septris [13]. Septris serious game was developed to provide a practical approach to the identification and application of evidence-based management and evidence-based guidelines. It was developed to target healthcare students and is composed of eight patients (clinical cases) who may have a sepsis infection and need medical treatment. If a patient has a confirmed case of sepsis and he or she is not treated in time, he or she dies, resulting in the loss of points. The player has several options available for diagnosis, namely lab exams, imaging, and cultures, as well as options for treatment, namely antibiotics, fluids, and pressors, among others.

B. Serious Games Models and Frameworks

Serious game models and frameworks allow developers to combine the engagement and fun element of traditional games in order to achieve specific learning outcomes. Below several models and frameworks for serious game development are described.

The Problem-based Gaming Model [15] is founded on the same principles as Problem-based Learning (PBL). PBL is a student-centred learning approach helping learners to acquire and develop the knowledge, skills, and capabilities needed to solve problems effectively [16]. The PBL approach aims to prepare students to encounter ill-structured problems normally encountered in real life. The main principles of PBL are contextuality, collaboration, and experimentalism. PBG is an approach that emphasises the meaning of learning tasks, experiential learning, and collaboration. Usually, games allow players to creatively test hypotheses and reflect on outcomes in the game world, so experiential learning theory provides an appropriate basis for PBG. The basic idea is to anchor the acquisition of knowledge and skills into meaningful problem-solving situations encountered in everyday life. This sort of approach supports the transferability of learned knowledge and skills into practice. In games, the storyline and the game world can be used to contextualise the relevant problems. In Figure (1), the PBG model is illustrated as a learning process divided into modules. The model describes learning, which is a construction of cognitive structures, as a cyclic process conducted through direct experience in the game world.

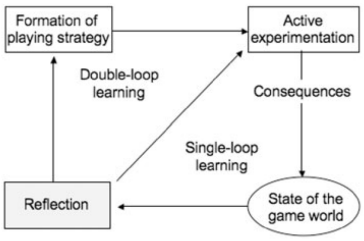

Fig. 1. Problem-based Gaming Model [15]

The Input-Process-Outcome Game Model [17] has the goal of developing learners who are self-directed and self-motivated, both because the activity is interesting in itself and because achieving the outcome is important, as represented in Figure 2. The objective was to design an instructional program that incorporates features or characteristics of games that trigger a cycle including user judgements and further system feedback. This allows the engagement of players leading to the achievement of training objectives and specific learning outcomes. The authors intend the learner to actively construct knowledge from experience. Although the model is represented as a cyclical training model, the authors do not imply that all learners necessarily learn in the same way, or that all learners proceed through these stages in a sequential or linear manner. Therefore, emphasis is placed on the idea that (i) people learn from active engagement with their environment and (ii) this experience, coupled with instructional support (i.e., debriefing, scaffolding), can provide an effective learning environment.

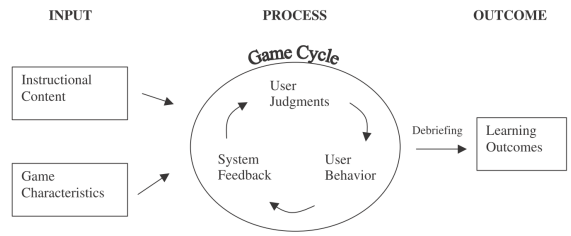

Fig. 2. Input-Process-Outcome Game Model [17]

III. Sepsis Fast Track Serious Game

A. Sepsis Fast Track Protocol

Sepsis Fast Track Protocol presents the required steps, and its sequence, to a healthcare professional in order to identify a possible case of sepsis, as well as the consequent medical procedures to treat the patient. It is divided into two main phases, the *Identification of a Possible Sepsis Case*, performed by a triage nurse, and the *Sepsis Case Confirmation and Therapy*, performed by an emergency department physician. These phases are subdivided into four steps.

B. Game Stages

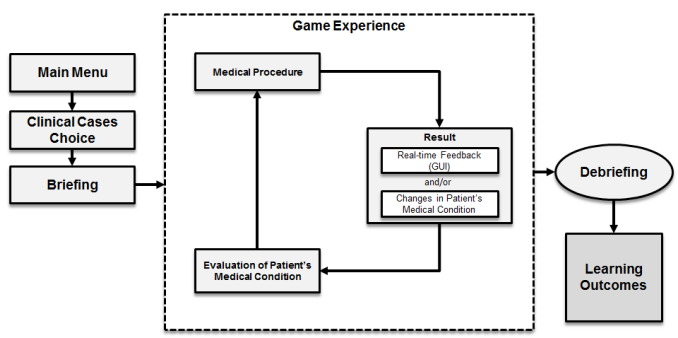

Fig. 3. Sepsis Fast Track Stages.

In Figure 3 the stages that compose this serious game are presented. When a player starts the Sepsis Fast Track serious game, he or she is prompted with the *Main Menu*, where he or she must identify him or herself using his or her name and personnel number. The player must also select if he or she is a nurse or a physician, which will allow him or her to play

the respective serious game phase. Afterwards, the player is presented with a menu for the *Clinical Cases Choice*. The gameplay of Sepsis Fast Track serious game is divided into three phases: Briefing, Game Experience, and Debriefing.

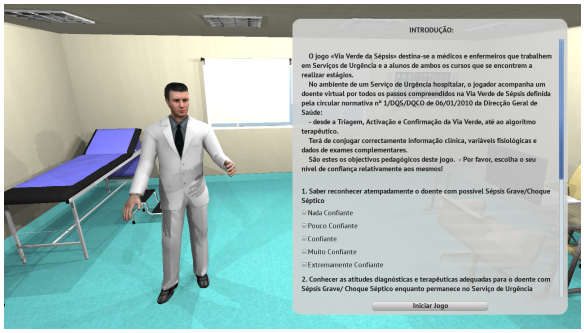

Fig. 4. Briefing.

1) Briefing: The briefing portion of the game is a reference point for the main target users (players) to explain the Sepsis Fast Track serious game, as well as the Sepsis Fast Track protocol. The main objectives are described in detail, allowing the player to understand what the serious game is all about. Also, the pedagogical goals are explained. There are four pedagogical goals; for each one, the player must choose his or her confidence level concerning their knowledge in that area.

To increase the player's engagement, a 3D avatar impersonating a physician was used to present the briefing. The briefing content was provided by physicians and is in accordance with the Sepsis Fast Track protocol.

2) Game Experience: After the briefing, the game experience begins. According to the role chosen on the main menu, a specified game's phase begins, either *Identification of a Possible Sepsis Case* for nurses or *Sepsis Case Confirmation and Therapy* for physicians.

When the game experience begins, the player is prompted with a help dialogue message asking if he or she wants to see the help screens (this is recommended for first-time players). This help option is also available during the game by clicking on the help button.

The goals of the game experience are not only to test the player's knowledge, but more importantly to teach and refresh his or her knowledge of the standard protocol. The game experience consists of evaluating a patient who was admitted to the hospital emergency department and may or may not have a sepsis infection.

The development of the game experience phase was based on both the *Problem-based Gaming Model* [15] and the *Input-Process-Outcome Game Model* [17], as shown in Figure 3. It consists of three main modules that form a cyclic process. During gameplay, the player interacts with the game environment, executing medical procedures that may have impacts on the environment and/or on the medical condition of the patient. Depending on the procedure and when it is conducted, the impacts can be positive or negative. This information is provided on the user interface, letting the player know if the procedure was correctly performed, and if not, what he or she should have done instead. If a procedure is correctly performed, it may have an impact on the patient's condition. Therefore, the player must re-evaluate the patient in order to identify the next appropriate medical procedure.

To bridge the gap between how healthcare professionals perform their tasks (medical procedures) in the real world and how they should be performed in the virtual world, several specific game mechanics were designed, as described below.

3) Game Mechanics: Game mechanics are the rules, processes, and data at the heart of a game [19]. In this serious game, several game mechanics were designed and are based on the real interactions of healthcare professionals concerning the Sepsis Fast Track protocol. These mechanics are divided by interaction type, namely, how or what a player interacts with.

4) Identification of a Possible Sepsis Case Mechanics: In the game's first phase, the player, playing as a nurse, can interact with a patient, with the IT system, and with the physician responsible for the Sepsis Fast Track.

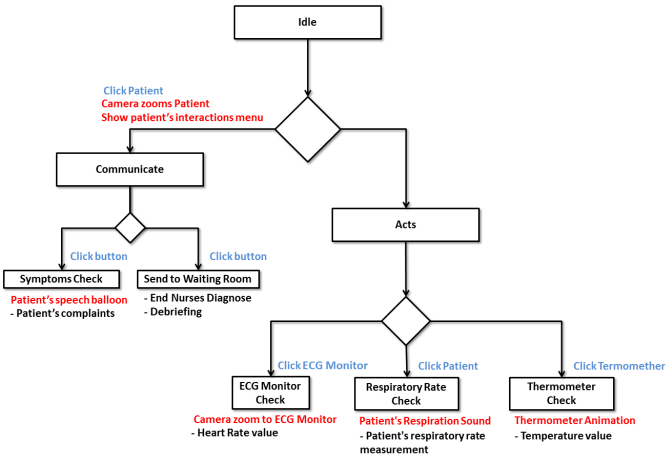

Fig. 5. Nurse-Patient Mechanics.

There are two main mechanics available in the Nurse-Patient relation, *Communicate* and *Acts* (Figure 5).

Communicate mechanics allow a player to question or request something from the patient who is being evaluated. The options are *Symptoms Check*, which allows the player to ask about the patient's complaints that made the patient visit the emergency department in the first place, and *Send to Waiting Room*, which, as the name suggests, allows a player to send the patient to the waiting room if the player concludes that the patient does not have a suspected sepsis infection.

The *Acts* mechanics allows the player to perform a diagnostic or therapeutic action, which can be invasive or non-invasive. In this game's phase, they all correspond to the evaluation of Systemic Inflammatory Response Syndrome (SIRS). The options here are *ECG Monitor Check* which allows the measurement of the patient's heart rate, *Respiratory Rate Check*, which allows the measurement of the patient's respiratory rate, and *Thermometer Check*, which allows the player to measure the patient's body temperature.

Regarding the hospital IT system, three main mechanics were implemented in the Nurse-IT relation (Figure 6). These

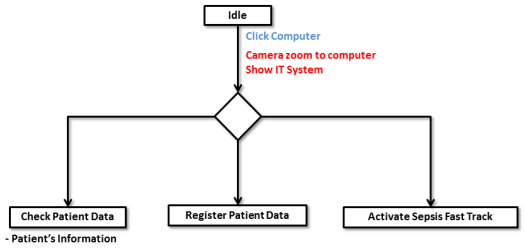

Fig. 6. Nurse-IT System Mechanics.

mechanics included *Check Patient Data*, which allows a player to check a patient's information given in the hospital's reception area, such as name, age, gender, and identification number; *Register Patient Data*, which is used to register patient's data related to the sepsis infection; and *Activate Sepsis Fast Track*, which allows the player to activate the Sepsis Fast Track alert in the IT system.

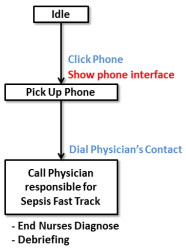

Fig. 7. Nurse-Physician Mechanics.

When the patient's evaluation is completed and a possible sepsis case is detected, the player must contact the physician responsible for the Sepsis Fast Track. This contact is made by phone, so there are two mechanics present that address the Nurse-Physician relation. These two mechanics are *Pick Up Phone*, which brings up a phone interface that should be used to dial the physician contact, and *Call Physician responsible for Sepsis Fast Track* (Figure 7).

5) Sepsis Case Confirmation and Therapy: The *Sepsis Case Confirmation and Therapy* game phase is composed of two main steps that match the last two main steps of Sepsis Fast Track protocol. In this phase, the player, playing as a physician, can interact with the patient, a nurse, and with the IT system, the respective mechanics of which are described below. Furthermore, there are interactions between the nurse and the patient, as well as between the nurse and the physician (player), which are also described below.

There are three main mechanics available in the Physician-Patient relation (Figure 8). These mechanics include *Examine Patient*, which allows the player to perform a physical exam on the patient and also to evaluate his neurological state, *Acts* (divided into *Check ECG Monitor*, which allows for measurement of the patient's heart rate, respiratory rate, and blood pressure, *Check Patient's Chart*, which allows a player to check the patient's personal and medical information, *Central Venous Catheterization*, allowing the player to apply a central venous catheter to the patient), and *Symptoms Check*, which allows the player to ask the patient about his or her symptoms and complaints.

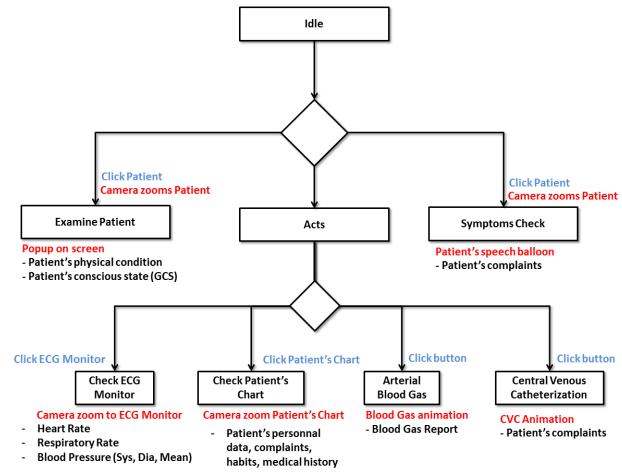

Fig. 8. Physician-Patient Mechanics.

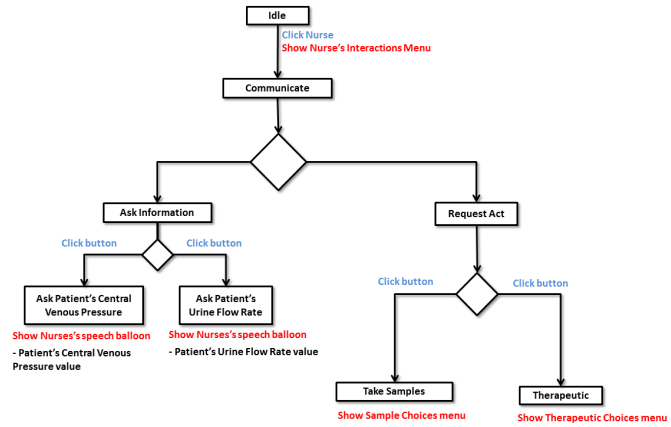

Fig. 9. Physician-Nurse Mechanics.

There are two main mechanics available in the Physician-Nurse relation that are specialisations of the *Communicate* mechanics (Figure 9). *Ask Information* allows the player to question the nurse about the patient's medical condition, (divided into *Ask Patient's Central Venous Pressure* informs the player of the patient's central venous pressure (CVP), *Ask Patients Urine Flow Rate* informs the player of the patient's urine flow rate, which is an indicator of the effectiveness of the fluid therapy), and *Request Act* which allows the player to request the nurse to execute medical acts (divided into acts for diagnosis, *Take Samples* mechanics and for therapy, *Therapeutic* mechanics).

The Nurse-Patient relation is composed of two main mechanics, a specialisation of the mechanics *Execute Act* (Figure 10). These include *Take Samples* for diagnosing the patient's medical condition (composed of *Venous Blood Gas*, which allows the player to perform a blood gas exam on the patient, *Blood Cultures*, so the player can take blood cultures from the patient for complementary exams), *Therapeutic* to execute the therapies needed by the patient (composed of *Fluid Therapy*, which allows the player to administer fluids to a patient as a treatment, *Fluid Challenge*, which must be used depending on the value of central venous pressure, *Antibiotherapy*, which is

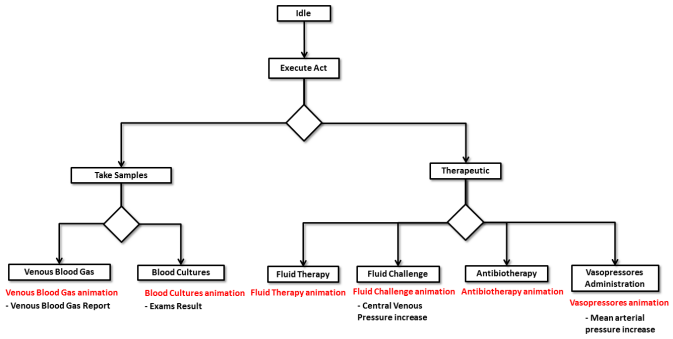

Fig. 10. Nurse-Patient Mechanics.

the most important mechanic of Sepsis Fast Track, allowing the administration of an antibiotic to the patient, and *Vasopressors Administration*, which is dependent on the value of the patient's mean arterial blood pressure).

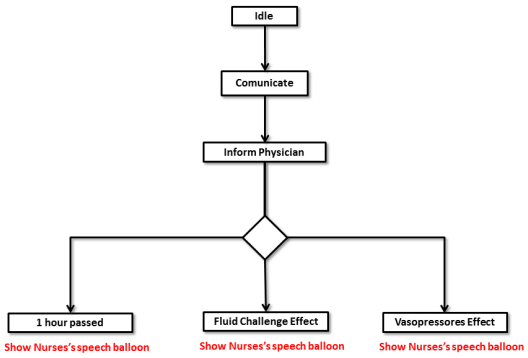

Fig. 11. Nurse-Physician Mechanics.

Mechanics of the Nurse-Physician relation were also included, which are triggered automatically without the player intervention, including *Inform Physician*, which is a specialisation of *Communicate* (Figure 11). These non-player intervention mechanics include *1 hour passed*, which is triggered when an hour (in game time) passes to verify if the *Antibiotherapy* mechanics were already performed, while *Fluid Challenge Effect* and *Vasopressors Effect* are triggered 30 minutes (in game time) after the application of the *Fluid Challenge* and *Vasopressors Administration* mechanics, which encouraged the player to re-evaluate the patient's condition to check the effects of the last therapeutic action.

As in *Identification of a Possible Sepsis Case*, there is an integration of IT System mechanics in the *Sepsis Case Confirmation and Therapy* game phase. The IT system is similar to the one used in the first phase, but at this point, it is now used by the physician and it includes other mechanics (Figure 12). *Check Patient Data* allows the player to check patient's information, given at the hospital's reception, such as name, age, gender, and identification number, *Fill Out Sepsis Form* is used to register all the information about the patient's Sepsis Fast Track, and *Request Complementary Exams* allows the player to request complementary exams that are needed for a proper patient evaluation.

6) Debriefing: Debriefing is the last phase of the gameplay and is a very important part of this serious game, as it

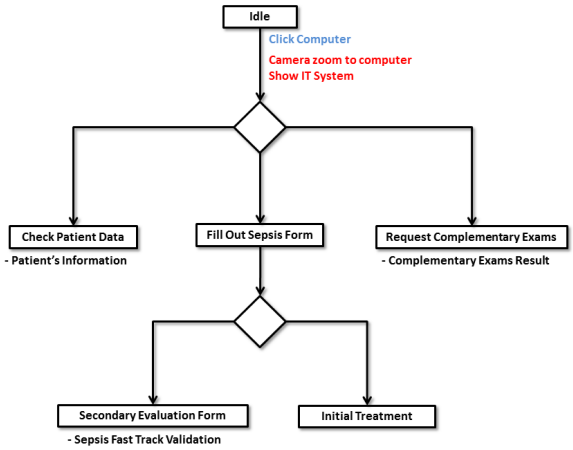

Fig. 12. Physician-IT System Mechanics.

functions as a final link between the game experience and the achievement of learning outcomes [17]. Figure 3 explains this link between the game itself and the learning outcomes through the debriefing.

At the debriefing, the players have the opportunity to analyse the procedures that they performed during the game. If a player performed a procedure incorrectly, it is mentioned in the debriefing, along with what the right procedural choice should have been and an explanation for it. All the procedures performed during the game experience were reviewed in a sequential manner, starting with the first procedure.

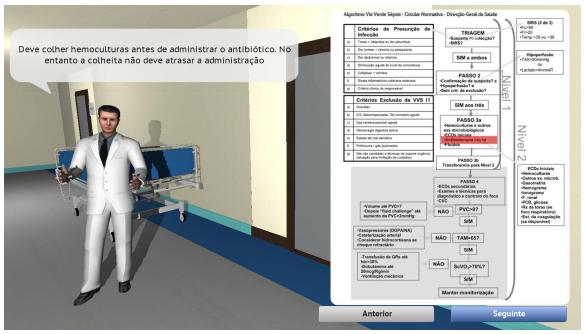

Fig. 13. Debriefing.

Figure 13 presents how the debriefing is shown to the player. It consists of an avatar representing a physician that reviews each procedure that was performed, and a figure of the Sepsis Fast Track protocol. Each time a procedure was reviewed, a box was shown on the protocol diagram, overlaying the procedure.

C. Game Environment and User Interface

The Sepsis Fast Track serious game environment was designed with the goal of increasing the player's immersion, thereby allowing the players to have in-game experiences that are as similar as possible to the real world. The underlying idea was to facilitate the player's interactions with the virtual environment and also to transfer the game world learning to real working practices. Therefore, at the beginning of this project's development, several observation sessions were

conducted, along with photography reports in the hospital's Emergency Department facilities.

Each game phase occurs in a particular part of the Emergency Department. Therefore, each phase has its own game environment.

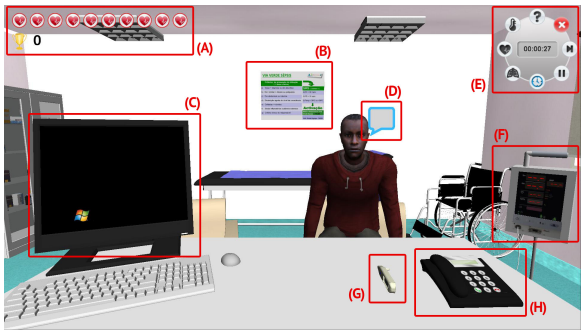

Fig. 14. User Interface - Identification of a Possible Sepsis Case phase.

The *Identification of a Possible Sepsis Case* phase takes place during the patient's triage and is performed by a nurse in a triage room. Figure 14 presents the elements that the player has available for the patient's evaluation, including Score and Lives HUD (A), Sepsis Poster (B), IT System (C), Information/Options HUD (E), Vital Signs Monitor (F), Thermometer (G), and Phone (H).

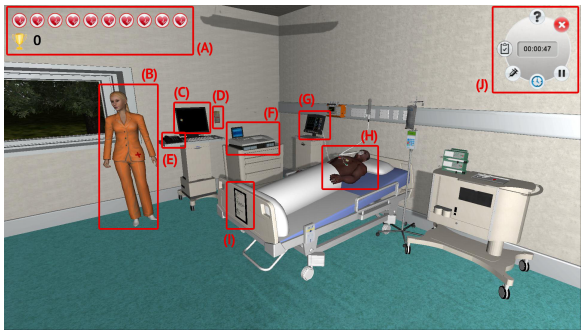

Fig. 15. User Interface - Sepsis Case Confirmation and Therapy Phase.

The *Sepsis Case Confirmation and Therapy* phase takes place after the triage and is performed by a physician in an observation room. Figure 15 presents all the elements that the player has available during this phase with which to interact: Score and Lives HUD (A), Nurse (B), IT System (C), Phonebook (D), Phone (E), Blood Gas Analyser (F), Vital Signs Monitor (G), Patient (H), Patient's chart (I), and Information/Options HUD (J). All the interaction with the elements of the game is made in the traditional point-and-click manner.

In order to make this serious game more challenging, the designers decided to measure the player's performance and present it in a *Score and Lives* HUD. The number of available *Lives* was decreased whenever a player made an error, either *major* or *minor*, depending on which procedure the mistake occurred in. *Real-time Feedback* is an important game feature and is also presented to the player. This feedback allows the player to know if the procedure that he or she executed was done right or wrong. If a procedure is correctly done, the player is presented with that information and the corresponding points that he or she won. If a procedure is incorrectly done, in addition to that information, the player is advised on the correct procedure and is informed about the lives that he or she lost.

D. Implementation

Sepsis Fast Track Serious Game was developed using Unity3D and a C# script based architecture.

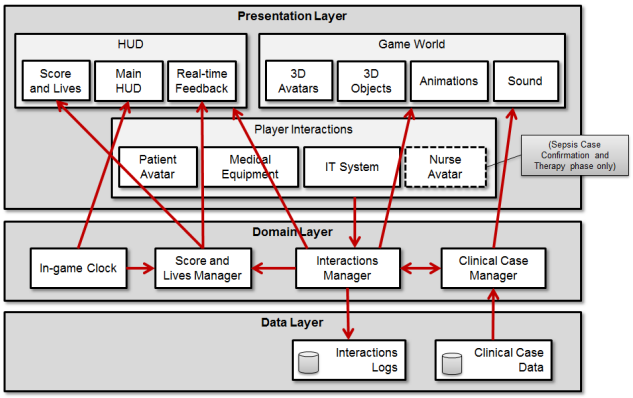

Fig. 16. Layer View with communication among modules and submodules.

1) Architecture: Figure 16 presents a layer view diagram where the main layers of the architecture of Identification of a Possible Sepsis Case and Sepsis Case Confirmation are represented, which are the two serious game's phases. The first layer is the *Presentation Layer*, which is meant to present the player with the serious game world, the head-up displays (HUD) and to record the player's actions within the game world. The second layer is the *Domain Layer*, which is responsible for managing the in-game actions and relating them to the real-world rules. The bottom layer is the *Data Layer*, which includes all the data of the serious game.

Sepsis Fast Track Serious Game extensibility was an important feature that was taken into consideration. Each clinical case was defined using XML notation in order to add, remove, and edit them easily. In order to achieve the extensibility and modifiability of this game, each element of mechanics, its data, and its pre-conditions were represented in an XML file. Since Sepsis Fast Track is based on a worldwide algorithm, globalisation through translation was discussed ever since the beginning of its development. Therefore, each string present in the game is defined in an XML file. The translation of the game can be made without any major difficulties, and can also be done by a non-programmer, if necessary.

One feature of this serious game is the data logging of the player's actions during gameplay. A log consists of the personal data of the player, namely his or her name and ID, the player's confidence level about the serious game goals asked about during the Briefing, and the procedures carried out during the game experience. Each time a player executes a procedure, the game logs it and includes information about it, including when it was performed (timestamp), the procedure identification name, and if it was correctly done (boolean). The logged data was used for the serious game evaluation.

IV. Evaluation

The main goal of the Sepsis Fast Track serious game evaluation was to assess its impact on the real world work practices of Emergency Department healthcare professionals, namely nurses and physicians.

As described previously, the Sepsis Fast Track serious game is divided into two main phases, each one with its own specific learning and training outcomes. Therefore, the evaluation study was also divided into two main phases. The following section describes the evaluation phases that were done.

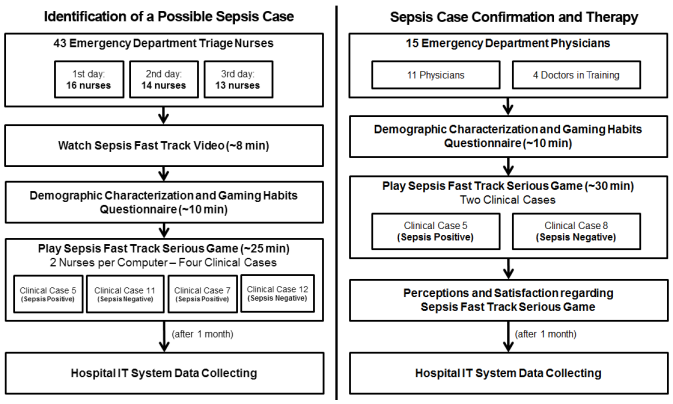

Fig. 17. Evaluation Research Flowchart.

A. Identification of a Possible Sepsis Case Evaluation

The *Identification of a Possible Sepsis Case* evaluation phase of Sepsis Fast Track serious game consisted of understanding how the game impacted the actual work practices of Emergency Department nurses after playing it in an evaluation session. The following subsections describe the methodology, the results, and a discussion about them.

This study was done over the course of three days on-site at the hospital facilities. It included all 43 Emergency Department nurses in the hospital responsible for the triage of patients. Figure 17 presents a research flowchart with the methodology that was used to accomplish this study.

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. Regarding their professional experience, the triage nurses had an average of 12 years (sd $\approx$ 6.61) of previous experience working in an emergency department. 13 of the 43 triage nurses played video games regularly, but the majority played less than three hours per week. Only 6 nurses had already used serious games to learn; they referred to examples such as the ACLS Trainer, Israel catastrophe game, and Resuscitation! serious games. 35 of the 43 nurses already had Sepsis Fast Track training; all those training courses had been in a traditional class setting.

B. Sepsis Case Confirmation and Therapy Evaluation

The *Sepsis Case Confirmation and Therapy* evaluation phase of the Sepsis Fast Track serious game was intended to understand how the game impacted the work practices of Emergency Department physicians. The following subsections describe how the evaluation study was carried out, its results, and a further discussion.

This evaluation study was conducted over the course of a week at the hospital facilities. It was composed of 15 Emergency Department physicians: 11 attending physicians and 4 interns. Figure 17 presents a research flowchart with the methodology that was used to accomplish this study.

The group of 15 physicians was composed of 11 females and 4 males with an average age of 36.81 years old. In terms of their professional experience, the physicians had an average of 6.63 years of previous experience working in an emergency department. Half of them played video games regularly, although most of them played less than 3 hours per week. Seven physicians had already used serious games and eleven, all attending physicians, had previous Sepsis Fast Track training.

V. Results

A. Identification of a Possible Sepsis Case Evaluation

The evaluation of the Sepsis Fast Track serious game focused on two aspects: the analysis of the in-game data logging and the hospital IT system logs.

1) In-game Data Logs: Sepsis Fast Track serious game is able to log every procedure that a player performs while playing the game. Therefore, it is possible to analyse which procedures were performed by the nurses and the mistakes that they committed during the gameplay.

All the nurses played four clinical cases, two nurses per computer. Two cases had criteria to validate the Sepsis Fast Track (clinical cases 5 and 7), and two cases did not have the criteria to validate the Sepsis Fast Track (clinical cases 11 and 12).

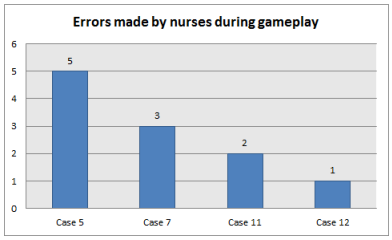

Fig. 18. Number of errors made by nurses playing four clinical cases.

Figure 18 shows the number of errors made by the nurses while playing the four clinical cases.

2) Hospital IT System Logs: After one month of the evaluation study with the emergency department nurses, we returned to the hospital to collect the hospital IT system logs. In respect to the nurses' evaluation, these logs reveal information about the number of patient admissions in the emergency department and the number of Sepsis Fast Track activations. The purpose of having this information was to assess whether there had been any impact regarding the activation procedures by nurses.

The hospital IT system logs that we were provided with included data from 2011 up to February 2014. The average number of activations was 0.26%, the minimum occurred in

May 2011 with a percentage of 0.01%, and the maximum occurred in February 2013 with 0.75%. The evaluation study sessions with the nurses occurred in the beginning of February 2014, which was the second highest month in terms of Sepsis Fast Track activations per patient admissions, with a percentage of 0.70%.

B. Sepsis Case Confirmation and Therapy

The results of the evaluation of the Sepsis Fast Track serious game for the physicians focused on three aspects: the interviews conducted during the gameplay, the analysis of the in-game data logging, and the hospital IT system logs.

1) Interviews Results: The interviews were done while the physicians were playing the Sepsis Fast Track serious game, providing us with their opinions about it and helping us understand if it could help teaching and training of the Sepsis Fast Track protocol.

All the attending physicians already had previous Sepsis Fast Track training. Therefore, they were aware of its goals and procedures in order to confirm a sepsis case and begin therapy. Most of them became upset when they made a mistake, causing them to lose lives and points. When an error occurs, feedback is provided, allowing the player to know which error was committed and which procedure should have been done instead. This also served as a bridge between how they normally perform in real life and how they should achieve their objectives in the serious game. Regarding the debriefing, some physicians felt that it was too long and did not pay adequate attention to it. On the other hand, some physicians agreed that it was important to understand why the game requires the performance of some procedures instead of others. The majority of the attending physicians stated that this serious game was a good tool to teach and refresh the Sepsis Fast Track protocol, namely to systematise its procedural sequence. They also suggested that this game would be more suitable for intern physicians. Regarding the player immersion, most of the physicians said that they did not feel immersed in the role of a real physician, nor did they consider the patients as real ones. They also forgot which procedures had already been done and repeated some of them. However, they did not seem to care much about it, saying *"oh, it's okay. Is just a game."*. In general they said that they enjoyed playing the game, but most of them said that they would not play it voluntarily. All the attending physicians pointed out the differences between the ways they needed to examine the patients in the game vs. patient examinations in real life. For instance, in real life, the patient's vital signs are always visible, opposed to the game, where players need to click on the vital signs monitor to check the levels.

The intern physicians that participated in these evaluation sessions had very little experience working in an emergency department and none of them had ever applied the Sepsis Fast Track protocol in a practical way by attending to a real sepsis patient. However, they already had theoretical contact with the Sepsis Fast Track protocol. Contrary to the attending physicians, the interns were more tolerant when they made errors while playing the serious game. When they received negative feedback, they quickly figured out what they had done wrong and what they were supposed to do instead. They all stated that the feedback was an important feature, because it helped them to know what to do next. All the interns agreed that this serious game helped them to know more about the Sepsis Fast Track protocol, particularly which procedures need to be made and in which order. They commented on the importance of the multiple types of information that the serious game provides, such as the in-game feedback and the debriefing presentation when they concluded the clinical case. In general, all the intern physicians enjoyed playing the game and felt that it was intuitive. Some of them wanted to play more clinical cases and even asked if this serious game was available so they could play it at home.

2) In-game Data Logs: Figure 19 presents the percentage of errors made by attending and intern physicians at a particular step of the protocol, while playing clinical case 8.

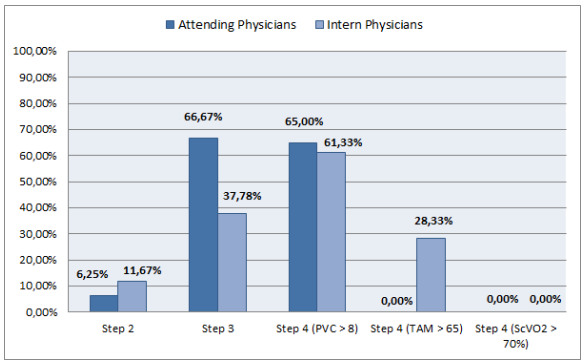

Fig. 19. Percentage of errors made by physicians playing clinical case 8.

Overall, the performance of the attending physicians was better. However, in Step 2, intern physicians performed better doing the *VVS Activation (IT System)* procedure, and in Step 4, (MAP >65 mmHg), the interns executed all the procedures without errors, as opposed to the attending physicians, who committed errors.

3) Hospital IT System Logs: In terms of the physician evaluation, the IT system logs show information about the Sepsis Fast Track forms that were filled out by physicians. After a nurse identifies a possible sepsis case and refers the patient to the physician responsible for the Sepsis Fast Track, the physician should register the patient's data concerning the sepsis case. By analysing this information, it would be possible to know if there had been any impact on physicians' work practices regarding the registration of the sepsis forms. The registration of these forms is important for better hospital management and ultimately for patient care quality.

The hospital IT system logs that we were provided with included data from 2011 up to February 2014. Analysing the data, we can conclude that only two months had an optimal form registration level: December 2012 and November 2013. Also, both of those months had very low rates of Sepsis Fast Track activations. Only an average of 35.63% of the total Sepsis Fast Track activations resulted in form registration. The evaluation of the physicians occurred in the beginning of January 2014, the percentage of form registration for January and February of 2014 are 58.33% and 30.43%, respectively. January is 22.70% above average, while February is 5.2% below the average.

VI. Discussion

A. Identification of a Possible Sepsis Case Evaluation

Since we are dealing with healthcare data, there is an unpredictability factor that may affect the results, more specifically, the seasonality and the dynamics of infectious diseases, sepsis in particular [20], [21]. Therefore, the results presented in the previous section may not be very conclusive, although we thought that some analysis could be made.

Analysing the in-game data logs, despite the difference between the number of errors across several clinical cases is not very substantial, there are noticeable improvements when comparing both types of clinical cases with each other. Comparing clinical case 7 with case 5 (positive sepsis case) and case 11 with 12 (negative sepsis case), there was an improvement. Overall, the nurses committed two errors less and one error less, after playing the other clinical case. This may indicate that the nurses were better trained after playing a clinical case, as they had been made aware of some areas they had failed in during the first playing time. The most failed procedure was *Register Data (IT System)* (with a total of 5 errors in the first three played clinical cases), mostly because the nurses forgot to activate the Sepsis Fast Track alert. However, by the fourth case, all the nurses performed this procedure correctly, suggesting that they learnt which information needs to be registered and how to activate the alert.

Upon analysing the results of the IT system logs in terms of the percentage of Sepsis Fast Track admissions, it was found that February 2014 (the month when this study was carried out), was the second best month in the period of 2011 to 2014. This may indicate that the evaluation sessions, where all the emergency department nurses played the serious game, resulted in a tangible improvement in their working practices. However, we cannot conclude that by simply analysing the data of Sepsis Fast Track activations, since there is a variance every month due to the previously mentioned unpredictable factor.

For a better Sepsis Fast Track serious game evaluation, it would be necessary to perform more evaluation sessions in order to compare the values over a longer period of time. This would reduce the impact of unpredictability and seasonality of patient infections and other diseases, allowing us to more accurately draw conclusions about the efficiency and efficacy of these serious games.

Nevertheless, during an informal talk with the nurses after they had played the game, almost every participant said that they enjoyed playing it and preferred this learning method in comparison to traditional methods. They stated that the interaction and the possibility of assessing a patient in a practical way would allow them to better assimilate the protocol requirements and necessary procedures.

In conclusion, the results of this evaluation study are promising. However, with the current data, both from in-game and IT system logs, there is no concrete way to prove that Sepsis Fast Track serious game had a positive impact on emergency department nurses work practices. Nevertheless, we can conclude that the serious game did not have a negative impact on the working practices of these nurses.

B. Sepsis Case Confirmation and Therapy

The evaluation of the *Sepsis Case Confirmation and Therapy* game phase is based on the same main goals as the previous phase - evaluating the impact on physicians' working practices. Additionally, we interviewed each physician in order to hear his or her opinion and measure of satisfaction with the game.

As in the *Identification of a Possible Sepsis Case* evaluation study with the nurses, the results of this evaluation do not conclusively demonstrate the efficiency of the Sepsis Fast Track serious game regarding the improvement in physicians working practices. However, some assumptions can be made.

During the interviews, every physician referred to the importance of the in-game, real-time feedback and the debriefing that was implemented in the game. They stated that the feedback facilitated easier gameplay; suggesting procedures that should be done and even losing a "life" were good forms of feedback. They commented on the debriefing phase, which is where they could understand which errors they committed and why. They pointed out that the inclusion of the Sepsis Fast Track algorithm in the debriefing allowed them to get a broader view of the issue and also provided them with a better understanding of the procedural sequence.

Analysing the in-game data logs, we can observe that the attending physicians performed better, but by quite a small margin, 3.22%. This can be explained by the fact that attending physicians have already mastered many of the necessary *mechanics* for a proper patient diagnosis and further treatment, without the need to follow the Sepsis Fast Track protocol to the letter, as the game requires. Moreover, during the evaluation sessions, the attending physicians generally seemed to concentrate less and did not take the game seriously, in comparison to the interns. This could be because the attending physicians are not as open to this new learning method and still see video games solely as a source of entertainment. This can also explain the hospital's IT system logs, which did not reveal any improvements regarding the physicians' working practices.

From the results, it seems that this serious game would be more suitable for intern physicians than for attending physicians. Also, by analysing the in-game data logs, it is possible to conclude that the attending physicians performed better than the intern physicians (even in a small percentage), indicating that the interns need to better trained on the Sepsis Fast Track. However, this serious game may be a way to teach the attending physicians new changes to the protocol procedures. Regarding the lack of proper form documentation in the IT system, particularly of the Sepsis Fast Track form, we don't think that this serious game would improve it substantially. Other approaches, such as the 'gamification' of the hospital IT system, would have potentially better benefits.

We also conclude that some changes could to be made to this serious game regarding the player's immersion. As pointed out by some physicians, they did not view the in-game patient as a real patient, resulting in errors and a lack of full attention to what the game was teaching and training. Virtual reality is coming back as trend, which could be a possibility for improving the player's sense of immersion.

For a better analysis of this serious game, more evaluation sessions need to be conducted. That would make it possible to analyse this game in a more comprehensive manner, comparing the results not only with a unique evaluation session, but also with other ones within a longer period of time.

VII. Conclusion

In this paper, we presented a serious game entitled Sepsis Fast Track serious game for clinical education. It was developed to teach and train healthcare professionals in hospital emergency departments, namely nurses and physicians, about the Sepsis Fast Track protocol. This serious game was based on the protocol issued by the Portuguese Directorate-General of Health [1] based on the Surviving Sepsis Campaign guidelines [2], which aims to regulate and spread awareness of implementation procedures of the Sepsis Fast Track in Portuguese hospitals.

The development was conducted together with healthcare professionals, which facilitated the requirements analysis. Moreover, during the game development, several meetings were held to ensure that the serious game was being developed according to the algorithm described in the Sepsis Fast Track protocol. Since we are dealing with medical information, procedures, equipment, and language, it was very important support.

In order to evaluate the impacts of this serious game on emergency department healthcare professionals' working practices, an evaluation study was done in the hospital facilities. This study was divided into two phases, one with 43 nurses that played four clinical cases (*Identification of a Possible Sepsis Case*) and another with 15 physicians playing one clinical case and being interviewed (*Sepsis Case Confirmation and Therapy*). In both evaluation phases, the players' actions during the gameplay were logged in order to evaluate their performance. In addition, after one month, we returned to the hospital to gather the IT system data logs, in order to understand if there had been an improvement in healthcare performance regarding the Sepsis Fast Track. The hospital's IT system data logs were not sufficient to assess the serious game efficiency. Because of the unpredictability factor that exists when dealing with healthcare, the data related to the number of Sepsis Fast Track activations was significantly variable over the analysed months. The physicians mentioned the importance of the in-game real-time feedback and the debriefing procedure. Both nurses and physicians said that they enjoyed playing the game. Most of the nurses and the intern physicians stated that they preferred this method of learning as compared to the traditional ones. They explained that the interaction that the game allows facilitates enhanced learning, rather than listening to a person teaching and explaining them the protocol in a traditional academic setting.

In conclusion, we think that the Sepsis Fast Track serious game has a lot of potential to be used as a real training tool for the Sepsis Fast Track protocol. However, more studies need to be conducted in order to understand if it is consistently efficient and effective as a training tool.

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