Critical Transport: A Serious Game to Teach the Recommendations for the Transport of Critically Ill Patients

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***Abstract*—At present, medical knowledge is experiencing an exponential growth. This results in serious difficulties to health-care professionals in keeping up to date. At the same time, medical education is mostly taught using traditional learning methodologies, not always the most efficient. Recently however, there has been a significant increase in the use of computer games for both teaching and training as several published studies are showing that serious games can be more efficient when compared to traditional learning methodologies. Although the current number of serious games used in medical education is still very limited, the authors agree that it's application could lead to the improvement of medical knowledge and skills. This paper describes the serious game Critical Transport which is based on the Portuguese Society of Intensive Care's recommendations for the transport of critically ill patients, as well as the results of a pre/post-test study focused in determining the Critical Transport serious game efficiency as a training tool for training medical students.**

I. Introduction

Healthcare is one of the most important topics across the globe and it is considered a priority by political decision makers. The everyday exponential increase in medical knowledge results in a major challenge for healthcare professionals, from the very beginning of medical school. Most of these professionals need practical experience without putting themselves or others at risk. This principle holds in many medical areas, such as medical decision making, behavioural training, and others, involving dynamism and complexity [Ribeiro et al., 2012].

Traditional medical education, mainly teacher-focused and based on reading, listening or watching, has proved insufficient in adult education as well as inadequate for teaching both technical and soft skills. It has been reported that physicians make mistakes to such an extent that medical errors can be counted amongst the leading causes of death in the United States [Institute of Medicine, 2001], [Kohn et al., 1999]. Moreover, there is also an increasing awareness of the importance of creating a learning environment that approaches real life as much as possible through simulation and immersive realities, especially in a safety-critical area like medicine.

Rethinking medical education must include the opportunities offered by new information technologies as well as important cognitive style changes of the new generation of trainees, the so-called digital natives. Technological innovations, such as virtual reality simulation and e-learning applications, have led to consistent improvements in learning outcomes, and already play an important role in surgical residency training programes [Schreuder et al., 2011], [Cook et al., 2011], [Thijssen and Schijven, 2010], [Marks et al., 2007]. Video games known as "Serious Games" have attracted a lot of interest in recent years, as a possible solution to answer the challenges currently faced by medical education. A serious game is formally defined as an 'interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality' [Bergeron, 2006]. Serious games differ from conventional video games and simulators in the sense that they are designed to provide a balanced combination between fun and learning. Balancing these two factors is one the main challenges currently faced by the serious game researcher community [Khaled and Ingram, 2012], [Isbister et al., 2010], [Malone, 1980].

Serious games have been used successfully as a means to engage patients behaviorally to improve their health outcomes [Høiseth et al., 2013], [Hernandez et al., 2012], [Kato, 2010] as early reports of case studies, using video games with patients experiencing diseases or physical disabilities, have shown [Kato et al., 2008], [Krichevets et al., 1994], [Szer, 1983]. Nevertheless, there is still a lack of equally successful examples used in formal medical education. Several authors [Graafland et al., 2012], [de Wit-Zuurendonk and Oei, 2011], [Kato, 2010] have conducted systematic reviews on the use of serious games for medical education and concluded that there is a lack of scientific evidence of its efficiency and effectiveness. This is compromising the adoption of serious games in medical education.

In this paper we present the results of a one year experiment using a serious game in formal medical education classes in an academic hospital. This paper describes the Critical Transport serious game, which aim is to teach the recommendations for the transport of critically ill patients, elaborated by Portuguese Society of Intensive Care, to undergraduate medical students. This game uses video game technology in order to establish a link between a framework computer-based case with e-learning functionalities. In order to achieve this, different clinical cases are presented, using computer graphics techniques, and they must be solved following the recommendations for the transport of critically ill patients in order to guarantee a safe transport of the patients. Also, in this paper, we will present and discuss the results of the study conducted during three formal classes. The objective of the study was to conclude if the Critical Transport serious game is an effective educational and training tool for training medical students.

The remaining sections of this paper are organized as follows: Section II presents the state-of-the-art of serious games for medical education. In section III the design and pedagogical considerations taken into account while developing Critical Transport are reported. In Section IV the Critical Transport serious games is described in terms of context and learners, learning objectives and game mechanics, representation, user interface design and implementation. Section V presents the methods and procedures used to evaluate the Critical Transport. This is followed by the description of the obtained results (Section VI). Section VII presents a critical analysis of the results as well as relevant insights learned with the experience of our study. Finally, section VIII presents the conclusions and future work.

II. Serious Games in Healthcare

In research literature, several studies have shown that games have a positive effect on skills that are important in medical / clinical work, such as visual skills, fine motor control, eye-hand coordination, visual spatial performance, visual selective attention, visual memory, etc. Although it has been argued that games in general permit constructive, situated and experiential learning, several reviews have analysed the empirical evidence of such claims and have reported inconclusive findings. Next we summarize the finding of recent meta-analysis and systematic reviews published in high impact journals focusing specifically on computer games developed for medical education.

Girard et al. [Girard et al., 2012] have conducted a meta-analysis of recent studies regarding the effectiveness of serious games. The studies included in this meta-analysis had to describe the use of a serious game or video game for education that had been submitted to an experimental study. From the nine studies identified only one was related to medical education, and described the results of evaluating the effectiveness of the Triage Trainer serious game in teaching major incident triage by comparing it with traditional methods [Knight et al., 2010]. In general, the authors have found several limitations in the reported studies, such as lack of control group, lack of testing transfer of acquired knowledge and skills, and the inability to compare finding due to the variety (design, mechanics, etc) of serious games.

Graafland et al. [Graafland et al., 2012] carried out a systematic review of serious games for medical education and surgical skills. Specifically, the authors aim was to review current serious games for training medical professionals and to evaluate the validity testing of such games. The validity types taken into consideration by the authors for games relevant to education of medical professionals where specifically: content validity; face validity; construct validity; concurrent validity; and predictive validity [Schijven and Jakimowicz, 2005], [Gallagher et al., 2003]. Regarding games and target users, in this review only included studies that focused on game-based learning programmes and that were intended for professionals in medicine (physicians, nurses, physiotherapists, paramedics, etc,). A total of 25 articles were found to be relevant, describing a total of 30 serious games (17 were specifically designed for educational purposes and 13 were commercially available games not specifically developed for medical personnel). Regarding serious games, the authors have concluded that although they present an innovative approach to the education of medical professionals, specifically as a means to reduce medical error, future research should define valid performance measures and also complete formal validation programmes, before they can be adopted as an educational instrument.

In the same year, Connoly et al. [Connolly et al., 2012] also conducted a systematic review aiming at investigating the positive impacts of gaming on users aged 14 years or above, specifically related to learning, skills enhancement and engagement. In this review were included studies using both entertainment games as well as serious games that reported experimental studies, both Randomized Controlled Trials (RCT), quasi-experimental controlled studies, case studies, single subject-experiment design and pre-test/post-test design. 129 studies were identified and categorized according to a multidimensional framework that related game variables such as primary purpose, game genre, outcomes and impacts of playing games among others. From the 129 studies, six were related to healthcare and were categorized according to the following learning outcomes: one study was related to knowledge acquisition and content understanding (tooth morphology); four were related to motor skills acquisitions (surgical skills); and one was related to perceptual and cognitive skills outcomes (surgical skills). Although empirical evidence was found regarding the positive impacts of gaming on learning, the authors have pointed out that there is still a need for high-quality studies, namely RCTs, and also qualitative studies to help understand the nature of engagement in games.

Akl et al. [Akl et al., 2013] reported the results of a systematic review which had the objective to assess the effect of educational games on health professionals' performance (e.g. adherence to standards of care) through improving their knowledge, skills and attitudes. In this review only RCT, controlled clinical trials, controlled before and after and interrupted time-series analysis where included. From the 2079 identified unique citations, only 2 studies where included which described a RCTs experiment. The findings reported in these studies neither confirm nor refuted the utility of games as a teaching strategy for health professionals. Therefore, the authors concluded that there is still a need for additional high-quality research to explore the impact of educational games on patient and performance outcomes.

In sum, although there is an interest in using serious game for medical education, their current use is still very limited, specially in continuing medical education. Also, from the reported studies there is still a lack of evidence that serious game have a positive impact on healthcare professionals knowledge, skills and patient care quality. In our paper we describe an experience that took place in a formal context during a year in an academic hospital. A part from reporting the results of conducting a pre/post-test design experience, we also report students perception of serious games in medical education as well as the relevance of specific game mechanics and game attributes in serious games for medical education.

III. Design and Pedagogical Considerations

A. Design Considerations

Critical Transport was built by an interdisciplinary group composed of physicians with teaching experience, software developers, and a 3D artist. The main goal of the project was clear to everyone from the outset. Nevertheless, due to the difference of such diverse backgrounds it was essential to build common ground upon which discussion could take place. 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 was documented photographically. Also, it was possible to observe how things were done in a real situation/environment.

To foster discussion and conduct initial verification of user interface concepts, the serious game was partitioned in several smaller blocks of development and incremental prototypes were developed and used to conduct user tests. These prototypes were tested by physicians as well as students and during these sections ad-hoc user observations were carried out. Also, users were asked questions after each testing session in order to understand their impressions regarding UI concepts and current phases of the game.

B. Pedagogical considerations

In addition to the design considerations it was also very important to integrate and then validate how the pedagogical content was transformed into game mechanics. To conceptually support issues of game design using pedagogically driven approaches, de Freitas and Oliver [de Freitas and Oliver, 2006] proposed the Four Dimensional Framework (4DF) of learning. This model proposes to inform game design by referring to four discrete dimensions including: the context within which learning takes place (e.g. disciplinary context, blended or standalone, place of learning, formal or informal), learner profiling (e.g. demography, ICT skills, gaming experience), selection of pedagogies used (e.g. learning methods, models and mechanics) and mode of representation (e.g. game concepts, game engines, mode of deployment, level of fidelity, interactivity). The consideration of the individual characteristics of each dimension contributes towards the creation of a successful game-based learning experience [Bellotti et al., 2011].

Following the same objectives, Kiili [Kiili, 2007] devised a problem-based gaming (PBG) model which is founded on the very same principles of PBL [Engel, 1991], [Kilroy, 2004]. The PBG model distinguishes the learning process into elements, namely: 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.

In the design and implementation of Critical Transport serious game 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 [Kiili, 2005], [Kiili, 2007] 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.

For this purpose, several informal interviews [Cohen et al., 2007] were conducted with domain experts. First, we wanted to understand what was the critical part of the recommendations that should be integrated in the game. Secondly, we needed to know all the actions that the user should be able to do when evaluating a patient condition and what was the information (e.g. patient clinical history, current condition, age) necessary to do so. Finally, it was also discussed what kind of feedback should be given to the user during game play and how this should be integrated in the UI in order to foster reflection.

In the next section, the result of these informal interviews is described.

IV. Critical Transport

A. Context and Learners

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 target at 4th year medical students. The rational of this choice was related with 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 I.

B. Learning Objectives and Game Mechanics

The main objective of the Critical Transport Serious Games is to teach students the recommendations for the transportation

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 critical ill patient.	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 need to be evaluated; the appropriate team and equipment of the ambulance that will transport the patient.	The recommendations for the transport of critical ill patient will use 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 implemented different clinical cases with increased level of difficulty .

TABLE I: Four-Dimensional Framework applied to critical transport serious game

of the 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 in the gameplay, nine main game mechanics were proposed for the critical transport serious game. These game mechanics incorporate possible kinds of interactions that take place during the game, be it general or specific. Also, they define how play progresses, what happens when, and what conditions determine victory or defeat [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 described each of these mechanics and related them to the pedagogical objectives of the serious game.

The *Examine Patient* game mechanic (Fig. 1 describes the 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. 2), saline flow meter (Fig. 3) and syringe pump (Fig. 4). In the case of the *ECG Monitor* game mechanic, 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 about the current flow of saline being

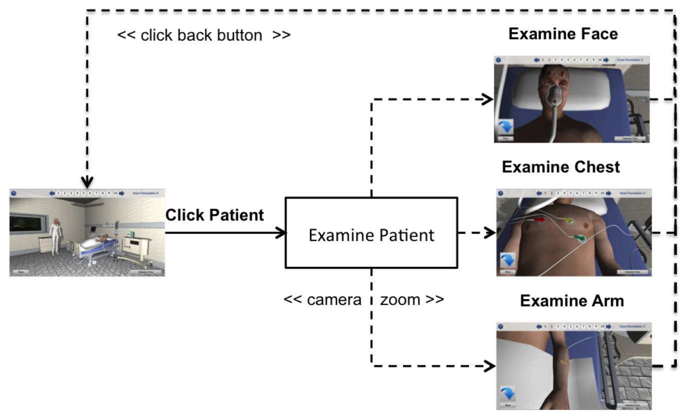

Fig. 1: Examine Patient Game Mechanic (GM1)

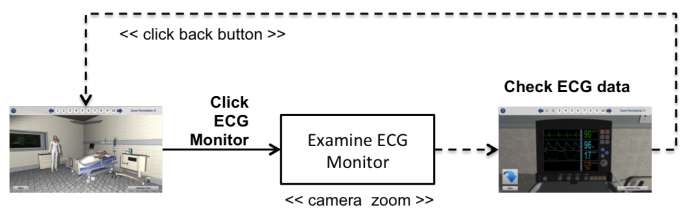

Fig. 2: Examine ECG Game Mechanic (GM2)

administrated to the patient. The syringe pump shows all

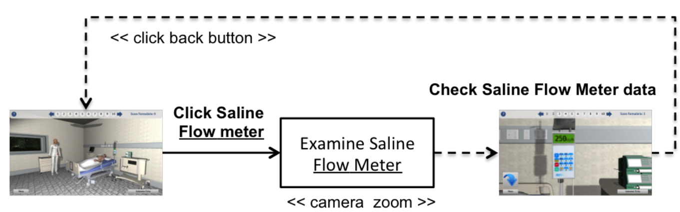

Fig. 3: Examine Saline Flow Meter Game Mechanic (GM3)

the information related to the medication currently being administered to the patient. The *Examine Patient Chart* game mechanic has all the relevant information regarding the clinical case and patient data, such as name, age, previous clinical

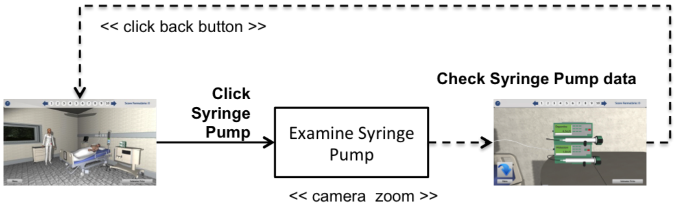

Fig. 4: Examine Syringe Pump Game Mechanic (GM4)

conditions and also a description of what was the situation that caused the patient to be in the hospital. The *Examine*

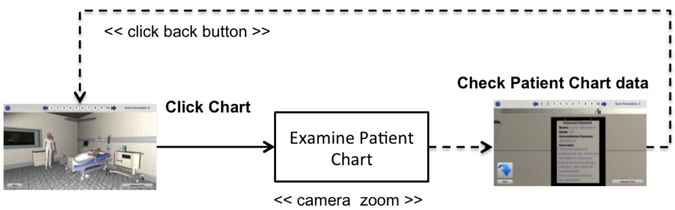

Fig. 5: Examine Patient Chart Game Mechanic (GM5)

Glasgow Scale game mechanic (Fig. 6) allows the player to ask the nurse for information. In the context of Critical Transport, the information the player 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

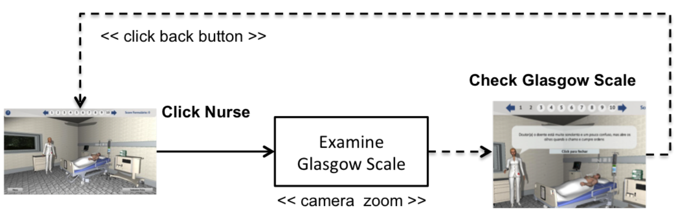

Fig. 6: Examine Glasgow Scale Game Mechanic (GM6)

examine and evaluate all the previous 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 gain by playing the game to her/his work practices. The only concerned 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 update every time the player fills out one of the questions in the form. This behaviour is encapsulated in the *Fill Out Questionnaire* game mechanic. The next two game mechanics are related to the team and equipment of the ambulance responsible for transporting the patient. The *Choose Team* game mechanic allow the player to choose the proper team having into account the patient's condition. The team can be composed by a combination of the following medicine professionals: paramedic, nurse and physician. Regarding the *Choose Equipment* game mechanic, it allows the player to choose to take in the ambulance an ECG monitor, a ventilator and defibrillator among other things.

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

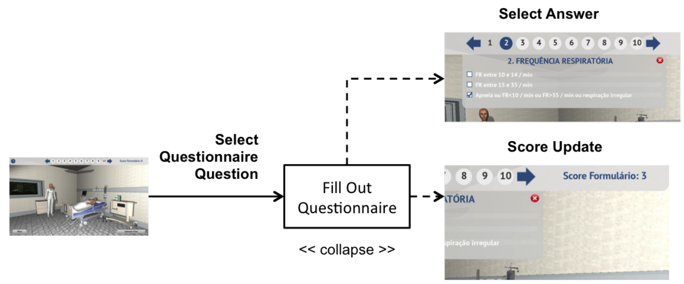

Fig. 7: Fill Out Questionnaire Game Mechanic (GM7)

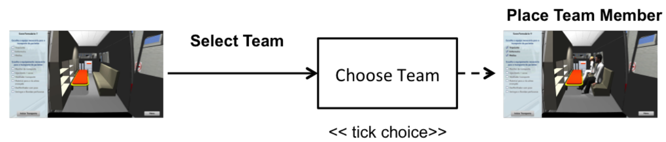

Fig. 8: Choose Team Game Mechanic (GM8)

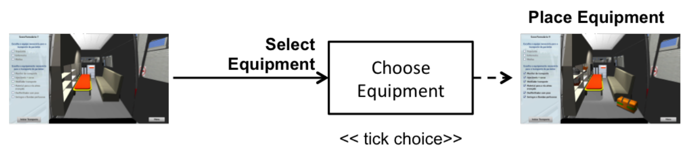

Fig. 9: Choose Equipment Game Mechanic (GM9)

C. Representation

In order to promote both single and double-loop learning the structure of each scenario was composed of three main components: the briefing, gameplay and debriefing.

In the first part of the briefing phase the pedagogical goals of the game are explained. This is presented in the form of a dialogue between two 3D avatars impersonating a physician and nurse in a hospital room. The content of the dialogue was provided by the physicians.

The second part of the briefing phase is a very critical and important part of strategy formation. It consists of the clinical case briefing, where the information regarding the patient data that is in need of transportation is described. This information includes the patient's name, age, medical history, cause of current hospitalization and the reason to be transported to another hospital. This information is presented by a 3D avatar impersonating a physician.

The third phase consists of the experimentation phase. The experimentation phase is mostly concerned with exploring the virtual environment and collecting all the necessary information to adequately assess the current condition of the patient. Therefore, is a crucial phase for medical decision-making process.

The final phase (debriefing), it is when reflection takes place. All the answers given by the player during game play are analysed and feedback is provided about her/his choices, pointing out the right and the wrong answers. Additionally, a score is attributed to the player based on her/his achievements

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 II: Learning Objectives and Game Mechanics

during the complete clinical case. The scoring system is based on minor to major medical errors. This score allows comparing the performance between players and single player performance evolution.

User Interface Design: 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 difficulties in navigating in a 3-D 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 3-D environments.

Secondly, it was important to avoid long training times. For this reason, we based many aspects of the user interface on well-known 2-D 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.

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 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.

Figure 10 refers to the evaluation of the patient's condition, where the user interface is composed of a help button (a) which will display the help screen (Figure 11), buttons to open the form's questions (b), the interface to answer the form's questions (c), the form's score (d), a menu button (e), and the submit button (f) which can only be used when the form is completed. Moreover, in Figure 10, the yellow circled areas are clickable interaction spots, namely, a nurse which informs the player about the patient's neurological status (help regarding Glasgow comma 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).

Figure 12 refers to the team and equipment choice. This user interface is composed by the form's score (a) to support

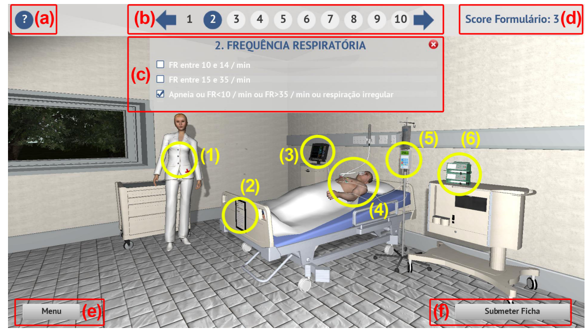

Fig. 10: Evaluation Phase User Interface

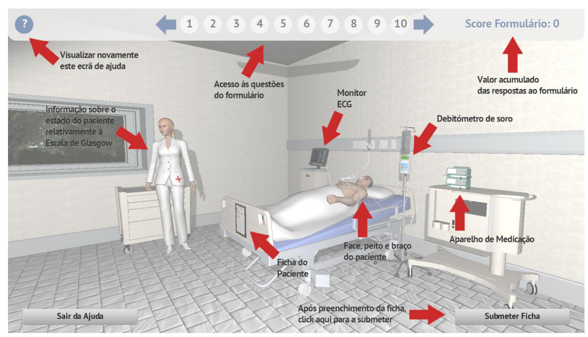

Fig. 11: Help Screen

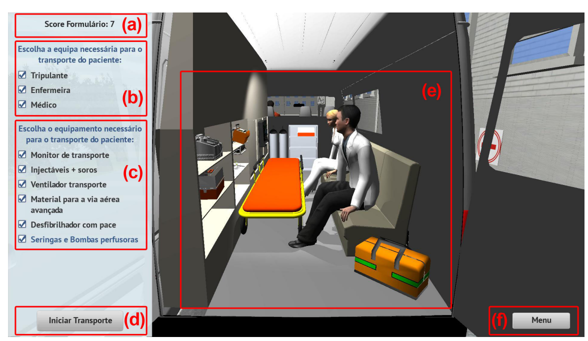

Fig. 12: Team and Equipment Choice User Interface

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).

Implementation: Critical Transport was developed in Unity3D pro [1] game engine and the game scripts were written in C# programming language. The 3D models used in the graphical environment were built in 3D studio max [2]; and among other things, it includes all the medical equipment, hospital facilities and surrounding environment. All the 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. The Critical Transport was deployed to run on a web browser, in order to be supported in any browser that runs unity3D web player. It this manner we were relieved of the possible limitations of graphic card rendering support. The general architecture includes the game and repository for the XML files and 3D models.

V. Methods

The objective of this study was to determined 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. The first results of this study were reported in [Ribeiro et al., 2013]. In this paper we describe the results of analysing the data qualitatively and quantitatively from the three studies. Due to the reduced number of students only having into consideration the three studies would allow us to do a proper statistical analysis. Also, in-game data from the second and third study are analysed and discussed.

A. 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.

B. Procedures

Prior to the beginning of the class, each computer was tested to ensure that the serious games 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 11). 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 III. 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 also would 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 students choices, both in criteria evaluation as well team and equipment choice, would be logged per student.

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.

C. Statistics

This study used a combination of qualitative and quantitative 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 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.

VI. Results

A. 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

[1] http://unity3d.com/

[2] http://www.autodesk.com/products/autodesk-3ds-max/overview

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 III: Clinical Case 1 and 2 description and medical data

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.

B. Pret-test and Post-test

The pre-test measures the knowledge related to the recommendations of the transport of critical 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 13. Nevertheless, and because the wrong answers were mostly 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 14 and Figure 15. 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 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 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

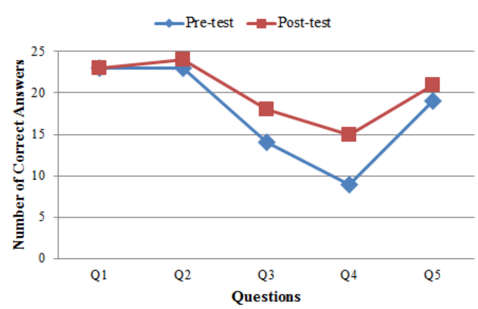

Fig. 13: Comparison between Pre-test and Post-test.

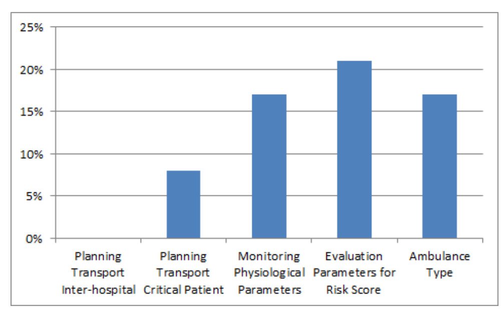

Fig. 14: Improvements in Post-test per Question.

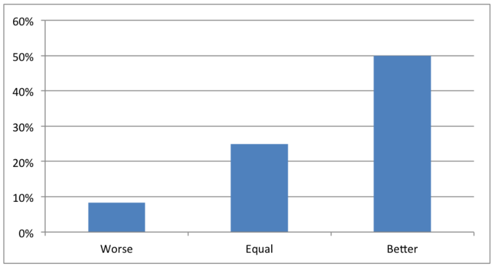

Fig. 15: Improvements in Post-test per Student.

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.

C. In-Game Data Analysis

The pre/post-test questionnaire allow us to test and measure the knowledge gain regarding both general and specific questions related to the pedagogical content. The in-game data collect 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 16 and 17.

Analysing each specific group shows that students perform better in the second clinical case when evaluating the criteria. In the other two groups, namely team and equipment the improvement was not clearly observed. In some choices student did perform better in the second clinical case but there others where they performed worse. This same trend was also observed in the post-test data. In the discussion section we provide possible explanations that might have motivated the discrepancy in improvement when considering different question groups.

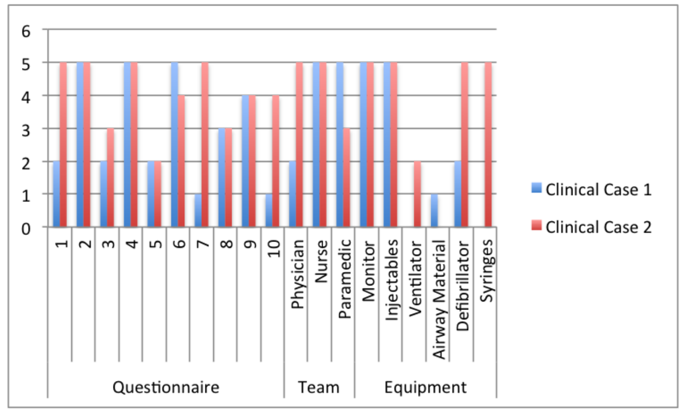

Fig. 16: Comparison of In-Game Performance: Second Group

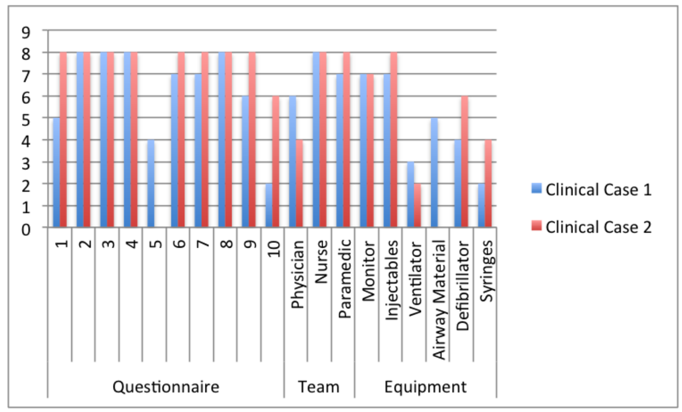

Fig. 17: Comparison of In-Game Performance: Third Group

VII. 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 students 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 this results we were also inclined to think that a more carefully designed debriefing, one that better contextualized and relate the students decisions and the recommendation would probably help the student 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 players previous knowledge and its presentation needs to be contextualized, meaning it should clearly connect players 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 particular sensible when certain values (e.g. ECG monitor data) was not coherent with patient data (e.g. medical condition, age) and also the medical terms used in the gameplay.

Pedagogical approaches, game mechanics and game attributes are the three pilar stones of serious games. Pedagogical approaches define how the pedagogical content should be express in terms of tasks and activities while game mechanics and game attributes determine how they are integrated in a meaningful gameplay. Moreover, by 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 mimicry what a physician would have to do in 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 other medicine professional. It would be interesting to verified 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 target at medical education that could be use interchangeably in different serious games. Also, it would be very useful to integrate in the mechanics the description of learning analytics that could be collect during gameplay to analyse how effective the game mechanic was in a certain learning objective. This not just allow to compare serious games but also students 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, it also changes the role of the trainer from just delivering material to being a facilitator. The role of the teacher becomes central as the facilitator of balancing the educational game experiences to other practices. For the teacher to become a facilitator means, in design terms, he or she must be involved in the game experience itself, either participating in the game or as a close observer. 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 observe 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. Whilst there is some evidence to suggest that serious games improve retention over other training methods [Roman and Brown, 2008] and although students impression are in accordance with this evidence, future studies should measure the ability of students to retain the skills learned in the serious game over a longer period of time.

Providing evidence of this 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 particular 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].

VIII. Conclusion and Future Work

The goal of our study was to evaluate the efficiency of serious games in formal medical education classes. Our results showed that training with Critical Transport had a positive effect on users prior knowledge. Specifically, there was a statistically significant difference in the ability of students answering the post-test. Moreover, the in-game data analysis also showed this positive, expect on the decisions regarding the ambulance team and equipment.

Conducting this study allowed us to understand some fundamental things about using serious games in formal medical education. First, the role of the facilitator has to be acknowledge and her/him has to be involved since the beginning of the design phase until the end of the development phase. The user interface 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. Finally, another important factor that presents itself as an opportunity, is the willingness of students to accept serious games as a training tools in their formal education.

Regarding game mechanics and game attributes, it was noted that assessment, performance, realism are central to serious games in medical education and some indications were provided on how they should be integrated in the gameplay. Also, we have identified groups of game mechanics that are useful to describe medical procedures in terms of game mechanics.

As a future work, it would be interesting to extend the logging abilities of the game and also capture the sequence of game mechanics (e.g. examine patient -¿ examine ECG, etc.) and try to correlate it with the performance of the player. In this manner it would be possible to understand why the player perform worst in some parts of the game as opposed to other.

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