Serious games to teach medical procedures: chest tube insertion

Nicolás Mendoza R., Pablo Figueroa, Juan David Hernandez, David Delgadillo.

Abstract—**Now days, at their student phase, future doctors have less exposure to real patients and real medical procedures. Some of these procedures are mandatory for newly graduated doctors so proper training is necessary. Chest tube insertion is one of those procedures. Procedure details and steps can be easy to forget if there is no practice, so students need a way to practice. We propose a serious game which implements a generic gameplay aimed at process remembering stimulation. Chest tube insertion is taken as the medical procedure to implement, even though the gameplay can be used to teach any kind of medical intervention.**

Index Terms—**Videogame, serious games, gameplay, medicine, chest tube.**

I. INTRODUCTION

Every human being has been exposed to a great variety human made processes. These can range from the simple steps involved when we need to tie our shoe laces to the steps involved in the landing of an unmanned spacecraft in a comet. Process learning can be a daunting task, especially if human lives depend on the execution of those processes. For instance, aircraft landing has to be executed every time with superior accuracy or a terrible disaster can occur where human lives can be lost. Pilots have to remember every aspect of the landing process by heart and pay attention to every detail of the process.

Even though processes play an essential role in our everyday lives, learning them can be a difficult task. Some can be taught in one day but sometimes processes require years of practice to master them. People has been always in the need to automate processes, improve them and create tools to complete them but each improvement requires that people learn a new way to do things. So as processes play such an important part of our lives, we need better ways to teach them.

Medical students often use mannequins and other kind of physical simulators to train their skills [1]. These tools provide a way of learning medical procedures without the risks of intervening real patients. They can teach the medical procedures as well as the motor skills required to perform them correctly. The problem with these kinds of tools is that they can be expensive and the student needs to be in a specific physical location to practice the procedures. Also, their availability may be reduced depending on their usage demand.

We propose a generic gameplay for serious games in order to reinforce knowledge about medical procedures. Even though we focus on medical procedures, the proposed gameplay can be used to teach or reinforce all kinds of processes. We validate the gameplay proposal with a prototype of the game using a medical procedure that, in some countries, every newly graduated doctor should be able to perform: chest tube insertion.

The purpose of our work is to explore new ways of teaching medical procedures by using serious games as a way of teaching. We don't plan to teach the motor skills involved in the medical procedures, we focus on the teaching of the process itself. As medical procedures can often be complex, we focus on the steps necessary to successfully complete a given medical procedure.

II. PREVIOUS WORK

Several works have been done in the area of serious games for medicine. Varied areas of medicine have been explored throughout different kinds of games created. There is an important difference between a simulator and a serious game that should be stated. Simulators try to emulate reality as good as they can, but they don't provide any kind of reward system towards the user. On the other hand, serious games provide various ways of rewarding the player, constantly communicating them whether the actions they perform are correct or not. Moreover, these games don't necessarily try to emulate the actions people can perform in real life. Gameplay can be very varied and the actions that can be done in the game can be very different from the ones in reality and yet the game teaches about a specific topic.

As an example, a game developed in the University Of Ontario Institute Of Technology tried to teach the steps involved in total knee arthroplasty (TKA) [2]. Their work focuses on the teaching of the steps and tools required to successfully complete the procedure, which is the same goal of the work presented here. In this work, they user sees the world in a first person perspective using an in game cursor represented by the surgeon hand. The user can interact with objects in the scene by pointing at them with the cursor. The user can move around and rotate the view using classic first person shooter mechanics, so the player has plenty of movement freedom. When the user interacts with a specific object, a window showing different actions to choose from is displayed. If the user selects the correct object and action, a multiple choice question, selected randomly from a pool of

questions is displayed to the user. If the user chooses the wrong action or answer, an angry assistant animation is played along with a voice. Then, explanatory text and images are show to the player so he can understand the right way to do it. The steps taken by the player are compared to the "ideal" way of doing things.

The freedom in movement that grants this game can be both good and bad. People who are used to play videogames may find easy and fun to navigate the scene with FPS (first person shooter) mechanics and the idea of experiencing the surgery in such view may be interesting, but people who have never played videogames can be confused with the mechanic and the learning experience can be compromised. Also, there is no extra gameplay portrayed, so if we would like to measure or teach specific knowledge about some of the tasks in the procedure there is no way of doing it.

In Z-DOC players do a z-plasty on a patient in order to make their scars less visible [3]. The game is designed to be played using a touch based interface such as a tablet computer. The gameplay is very specific to the procedure; the player has to make accurate cuts on the patient's skin, taking into account the angles and linearity of the cuts. A set of tools is given to the player so knowledge on the steps involved in the procedure can be measured and compared to the "ideal" way of doing things. Player's scores are compared against each other, fostering competition among players.

Although it provides a good experience about the z-plasty procedure, the gameplay portrayed in the game is too specific, so trying to provide training experiences for different medical procedures using the same approach that was developed for Z-DOC is not possible. The gameplay would have to be totally re invented.

On the commercial side we found an app for iOS and Android called Touch Surgery [4]. It is a complete product where people can register, add interests and most importantly, play their animation based game. The app presents a several medical procedures, with a wide variety in terms of complexity and areas of specialization. There are two modes available to the player: "learn" and "test". In the first mode, the player is guided throughout the medical procedure, showing step by step the actions that the physician has to make in order to complete the procedure. Each step is explained with text and the player can go forward or backwards whenever they want. Some steps require that the player move a circle shown on the screen to a red dotted circle shown in another part of the screen. If the player drags the circle to the correct spot, an animation is played showing how the step should be performed. An animation is played throughout every step transition in the game. In the test mode, each step shows the player 4 possible actions to take and some text giving context on the step. If the player answers correctly, points are given, if not the player can try all the possibilities until the right one is chosen, but no point will be awarded. Sometimes, a blue circle will appear on the screen so that the player drags it to the right point on the screen, emulating a motion inside the scene. If the player makes the right motions, points are given, but if the player cannot find the right point on

the screen, he can press a button that will show the right position without giving points.

Touch Surgery provides a simple generic way to teach medical procedures, providing great visual quality in the animations, but their proposed gameplay is somewhat shallow, as the player is limited to answering multiple choice questions and moving circles on the screen.

We see various attempts at teaching medical procedures using serious games, and each one of them accomplishes the objective of teaching something useful to future physicians but none of them describes a generic yet deep way of teaching these procedures. Some lack genericity and some lack more elaborate mechanics. The work we present tries to provide both: a generic gameplay that can be reproduced for every medical procedure and deep mechanics that can test the knowledge at the detail of each task.

III. GAMEPLAY DESCRIPTION

The primary objective of the serious game presented here is to aid in the process of remembering and learning medical procedures in a fun and compelling way. Taking that into account we designed and implemented a generic gameplay that can be used to teach any kind of medical procedure, without leaving details of the procedure away from the learning experience.

The gameplay is based on the premise that every process can be broken down into tasks. Tasks relate themselves in different ways indicating the order in which a process can be completed. The learning process id based on trial and error, where the player tries to complete the procedure even if he has no previous knowledge. The idea behind is that the player should not be scared of trying things in a virtual environment, so that he can see the consequences of doing things one way or another. Unity 3D was used as the game engine, Blender was used to create animations and modify 3D models and GIMP was used to create illustrations.

To fully understand the gameplay proposal we need to expose some definitions used extensively throughout the game design.

Task: As stated before, the gameplay is based on task decomposition of processes. The definition of task we used can be associated with the task definition seen on the process definition language BPMN [5]. A task represents a specific action within a process. Task definitions can't be too broad or too granular. They have a title, a description, an illustration and associated animations.

Interactive tasks: This definition takes into account the definition of task stated above. Interactive tasks are special kind of tasks that define specific game mechanics aimed to provide an interactive experience at a specific task and to measure player knowledge of the details keen to the task.

Required sequence: It is a set of tasks that represent an order in which some tasks need to be executed. A given required sequence must not contain a task from another required sequence. All the level tasks must be contained in some required sequence. If the player doesn't execute tasks in the specified order, the player loses the level. This concept is

used to model things that need to be executed in a specific order.

Non serious fault: Takes two required sequences. When the tasks are executed such that the given two sequences go one after the other (one first then the other) a penalty on the score is applied. This is used to model cases when doing something in a specific order can be tolerated but it's not the ideal situation.

Fixed sequences: Some tasks need to be accomplished at a specific index within the process. For example some things are needed to be done at the very beginning and others at last, or maybe at the exact middle of the process. To model this behavior we introduce fixed tasks. They are represented by an array of required sequences. The length of the array is the total number of required sequences in the level. If the array is empty, it means that there are no fixed sequences, but if a required sequence is at a certain positions in the array, it means that it has to be executed in that order. If this rule is not accomplished, the player loses the level.

Requisite sequences: Sometimes a task needs a previous task to be done in order to be successfully accomplished, but the previous task can be done in different orders without altering the successful development of the task. For this kind of situations we use requisite sequences. A soliciting required sequence needs another required sequence in order to be completed successfully.

All the definitions described above make up the rules of the game. These definitions provide tools for game designers to create levels according to the medical procedure that is being taught. We use these definitions to model the levels of our game. To design a level using our approach, the designer must be able to break down the medical procedure according to the most important parts of it. A good level designer using our approach would break down the whole procedure into tasks, identify the most trivial parts and encapsulate them into the easiest levels of the game. Progressively, other parts of the game should be encapsulated into medium and hard levels, so the player experiences a gradual increase in difficulty and knowledge level.

Gameplay is divided into two principal mechanics: task ordering and task playback. The first mechanic wants to measure player's knowledge regarding the order in which the tasks are executed. The latter shows the player the consequences of the task ordering, plus interactive tasks offer additional gameplay that challenges player's knowledge about specific tasks. Before these two mechanics become available to the player, a briefing section gives context to the player about the situation that play through. This section tells the player the patient background, symptoms, medical case and what has been done to the patient at the hospital.

Fig. 1 Screenshot of the briefing section

Task ordering displays a set of tasks to the player. Each task is displayed as a squared card with a representative drawing that tries to explain what the task is about. If the drawing is not self-explanatory, the player can click the card in order to read an explanation of the task. The objective is to organize the tasks according to the situation and medical procedure that is being developed. The player has to drag and drop the tasks to empty boxes aligned on the screen so that the first task is at the leftmost box of the screen. The set of tasks that are displayed to the player can the full set of tasks contained in the level or a subset of tasks randomly chosen. If a level shows only a subset of the tasks, an algorithm fills the complete set of tasks contained in the level, keeping consistency with the order chosen by the player. A time bar represents the time left that is available to the player. If the time runs out or the player hits the "finished" button, task playback is immediately started.
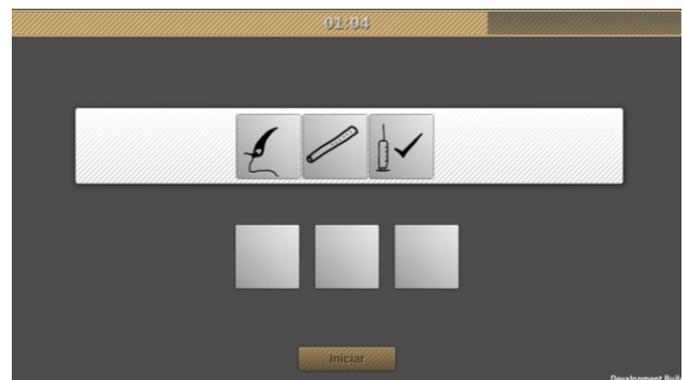

Fig. 2 Screenshot of task ordering

Task playback shows the consequences of the task ordering done by the player. For each task an animation is played, showing the actions that represent the task. If a task is interactive, the player will be informed and the player will have to perform the desired task in a certain amount of time. The game features a task bar that shows the tasks that have been already played, the task that is being played and the incoming tasks. Each time a correctly ordered task is played, player's score go up and a green overlay is shown on the screen. When an incorrectly ordered task or when the player doesn't perform as expected at an interactive task, a red overlay is shown. Also, when a mistake is made, a nurse avatar appears on the screen with a speech bubble that

explains what the player has done wrong. The maximum score that a player can achieve is 5 and the minimum is 0. The score indicator is located at the top right corner of the screen, having a "smiley" face shown depending on the actual score of the player.

Fig. 3 Screenshot of task playback

IV. LEVELS

Three levels were developed for the game. The first level encompassed one of the initial parts of the procedure which involved anesthetizing the zone of the patient where the chest tube must go in. The second level is about the larger and most important part of the procedure but showing only 3 of the 8 tasks involved in the level and the final level was the same as the second one but showing all of the 8 tasks that composed the level. The game design was based on a video made by the New England Journal of Medicine [6] where the whole procedure is depicted and explained very clearly. We also had a lot of help by a local thorax surgery expert and a student.

The first level of the game is called "preliminary". The objective of the level is to give the player an introduction to game mechanics, so we chose only 3 tasks for the level so that it would be easy for the player to complete the level. Also, the tasks chosen were fairly standard to most procedures so difficulty would be minimal as these tasks could be fairly familiar even to non-experienced students. The tasks given to the player were:

- T1: Security pause
- T2: Prepare syringes
- T3: Anesthetize zone

Only one of the tasks was an interactive task, as the player had to interact with the game so that the anesthetic was delivered in a special way. The rules for the level using the definitions stated before were these:

Required sequences:

S1: [T2]
S2: [T1]
S3: [T3]

Fixed sequences:

| | | | S3 |

The second level showed only 3 out of 8 possible tasks to the player. The level tasks had the most important part of the procedure, starting from the anesthetic verification to the suturing of the tube to the patient. Out of the 8 tasks, 3 tasks were interactive. These tasks were chosen based on the most important needs of the students. We had conversations with some students who told us their major pain points when they go out to reality and confront real patients. The tasks for this level are:

- T1: Anesthetic verification
- T2: Make incision
- T3: Dissect with clamps
- T4: Dissect with finger
- T5: Prepare tube
- T6: Prepare drainage system
- T7: Insert tube
- T8: Suture tube

The following are the level rules:

Required sequences:

S1: [T1, T2]
S2: [T3]
S3: [T4]
S4: [T5]
S5: [T6]
S6: [T7, T8]

Fixed sequences:

| | | | | | | S6 |

Requisite sequences:

Requisite sequence 1:
  Needed sequence: S1
  Soliciting sequence: S2
Requisite sequence 2:
  Needed sequence: S1
  Soliciting sequence: S3

For the last level the same tasks and rules that appear on the second level are used, the only difference is that the level shows all the 8 tasks to the player all at once.

V. USER STUDY

To validate the proposed gameplay, a user study with surgery students was conducted. Two tests with a similar testing methodology were done. The objective of the tests was to see if the students actually had learned something by playing the game and to see if the game was fun or not.

First an explanation of the purpose of the test was given to the students. Then a visual and verbal explanation of game

mechanics was done. If any student didn't understand something, the explanation was repeated. Then a small questionnaire regarding demographic questions was filled by the students. After that, students had to complete a pre-test with questions about the procedure. After the test, students had to play each level 3 times. After playing, a post-test had to be answered by the students. Finally the students had to answer some qualitative questions about the game.

For the first user study, 12 students attended. At this time, only 2 levels were available for the students. The first level was the same as the preliminary level but the second was the first version of the test level. The latter had 5 tasks and showed all of them to the user. One of the questions asked to students before playing was: About how many times has put a chest tube? For this question just 3 students responded that they had put a chest tube 1-2 times, the rest responded that they had never put a chest tube. The average age of students was 21.1 years.

The questions in the test were open questions and were validated by an expert who provided the answers to each question. The assessment of student responses in each test was done in a qualitative way by comparing the responses of the expert with student responses. For the pre-test, average student scores on a 100-point scale was 17.17. There was a question that was not well understood by students, so the average score was 17.22, removing that question. For the postgame test, average score was 41.25. In this test there were 5 questions that the answer was not well depicted by the game, so average score removing those 5 questions was 65.83.

For the second test we had a sample of 11 students. In this case the levels had the characteristics described in the "Levels" section of this document. For the second test, students had a similar experience to students in the first group because 4 of them responded that they had put a chest tube 1-2 times and the rest responded that they had never done it.

Question format changed and the tests used a multiple-choice format. Average score of the pre-test on a scale of 1 to 100 was 59.59. This shows a significant change from the first test. The reason for this change is based on the multiple-choice format, which in one way or another guide the students to the correct answers. The average result for the post-test was 58.33.

VI. CONCLUSIONS AND FUTURE WORK

Tests show mixed results. One user study shows transfer of knowledge to students by just playing the game. Post-test assessment shows a significant improvement compared to the test done before playing. The second user study shows no improvement over the pre-game test; however it is known that the evaluation format changed from one test to another. In the second user study, multiple choice questions are used, which can serve as a guide for students who don't know anything about the procedure, leading them to the correct answer by discarding incorrect choices. This is reflected in the set of chosen answers. For some questions of the pre-test, students did not select some of the given choices, indicating that the option did not provide a significant distraction and was easily dismissed.

For easy creation and editing of levels, a level editor that allows the easy creation of tasks and their relationships is suggested. The editor can be thought of as a Unity plugin where the interface provided by the editor allows the specification and edition of tasks within medical procedures. Using Scrum [7] as a methodology to state the functionality of the editor, the following user stories arise:

- As a game designer I want to create a task so I can create the building blocks of a medical procedure.
- As a game designer I want to create a required sequence so I can add rules to the medical procedure that I'm trying to teach with a game.
- As a game designer I want to establish fixed sequences of a level so I can specify strict rules about task execution order.

Of course these are only some of the user stories that such editor would need. The biggest challenge for such software would be the task editor as the game designer would need to map in-game animations and objects with the task. Nevertheless, with a tool that would allow the rapid creation of complete levels rapid iteration over future serious games would be possible.

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