

Review Article

A Comprehensive Review of Serious Games in Health Professions

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Education of healthcare professionals is of primary importance for patient safety. In some health related professions, education and training have to be practiced during the entire working period and not only limited to school years. The use of new technology such as virtual reality and e-learning brings new possibilities with significant improvement in learning outcomes. Serious gaming describes a technology that can educate and train while entertaining users. This type of training can be very useful for health professions because it improves learning outcomes creating a learner oriented approach and providing a stealth mode of teaching. In some fields it represents an ideal instrument for continuous health professions education also in terms of costs because it is cheaper than traditional training methods that use cadavers or mannequins. In this paper we make a scoping review of serious games developed for health professions and health related fields in order to understand if they are useful tools for health related fields training. Many papers confirmed that serious gaming is a useful technology that improves learning and skills development for health professionals.

1. Introduction

Training and education of healthcare workers are of primary importance for patient safety. In 1999 a study estimated that preventable medical errors accounted for 44000–98000 patient deaths annually in US hospitals [1]. This study proved the importance of a more accurate medical education and subsequently many actions were taken to reform the field of medical education.

In some health related professions, education and training have to be practiced during the entire working period and not only limited to school years. Continuous training is useful and sometimes necessary, especially in surgery, but it has a high associated cost and sometimes could not be ever achievable. This is because such kind of training requires human and animal cadavers, human actors, or dolls to exercise practitioner skills.

New technologies such as virtual reality and e-learning applications bring new possibilities not only in the field of medical training but also for other health professions and

could lead to valuable improvement in learning outcomes [2–4]. Friedman described the importance of using new media in medical education [5]. Besides traditional surgical simulators that use computer technology to offer the medical personnel a tool for skills training, there is another tool that uses also computer technology that healthcare workers can practice with: serious games. Using Stokes' definition, serious games could be defined as “games that are designed to entertain players as they educate, train, or change behaviour” [6].

These technologies can be also useful for patients, in order to teach them procedures regarding their health habits. For example, a serious game was used to teach healthy alimentary habits in patient with diabetes.

From our point of view several benefits are associated with a serious game: the provision of a “stealth mode” of learning because the education goal is mixed up with the entertainment factor; a learner oriented approach in which students can control their entire learning process; the cost, games being cheaper than other health professions learning tools.

When we started to develop a simulator for training surgeons in microsurgical sutures, we faced the problem of choosing among a “traditional” approach, with the development of a classical simulator, and an innovative approach like a “serious game” application. To solve this problem we needed to investigate the universe of serious game developed for healthcare. We found and classified many papers regarding serious game developed for healthcare, in order to describe the state of the art of serious gaming in healthcare and to understand if a similar application paradigm could be useful for our purposes and in general for professional training in health related ambit.

2. Serious Games

The expression “serious game” appeared long time before the diffusion of computer technology in everyday life. In 1970s Clark Abt used this expression in his book entitled exactly “serious games” where he also gave a first definition of what is a serious game: “reduced to its formal essence, a game is an activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context. A more conventional definition would say that a game is a context with rules among adversaries trying to win objectives. We are concerned with serious games in the sense that these games have an explicit and carefully thoughtout educational purpose and are not intended to be played primarily for amusement.”

In 2005 Stokes [6] defined serious games as “games that are designed to entertain players as they educate, train, or change behaviour.”

As we can see these two definitions are completely independent of the information technology terminology but define the fundamental concepts behind a serious game: the educational purpose mixed with the gaming nature.

In the 1990s the word *edutainment* was very popular in the growing multimedia PC market and described a concept that could be summarized as “education through entertainment” [7]. By comparing the definition of edutainment and the definition of serious game we can conclude that these two expressions refer to the same matter.

A more recent definition that uses explicitly terminology of computer technology in the definition of a serious game could be found in [8]: “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.”

It is clear that the learning function is mixed with the gaming nature of application. Playing a serious game must excite and involve user while ensuring the acquisition of knowledge. Regarding this concept Michael and Susi stated the definition of a “stealth mode” of learning in serious games [7, 9].

Unlike traditional teaching environments where the teacher controls the learning (teacher centered), the serious games present a learner centered approach to education in which the trainee controls the learning process interactively [10]. Such engagement may allow the trainee-player to learn

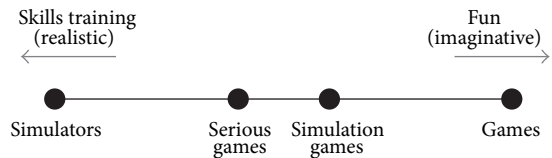


FIGURE 1: The computer game spectrum.

via an active, critical learning approach. Game-based learning provides a methodology to integrate game design concepts with instructional design techniques to enhance the educational experience [11].

Games inherently support experiential learning by providing students with concrete experiences and active experimentation [12].

In Figure 1 we propose the game spectrum classification reported by Qin et al. [13]. At one end of this imaginary line there are classical simulators, developed for skills training and providing maximum realism. This type of simulators tries to replicate the real world. On the other end of the line there are games developed for fun and entertainment that are completely imaginary. In the middle of the line are serious games and simulation games. Serious games are developed for nonentertainment purposes and designed for skills development. They offer a good dose of realism together with the entertainment factor of a traditional game, while simulation games are typically placed in imaginative or fictitious environments.

If we compare serious games with traditional simulators we can focus the differences between them on four fundamentals factors:

- (i) entertainment factor;
- (ii) development costs;
- (iii) development time;
- (iv) deployment costs.

The entertainment factor of a serious game denotes the main boundary between these two technologies. In traditional simulators there is no entertainment because the application is only developed for user training. In a serious game the user is entertained by the need to improve his performance, measured by the scoring mechanism and by the challenge to reach a precise goal.

The development costs of serious games are reduced if compared to development costs of classic simulators. This is because they do not use custom technology solutions but the same technology on which entertainment games are based and development time are generally shorter.

The deployment cost of a serious game is also reduced because the supporting technology (hardware and software) is widely diffused. Today this technology is also available in many smartphones so serious games can also be played on this type of device.

3. Review Methodology

In this paper we make a scoping review of serious games developed for healthcare and health professions. The first aim of our research is to describe the state of the art of serious games developed for health related applications. We want also to understand if a serious game approach can be useful for health related training and what kind of benefits it can provide if compared with other types of learning tools. We tried to answer the following questions.

- (1) Could serious gaming be a useful approach in health profession training?
- (2) What are the benefits of serious gaming versus another type of training approach in health related ambit?
- (3) What are (if there are) the current open issues of serious games designed for health related fields?

To write this review we searched for serious games developed for healthcare and health professions topics over the web. Our research was limited not only to scientific papers but also to any type of web contents describing serious game solutions developed for healthcare ambit. We have included in our research also items that do not result in a scientific publication in order to have a complete panorama of developed serious games for healthcare.

We searched for scientific papers on IEEE Xplore, PubMed, and Google Scholar search engines. We used the base search expression “serious games” followed by one of the following words: healthcare, medical, medicine, medical training, and surgery. We excluded papers focused on traditional simulators although developed for healthcare; our results include only papers describing explicitly the use of serious game paradigm.

In these papers we searched for results of studies that evaluate the usefulness of this approach in healthcare and health professions training. Unfortunately only a few papers report such results. Many papers presented only the serious game development and its application area without describing the innovation components of the work nor giving data from evaluation studies. Two previous papers [14, 15] were used as the starting point of our review.

For web contents research we used Google search engine with the same keywords and inclusion/exclusion criteria presented for scientific papers.

To present and discuss the collected information we decided to classify serious games by health application area (surgery, nursing, etc.). For each paper we describe the application that was developed, its main characteristic, and eventually results of related evaluation studies.

4. Serious Game Review

In the following subsections we present the review of serious games developed for healthcare and health professions. We grouped them by application area.

4.1. Surgery. Sabri et al. [16] created in 2010 a serious game for knee replacement surgery procedure. Total knee

replacement or total knee arthroplasty (TKA) is a surgical procedure whereby the painful arthritic knee joint surfaces are replaced with metal and polyethylene components. They substitute bone and cartilage providing patients with painful, deformed, and unstable knees pain relief and improvement in function [17]. The serious game described permits training of orthopaedic surgical procedures to orthopaedic surgical residents outside the operating room with a multiplayer modality. The game was designed to evaluate if a serious gaming approach will enhance complex surgical skill acquisition. The user is required to successfully complete the TKA procedure focusing the attention on the sequence of step to perform while minimizing time and maximizing the score. They begin the game in the operating room and with a first-person viewpoint. Other avatars such nurses, assistant, and patient appear in the scene. The user should know the correct order of the steps of TKA procedure as well as the tool used to begin each step. Each step begins with the selection of a specific tool. If the user selects the correct tool and so performs the correct step, he will be asked a multiple-choice question to test his knowledge of that step. Otherwise, if the user performs an out of order step, he is corrected by an animated angry assistant. In this case a short video segment was presented illustrating a surgeon performing that particular step on a “real” patient and narrating the operating details of the step. At the end of procedure the score is presented to the player. The game uses a 3D rendering engine based on OpenGL and is developed to give more realism as possible. To achieve maximum realism models were being developed using the Maya 3D modeling software with visual effects software, 3DS Max modeling software with rendering software, and the ZBrush tool. The paper does not present any test results made on serious game users.

Blood management is particularly important in surgical procedures, especially in orthopaedic procedures, because in this context bleeding is common and can be fatal. Qin et al. [13] realized a serious game to train blood management in orthopaedic surgery context to orthopaedic surgeons. The game uses a haptic interface and is structured in three parts. The first two parts are “Stopping the Fountains” games. The first consists of a fountain placed on a plane and the second of a fountain placed on a curved surface. The user should stop the fountain water loss using a virtual tool. These two tasks permit the users to adapt to 3D environment and develop the required hand-eye coordination using the haptic interface. Third part of the game is the orthopaedic-surgery game. In this part three modalities were provided: training mode, time-attack mode, and collaborative mode. The training mode is designed to teach trainee the correct steps to execute the procedure. Player has to complete the assigned operation. Hints on the correct steps are given and no time limit is imposed. Conversely in time-attack mode the player must finish the task correctly within a time limit or the virtual patient will die. In collaborative mode several players work together connected in a network to complete a task. Patient resuscitation is function of the entity of blood loss and is based on four bleeding severity classes defined by the American College of Surgeon. The game uses a mass-spring model for soft tissue deformation modeling and a blood

flow distribution model based on human physiology mixed with smoothed-particle hydrodynamics (SPH) to allow for real-time interactive bleeding management. Haptic rendering is used to simulate the contact between surgical tools and soft tissue. Haptic Library API of the OpenHaptics toolkit was chosen as rendering engine to provide a realistic touch response. To evaluate how the game enhances blood management skills authors asked a group of trainees to perform vessel-sealing training sessions. Final score was determined evaluating two parameters: completion-time and off-target contact errors. An off-target contact error is generated when the user touches with the vessel sealer soft tissues placed outside bleeding location. Game evaluation was realized in two experimental sessions simulating a Class I hemorrhage and a Class IV hemorrhage. In this second experiment 21 undergraduate students were divided into two groups. First group was composed of 11 students (group 1). Second group was composed of 10 students (group 2). Group 1 completed the entire game-based training process using "Stopping the Fountains" parts of the game whilst group 2 performs task 3 directly. Experiments results analysis shows that both groups reduced mean execution time as they proceed in game sessions. Group 1 has a mean execution time lower than group 2. If we focus our attention on game score we can see a positive trend with performance improvement over the sessions. Group 1 has a mean score value higher than group 2. After experiments practice, participants were asked to complete questionnaires on the used application. Players feedback showed that the game-based interface increased their interests in learning the overall blood management process. Authors concluded that virtual patients are more realistic than manikins and are useful for medical professional training.

In 2011 the research group of Cowan et al. developed another serious game for off-pump coronary artery bypass grafting cardiac surgical procedure (OPCAB) training [18]. Off-pump coronary artery bypass (OPCAB) was introduced in 1960 to avoid potential complications of cardiopulmonary bypass circuit (CPB) technique during the coronary artery bypass graft (CABG) surgery. Using the CPB technique the patient's heart is connected to a heart and lung machine during the surgery and this allows the heart to be arrested while the rest of body is perfused. The use of CPB may contribute to a number of postoperative problems. OPCAB technique permits us to position the heart and stabilize the segments of interest allowing the bypass grafting without CPB. In this way the bypass grafting is performed as the heart beats spontaneously. Like the total knee arthroplasty game the users will begin the serious game viewing the scene in a first-person perspective. He is placed in the operating room taking on the role of the cardiac surgeon. Gaming modality is the same as total knee arthroplasty game cited before and uses also the same development technology. In the paper the authors detailed technical aspects of these applications in terms of developed shader and game sounds recording. The same group presented also a surgical cognitive education and training framework (SCETF) [19] for serious game development. The aim of this project is to offer a modular tool on which domain-specific surgical modules can

be developed. SCETF is being developed as a research tool. For this reason various simulation parameters such as levels of audio and visual fidelity can be adjusted.

In the field of interventional radiology Chan et al. [20] introduced a serious game developed for radiologist training in the ultrasound-guided needle placement procedure. In this serious game training scenarios are interactively generated via a block-based construction scheme. A novel example-based texture synthesis technique was used in order to simulate corresponding ultrasound images. Interactive recommendation of desirable insertion paths during the training and integrated game elements such as time-attack tasks, hints, and performance evaluation tools were also provided. The game was evaluated over 21 participants with 18 of them having experience in neither needle placement operations nor related simulators. The remaining 3 participants have from 3 to 4 years of simulators experience and their results were used as benchmark in the analysis. In the first experiment participants were asked to locate the needle with ultrasound transducer in the in-plane manner. Each participant carried out 20 sessions in time-attack mode. Time allowed for each training session was 8 seconds. At the end of each session the distance from the needle tip to the ultrasound imaging plane (TPD) and the angle between the needle and the ultrasound imaging plane (NPA) were evaluated. In the second experiment it was evaluated if the game based training process can outperform the simulation-based training process. The 18 inexperienced participants were divided into two groups. The first group carried out game-based training. The second group has practiced free training. Game-based training group were asked to play four training stages (plus a fifth special stage) with ascending difficulties. Every training stage is composed of five sessions of 30 s duration time. Practice scenario of the free training group was a simulation-based environment without game elements. The free training group was trained with clinical data and was free to choose the number of sessions/repetitions.. There was no time limit in each session and the amount of free training time is of about 45 min. This time is similar to the time taken from game-based training group to complete stages 1-4. The distance between the needle tip and the target (TTD), the success rate, and the completion time were evaluated. Evaluation of TTD showed an increase of performance in terms of precision and success rate and also a decrease of the task execution time in the five training stages. Authors concluded that these experiments demonstrate the efficacy of the serious game training method on surgical skills teaching for surgical novices.

De Paolis [10] in 2012 presents a serious game for training surgeons on laparoscopic surgery suturing. In his work a pair of haptic devices is used in order to simulate the manipulation of the surgical instruments. He focuses the attention on an accurate physical modeling of the virtual environment. Soft tissues are modeled using a mass-spring model. The tissue is represented as a three-dimensional grid of point masses connected by spring. Tissue deformation depends on dynamics of the masses, elasticity, and damping factor of the springs which connect them. Additional springs have been used in order to fix the grid of springs and point masses in

the virtual space. These springs allow the tissue to resume its original shape when deformation forces are left. High performance computation of tissue model is obtained using NVIDIA PhysX library running on Graphics Processing Unit. In this way the CPU is free to execute other tasks. Surgical thread dynamics is modeled with “follow-the-leader” model. The thread is modeled by means of a chain of cylinders connected by spherical joints. These joints permit bending of the thread allowing rotation of adjacent segments. Also for the thread the PhysX features are exploited in order to manage the dynamics. Position and collision detection are computed using this library. OGRE 3D engine is used for graphics tissue rendering and HAPI library for the haptic rendering. A set of numerical indicators are also defined for the assessment of a suturing procedure: duration time, accuracy, force peak, tissue damage, angle of entry, and needle total distance. The software architecture of the serious game has been developed using the model-view-controller (MVC) architectural pattern.

The latest work we found in surgery field regards the development of a serious game for teaching Z-plasty surgical procedure to plastic surgery residents [21]. The game employs a touch-based interaction on the screen of a tablet computer. To promote engagement and motivation competition amongst multiple players/users is provided.

4.2. Odontology. In odontology field we found only two serious games. The first one is developed for dental students training and provides a game-based simulation in the area of diagnostics, decision-making, and treatment protocols for enhanced patient therapy outcomes and risk management [22]. The users interact with patient in a virtual 3D dentist office. The game is powered by BreakAway’s “Pulse!!” proprietary technology.

The second game is developed to evaluate the dissemination of public awareness through this type of approach on preschool children’s oral health [23]. An evaluation study was performed by dentists, teachers, and parents and is divided into two parts. The first part of the study was designed to evaluate the applicability of this technology as well as the opinions on the effectiveness of games in education and oral health promotion. In the second part of the study, the game is presented to the same subjects and an evaluation questionnaire was administered. Eighty percent of testers evaluate the serious game approach to be useful in the prevention of dental awareness.

4.3. Nursing. Virtual Pain Manager is an online serious game that simulates the use of a patient controlled analgesia machine with a postoperative patient [24]. Students are first taught pain management theory in the classroom and then they can access the simulation platform. The student nurse must control and reduce the patient’s pain within 48 game hours. After this period, if it is all ok, the PCA may be withdrawn and substituted with oral analgesia. The patient pain is controlled over 72 game hours. If after this time the patient’s pain remains high, or is not under control, the student nurse is judged to have failed. Negligent care can lead to complications and possibly death. The game should be used

by nursing students to fill the gap between theory and practice in the patient pain management.

VA Critical Thinking [25] is a serious game that allows nurses to practice assessment, prevention, and treatment of patient health conditions related to patient skin integrity and pressure ulcers. The player should interview the patients and have a visual inspection of the patient’s skin to mark the areas at risk for pressure ulcers and carry out actions to avoid this phenomenon. After the gaming phase there is a review phase where the player can view detailed information about which answers were correct, incorrect, or missed.

Florence is a multipurpose serious game developed for nurses training in areas that are hard to experiment in real life [26]. The game is focused on three risky domains: blood transfusion, fire safety, and infectious hazard. It has also been tested and validated by a commission of experts gathering two doctors coordinators of haemovigilance, two healthcare facility managers, six nurse practitioners, and one midwife.

4.4. Cardiology. In the cardiology field Virtual ECG offers an online serious game for electrocardiographs accurate recording [27]. The players have to place electrodes on a virtual patient, connect the ECG machine leads, and record an ECG. The simulation uses real patient ECG scan data to generate an ECG corresponding to the user’s configuration of electrodes and leads. The practitioners ECG is then presented with an overlay on an ECG expert’s recording to have a direct and visual comparison with a correct recording. The user can adjust electrodes positioning until he is satisfied of the recorded track. The game should be used by cardiology physician to improve the ability in accurate 12-lead ECG recording and has an online feedback to help them when making mistakes.

Delbressine et al. [28] presented a serious game for the rehabilitation of arm-hand performance for stroke survivors. Upper extremity of stroke survivors is often affected by hemiparesis and spasticity. To help these patients, rehabilitation methods like task-oriented training methods have been shown to be effective. These training methods require that patients train on realistic tasks in real life rather than in a dedicated environment. A common problem regarding rehabilitation training for arm-hand performance is that hemiparetic patients use compensation strategies to achieve task completion. Usually they made trunk movement to reach with the hand a target object. The authors developed a serious game based on technology-supported task-oriented armhand training (T-TOAT) method. T-TOAT method has been designed to enable implementation of task-oriented training in rehabilitation technologies. It has been used in many rehabilitation systems. The authors would improve the state of the art of this rehabilitation method providing sufficient level of challenge, fun, performance feedback, and exercise variability using the serious gaming technology. The system consists of a tactile tabletop combined with a wearable jacket that supports tilt-sensing and vibrotactile feedback. The use of this type of jacket guides the patient in the correct execution of exercises. If users trunk or shoulder movement exceeds the specified range, vibrotactile feedback is provided

on the corresponding body part. In a first prototype of rehabilitation system the patient should catch a virtual bug displayed on a horizontal tabletop surface using a physical fork to arrange digital salad and trap the bug. If the users compensatory movement exceeds the accepted compensation range, the bug gets smaller and harder to catch. The test in a Netherlands clinic was conducted over seven subacute and three chronic stroke patients. The test session showed that playful rehabilitation concept was regarded as a credible training approach from patient. They would like to have an audio and spoken feedback from the game as well. In the second prototype of the serious game rehabilitation system there was an improvement of the sensor vest, an upgrade in the interactive tabletop technology, and an extension of the number of games. The new vest was designed to fit better over the patient body to avoid measure errors and the impairment of patient freedom of movement. Tablet technology was also substituted. The touch screen of the first iteration was replaced by a display monitor combined with a Kinect sensor. Many games were added to the platform: a game where patients need to reach a target, a labyrinth game for writing training, a knife and fork game to relearn how to cut with a knife, a game where the patient has to fill a virtual glass without spilling water while holding a real glass and wearing the sensor glove, and finally a multiplayer game. These platform improvements will be followed by a clinical evaluation.

4.5. First Aid. First aid, triage, and mass emergency are, without doubt, the fields where we found many serious games. Code Orange [29, 30] is a serious game where the players work in concert with the first-aid staff of a hospital to save people injured by a weapon-of-mass-destruction event. The game scenario is a virtual hospital and the user should implement the hospital's streamlined process for handling mass casualty situations. The game is based on the Hospital Emergency Incident Command System (HEICS) protocol. Nuclear Event Triage Challenge [31], Radiation Hazards Assessment Challenge [31], and Peninsula City [32] are serious games developed also for emergency personnel training.

Virtual Heroes presented 3DiTeams [33, 34], a serious game developed with Duke University Medical Center and used for medical training. 3DiTeams is a first person, multiplayer training application where the user is placed in a high-fidelity virtual hospital. The training is based on the DoD Patient Safety Program and Agency for Healthcare Research and Quality's Team STEPPS curriculum. The game privileges team-working and consists of two phases. In a first phase the user is introduced to teamwork and communication skills. In the second phase he applies these skills on a virtual scenario where up to 32 players can play together. Each player acts in his predetermined role. Doctor, nurse, technician, or observer start the game with an instructor briefing focused on the upcoming patient. The instructor can manually control the patients vital signs in response to the player actions or can leave the patient control to the embedded physiology engine. Players can have a video playback of the scenario to observe and reflect on their own behaviors as well as those of the team.

In 2008 the serious game Triage was used to compare the relative impact of two simulation-based methods for training emergency medicine residents [35]. The application of simple triage and rapid treatment (START) algorithm in a full-immersion virtual reality (VR) scenario was compared with standardized patient (SP) drill. Fifteen postgraduate year 1 to postgraduate year 4 emergency medicine residents were randomly assigned to two groups. In the VR group, learners were placed in a room where the virtual mass disaster scenario was projected on four walls, ceiling, and floor. They performed triage by interacting with virtual patients in an avatar form. In the SP group learners used SP victims to simulate triage. Setting and patient presentations were identical between the two modalities. The study assessed resident performance of triage during the drills and knowledge of the START triage algorithm pre/postdrill completion. From the collected data it was seen that there were no significant differences in the final score of the two groups. There is a slight better score performance for the SP group. The authors of the study concluded that virtual reality can be a feasible alternative for training emergency medicine personnel in mass disaster triage.

Burn Center [36] is a web based triage game built with Macromedia Flash CS3. The game is divided into two sections and permits the users to practice triage and resuscitation. In the triage section the player should correctly stabilize, sort, tag, and transport burn victims during a mass casualty event in a busy theme park. At the end of this section the player receives an overall grade assessment on his performance and can see his score. The application of proper procedures and correct burn estimations on patients increase the player score. Once completing the triage component, the player will take on the role of a burn care provider. Using familiar computer-simulated hospital devices it should satisfy the clinical needs of multiple burn patients through a 36-hour resuscitation period. One important factor in the two game sections is the time. As the time goes on the user should complete efficiently and correctly his tasks. A first nonsystematic evaluation of the game showed a positive correlation between Burn Center training and student performance in a traditional lectured course.

Zero Hour: America's Medic is a serious game designed to train emergency medical services operators to respond to mass casualty incidents such as earthquakes and terrorism attacks [37]. The game is designed as a first person videogame. The player starts his mission in ambulance receiving the call from emergency medical services dispatcher from which he receives the instructions to reach the accident place. Once reaching this place the player needs to choose which equipment to bring. Equipment should be chosen in accordance with the requirements of the situation. The game is developed using Unreal Engine 3.

Triage Trainer [38] was also used to compare the effectiveness of serious gaming in teaching major incident triage versus traditional training methods. The serious game was designed to allow learners to play through a major incident scenario. Learners should triage casualties as they discover them in the game scenario. The scene shows a bomb just exploded in a busy urban street with the expected infrastructural destruction along with a number of casualties located

around the scene. The player should tag each casualty with the appropriate priority. The comparison study was conducted during Major Incident Medical Management and Support Courses over 91 learners. The learners were randomly divided into two groups. A group was composed of 44 participants that practiced triage sieve protocol using a card-sort exercise. The other group was composed of 47 participants that used the serious game instead. After the training sessions, each participant undertook an evaluation exercise. In this evaluation session they were required to triage eight casualties in a simulated live exercise. The evaluation was conducted in a mock-up scenario of a domestic outdoor gas explosion. Eight local actors simulate a range of injuries. Participants enter in the simulation scenario one at a time. They were required to triage sieve the eight casualties and assign each of them a priority tag. The aim of this evaluation exercise was to assess the learners performance in terms of tagging accuracy (assigning the correct triage tag to the casualty, step sequence correctness, following correct procedure) and time taken to triage all casualties. Tagging accuracy evaluation exercise showed that the participants that used Triage Trainer performed significantly better than the card-sort group. Step accuracy test showed the same result. Triage Trainer group has 68% of the casualties triaged without a step error versus 57% of the card-sort group. Evaluation of time parameter showed no significant differences between the groups. Overall tests results proved that serious game approach enhances learning and improves subsequent performance when compared to traditional methods.

Clinispace [39] offers immersive 3D virtual environments in a web-based application. It offers residents and nurses training experiences for many typologies of emergency patients. The development of the game has been based on a previous study where the authors noted that users need more accessibility and ease of use of the game. They used a 7-point analysis to understand where the application can be improved and applied this improvement to Clinispace. Improvements regard robustness of system, medical contents of the game, usability, and learning outcomes. Authors retained the richness of previous virtual environment but modified the user interface to meet the user needs. The player can play alone or in teams and the game supports many clinical spaces as well as interactive objects and medical instruments. With the addition of servers and cloud computing this serious game can be scaled to large class sizes.

Pulse!! [40] is a serious game developed for healthcare professional. It helps student in practicing clinical skills to better respond to injuries sustained during catastrophic incidents. Highly interactive and detailed 3D world with accurate physiology models and fluid dynamics were used to simulate blood flow in the human body.

AED Challenge [41, 42] is a web-based serious game for teaching and training automated external defibrillation (AED) and first aid maneuvers to lay people and emergency medical services professionals. For emergency professionals there is a training website that stores the player scores and sends a report to the emergency medical service coordinator. Actually this game is used by over 500 organizations worldwide. Game validation was done over 105 firefighter

and emergency medical technicians with experience in AED in a one-year project. They were divided into three groups. Groups A and C received a brief introduction to the computer program. Group A (37 subjects) used the program for a continuous training over the first 6 months. After this period they were restricted from computer use. Group C (35 subjects) received alternated computer use and instructor-led reviews every 3 months. Group B (33 subjects) was the control group and received instructor-led reviews once every three months. Skill evaluations were held immediately after the instructor's reviews. This evaluation method allowed authors to examine the effects of a realistic practice regimen using both computer and instructor-led methods during the study period. The study results showed that there were no significant differences in learning outcomes if we compare the three groups. Conclusions are that computer aided learning can be useful for some learning tasks but for others there is the necessity of a closely supervised hands-on initial training.

Buttussi et al. faced the problem of advanced life support retraining courses with a serious game [43]. Advanced life support is affected by the problem that knowledge and skills decrease in as little as three months and only a few of advanced life support providers attend retraining courses. EMSAVE is a 3D serious game for scenario-based advanced life support retraining. The game was designed to promote self-correction while playing. To evaluate its efficacy an evaluation was done over 40 advanced life support providers in two cardiac arrest scenarios. A 38-multiple-choice question test was administered before and after playing and also three months later to evaluate knowledge retention. Test results after game playing showed an increment of 21% of correct answers if compared before playing test results. In the retention test there was a decrease of 7% in correct answer with respect to posttest but this represents still an increment of 12% compared to the test administered before playing. From a statistical analysis of this data the authors proved that EMSAVE improved significantly not only knowledge and skills acquisition after playing but also knowledge retention over 3 months. From the test emerged also the evidence that 85% of participants are willing to devote an hour per month to retrain skills with the serious game. The authors consider this thing very encouraging because serious gaming is a novel tool in advanced support retraining and most participants of the study were not acquainted with videogames and 3D application.

4.6. Dietitian and Diabetes. For diabetes patient education the French team of Dr. Aurore Guillaume commissioned the development of three serious games. *Affaire Birman* [44] is a serious game where the user develops skills in dietary terms, insulin injection, and physics activity. The game was designed for children and teenagers with type 1 diabetes and with multiple daily injections regimen. *Méli-Mélo Glucidique* [45] is a quiz form serious game that improves the dietetic knowledge of patient. It is focused on carbohydrate knowledge. *Timeout* [46] is a serious game developed for teenagers and adult with type 1 diabetes and pump treatment. These three games are 2D web-based games.

InsuOnline is a serious game developed to teach insulin therapy in adults with diabetes mellitus to primary care physicians. One of the causes of a poor glycemic control in adults with diabetes mellitus is physician's lack of knowledge. InsuOnline was designed to improve an appropriate initiation and adjustment of insulin therapy for the treatment of diabetes mellitus. A multidisciplinary group comprising clinical endocrinologists, expert in medical education, and software/game designers was created for game design and development. In the game the user plays as a substitute physician and takes care of diabetic patients. Main goal of the game is to have each player correctly initiate or adjust insulin therapy for each patient case. Right decision leads to the next level. Each successive game level has a new patient presented to the player and increasing complexity. To assess the validity of InsuOnline on the web an unblinded randomized controlled trial with primary care physicians was done. The trial comprised 128 primary care physicians divided into two groups, 64 played insuOnline and 64 underwent traditional instructional activities. Knowledge is assessed by a web-based multiple-choice questionnaire before, immediately after, and 6 months after the intervention using the Diabetes Attitude Scale. The study [47] showed that InsuOnline can be an attractive option for large-scale continuous medical education. This game improves primary care physicians knowledge on insulin therapy and also diabetes mellitus patient's care.

Healthy eating habits can be trained with yummy tricks [48]. This serious game contains several minigames. In each minigame the user learns a trick about correct eating. The game was developed in the contest of Global eHealth Challenge in 2010.

Squire's Quest! II is a serious game developed to increase fruit and vegetables consumption in the elementary aged children. In [49] the authors described the validation protocol of the game. The game is structured as a 10-episode videogame and is developed for 4th and 5th grade children. The game scenario is a medieval kingdom and the game story was expressly written for that age children. They play a 10-episode online videogame. Parents receive electronic newsletters and access to a parent website which is updated on the completion of every episode. To assess usual dietary intake, three unannounced 24-hour dietary recalls were conducted with the children. Data were collected using the Nutrient Data System for Research. Children were asked where each meal/snack was eaten, who else was present, whether a TV was on, and whether they watched TV during the meal. Parents provide, through a self-report, data regarding fruit and vegetables parent consumption, fruit and vegetables home availability, fruit and vegetables home accessibility, and fruit and vegetables family barriers to eating. Other data provided are fruit and vegetables parent self-efficacy to get their family to eat, fruit and vegetables child asking behaviours, and fruit and vegetables child executive function and demographic information at baseline. Data were also collected from researcher through staff logs, as children navigated the game and as parents accessed the parent sections.

4.7. Psychology. Treasure Hunt [50] is a serious game developed to support psychotherapeutic treatment of children. It is the first serious game based on principles of cognitive behaviour modification and developed for eight- to twelve-year-old children who are in cognitive-behavioural treatment for various disorders. The game includes therapeutic concepts and attractive electronic homework assignments can be offered to them. This enables children to rehearse and repeat basic psychoeducational concepts they have learned during therapy sessions. Therapeutic games can also help therapists to structure therapy sessions. An evaluation study has not been made yet but first impressions of therapists in the use of this platform were positive.

iSpectrum [51] is a web-based game developed in the context of iSpectrum project for social interaction abilities improvement for patient affected from autism or Asperger's syndrome. The game offers the player a game environment that is similar to a real work environment. In the game he can exercise his social skills and improve his social interaction abilities to use them in real life. The player is projected into a scenario that is like the first day at work or like a job interview situation. Gaming sessions can be divided into three phases. The first phase takes place in a placement office where the player meets his employment advisor who explains to him each available job and some general employment advice. Here he can choose from three available jobs: office administrator, supermarket worker, or commercial gardener. After this phase there is a job interview with the new boss. The player is put in different situations, typical for the chosen environment, and asked to complete associated tasks. These tasks were all developed in a strict collaboration with experts related to disorders like autism or Asperger's syndrome. When the player has completed a game session he can go back and try a different work environment. The use of this serious game can advantage the player's real life work experience. A secondary aim of the iSpectrum project is to make available to DSA professionals knowledge on the advantage of serious gaming approach in this context.

4.8. Others. eMedOffice [52] is a serious game that has the aim to teach medical students the organizational and conceptual basics of the medical practice of a general practitioner in a problem-based learning environment. In the first phase of the game the player assigns functionalities to the rooms. He selects and places interior furnishing and supplements furniture items with specific equipment. The player can decide to open his medical practice after this phase. He starts a simulation of agents that represent the patients, medical doctors, and their assistant. These actors use interior furnishings and interact with each other. If an agent detects a problem like a missing furniture item or equipment component while executing a workflow-task he informs the player. The scoring algorithm verifies rule formalized as restrictions like "all beds must be usable" and "in the briefing room there is a medicine cabinet." Some rules check the existence of furniture and equipment items in a specific room and others check useful composition and usability of placed furniture and equipment items. A usability questionnaire for serious game quality evaluation

was administered to the users with an evaluation sheet that contains 22 scale items from five (best) to one (worst). The questionnaire asks the users if the quality of the serious game meets the requirements of a practical real world learning application. Then a second evaluation was conducted as a self-report quantitative evaluation of skills and knowledge before and after the game playing using the same evaluation metric. The usability evaluation on 27 students revealed high overall usability of the proposed game with a score of 4.07 points on average. A self-evaluation was done on 41 people and showed an increment of players skills and knowledge after game playing.

Free Dive is a serious game developed to entertain and distract children who often undergo painful medical procedures [53]. It has not an educational purpose but we considered it because it was developed as a care tool for hospital children. The game is structured as 3D undersea exploration adventure. It invites the players to swim with sea turtles and tropical fish as they hunt for hidden treasures.

Sourina et al. [54] developed an EEG-based serious game that can be used for pain management. The game uses wireless EEG sensors and a novel spatiotemporal fractal based algorithm for brain state quantification that is used with blobby visualization tools. It could be used by patient at home for pain management as an alternative to traditional drug treatment.

Time After Time is an interactive decision aid for men diagnosed with localized prostate cancer [55]. The purpose of this serious game is to translate evidence-based treatment outcome data into an accessible and understandable format that men can utilize in their prostate cancer treatment decision-making process. This aid is important because prostate cancer treatments often come with serious side effects, which can significantly affect patient quality of life in the short and long term. Health-related quality of life (HRQOL) can demonstrate measurable differences between treatment options in the short and long term. To address the challenges of localized prostate cancer treatment decisions authors developed a variety of decision aids. Usefulness of these aids is reported by the authors: "these decision aids have successfully demonstrated the ability to increase knowledge, enhance active involvement in decision making by patients, and decrease patients' decisional anxiety." Time After Time attempts to elicit user preferences regarding the impact of treatment side effects on a user's preferred quality of life and presents to the user some possible scenarios based on statistical probabilities derived from a large, prospective, multiregional study. To play Time After Time users have to securely log in the game platform. Before starting the game they are guided in an orientation round. Time After Time allows the user to explore potential side effects of 4 treatment options. These are radical prostatectomy, brachytherapy, external radiotherapy, and watchful waiting. For each treatment and each time period side effects cards are shown to the user. He must rate it on a 5-point scale. The lowest value equals "no problem," while the highest value equals "big problem" in side-effect rating. At the end of side-effects card evaluation done at the time periods of 2-month posttreatment and 12-month posttreatment he sees a categorized summary

of how he rated cards by time period and side effect domain. When the user completed the rating of all treatments side effects in all of treatment and time periods he has completed the first game round and can play additional game rounds to experience alternate side effects possibilities. The validation test of Timer After Time was done over a population of men between the ages of 45 and 85 who were diagnosed with localized/early-stage prostate cancer. A total of 13 participants attended 1 of 4 focus group sessions divided into 3 groups of 3 participants and 1 group of 4 participants. Quantitative measures of acceptance and usability were made with an 18-item instrument based on a 7-point Likert scale. This study is focused on three researcher questions: the users acceptance of a serious game as a decision aid for prostate cancer, the game usability, and the increasing of user confidence and participation in the decision-making process. Regarding the software help in the decision process users prefer speaking one-on-one with doctors, friends, or family members previously diagnosed and treated for prostate cancer. Time After Time was positively evaluated because it permitted them to highlight some side effects they did not understand before. The game allowed them to print these questions to ask to their doctors. The focus group revealed some flaws in the game design that should be corrected to improve the game usability. These aspects regard navigation and introductory information as well as content issues. Regarding the game participation in the decision-making process, users revealed that the actual game design leaves out several treatment aspects that participants identified as crucial features in the decision-making process. Aspects like cancer recurrence and long-term survival rate were not accounted in the actual version of the game but they were evaluated as of fundamental importance from patient.

5. Discussion

From the results of this review we can admit that serious games developed for healthcare are generally not widespread as we expected. In some health related fields we found much more developed solutions with respect to others. First aid is the field where we found the highest number of developed serious games. This is because continuous training is very important in this field and serious games can achieve this goal with lower costs.

In order to understand if a serious game approach can be useful in healthcare and health professions training and to answer first two questions we can consider the results of some evaluation studies reported by some scientific papers. Unfortunately among scientific papers we found only some works [13, 20, 28, 35, 36, 38, 43, 47, 52] reporting results of evaluation studies made on users the games were developed for. The aim of these studies was to evaluate the effectiveness of this type of training.

Studies [20, 28, 36, 38, 47, 52] demonstrate that users who practiced a serious game training have better results than users experiencing traditional learning processes. In [43] the authors measure that users practicing serious game training have an increased number of acquired skills with respect to traditionally trained users and also that the serious game

approach increases the skill retention after three months. Conversely the work [35] shows that the results of serious games training and traditional approach are comparable. In the study [13] serious game users indicate that the game-based interface has increased their interest in learning.

As we can see from the results of these studies serious gaming represents a useful training technology in health professions and should be considered as an effective training tool. In some cases it also improves learning and skills acquisition. From the results of the discussed studies it is straightforward that if a serious game does not enhance the learning process it has comparable performance with traditional learning approach. In these cases an evaluation of the cost factor could advantage one more time the serious game solution. In some cases we can also admit that serious games offer a more realistic approach than other types of training.

One open issue in serious gaming for health related applications is that only a few of the serious games analyzed [16, 28, 34] have a multiplayer component. A social interaction paradigm should be experienced in health professions serious gaming because health professionals often need to work in team. This is important not only to stimulate the attitude to teamwork but also because challenging a colleague or a friend is at same time attractive and funny. Social games like Ruzzle had a great success for this last reason. The same playing paradigm should be experienced in a serious game.

In the conclusion of this review we can confirm that serious gaming technology represents a useful training technology for health profession and health related education. Based on this result we choose to use this paradigm to develop a training application for surgeon working on microsurgical sutures.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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