# Chapter 2
# Healthcare Training Enhancement Through Virtual Reality and Serious Games

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**Abstract** There has been an increase in the use of immersive 3D virtual environments and serious games, that is, video games that are used for educational purposes, and only recently serious games have been considered for healthcare training. For example, there are a number of commercial surgical simulators which offer great potential for the training of basic skills and techniques, if the tedium of repeated rehearsal can be overcome. It is generally recognized that more abstract problem-solving and knowledge level training needs to be incorporated into simulated scenarios. This chapter explores some examples of what has been developed in terms of teaching models and evaluative methodologies, then discusses the educational theories explaining why virtual simulations and serious games are an important teaching tool, and finally suggests how to assess their value within an educational context. The tasks being trained span several levels of abstraction, from kinematic and dynamic aspects to domain knowledge

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training. The evaluation of the trainee at each level of this hierarchy necessitates objective metrics. We will describe a unifying framework for evaluation of speed and accuracy of these multi-level tasks needed for validating their effectiveness before inclusion in medical training curricula. In addition, specific case studies will be presented and research results brought forward regarding the development of virtual simulations, including those for neurosurgical procedures, EMS training, and patient teaching modules.

## 2.1 Introduction: Games and Simulation in Medical Education

Learning health-related subjects during medical, nursing or any other allied health profession training involves the study of extensive material and the acquisition of a variety of new skills. Over the years, teachers have tried to incorporate new technologies as tools into the curriculum, to make the material more interesting and easier to learn. The ubiquity of videogame play today has seen a recent push towards serious games, that is, the application of videogame-based technologies to teaching and learning A study over 200 medical students in 2010 indicated that 98 % of medical trainees supported technology to enhance healthcare education and 95 % thought new media technology (i.e., game play) could be better integrated or used in the curriculum [1]. Leveraging this interest in new media by incorporating "serious games" into the surgical curricula may enhance surgical training for the current generation of learners [2]. Game-based learning "leverages the power of computer games to captivate and engage players/learners for a specific purpose such as to develop new knowledge or skills." [3] With respect to students, strong engagement has been associated with academic achievement [4].

The presence of this new media, however, is insufficient to ensure its effective use; the mode of delivery of educational content is also an important consideration. Although recent technology has made available an increasing number of surgical simulators, most are used infrequently by trainees. As a result, many surgical simulators sit unused in hospitals and simulation centres, except when they are specifically incorporated into structured educational sessions (e.g. weekend training courses) or used for demonstration.

A potential reason to explain the lack of use of these training tools beyond the confines of structured educational activities is that despite their potential educational value for training specific technical and cognitive skills, these simulators often lack specific design features that would make them enjoyable for learners [5]. Mastery of a skill requires repeated and deliberate practice. However, the instructional design of current simulators is largely focused on replicating the educational content using pre-defined activities that students have little control over; thus the process of practicing a skill on existing simulators until this mastery is achieved is not associated with the thrill inherent in games (e.g. winning a game or having the best score). As a result, motivation to engage in the deliberate practice necessary to glean the educational benefit from this technology is low [5]. In contrast to such traditional teacher-centered learning environments where the teacher controls the learning, serious games and virtual simulations allow the student to interactively control the learning thereby promoting an active, critical learning approach where the teacher now takes on the role of facilitator [6]. Although the term “serious games” is rather new, game-based learning has been employed for many years in a wide array of training applications, most notably by the military, and is currently growing in popularity in the medical education including surgery. This should come as no surprise, as the use of simulation in medical education has been widely accepted and according to Becker and Parker [7]. In the end, all serious games (or game simulations as Becker and Parker refer to them) are games, and all games are simulations and can employ identical technologies (hardware and software). Through game constructs, realistic situations can be simulated to provide valuable experiences that support discovery and exploration in a fun, engaging, and cost-effective manner.

Serious games have the potential of bridging the simulation and gaming worlds by harnessing the educational value of technology-enhanced simulation to teach specific technical or cognitive skills to learners (be they trainees or patients), alongside the motivational, interactive, and engaging aspects inherent in games. In addition to promoting learning via interaction, serious games are ideal for surgical simulation as that they allow users to experience situations that may be otherwise difficult to experience in reality, due to factors concerning cost, time, safety, and ethics [8].

One of the most expeditious ways to introduce new technology in the curriculum is to use it as part of serious games. The ubiquity of videogame play today has seen a recent push towards serious games, that is, the application of videogame-based technologies for teaching and learning. Serious games have been used in nursing curriculum since the late 1970s (1976–1977) first with role-playing, then using mannequins, finally progressively using avatars in digital games [9]. A complete discussion of serious games assessment is beyond the scope of this chapter; a more comprehensive review is provided by Bellotti et al. [10]. A short and non-exhaustive overview of published studies focusing on serious games to teach some aspects of health-care training is presented below. We searched several databases (Scopus, PubMed, Google Scholar) with the following keywords “serious games”, “healthcare training” “medical students”, “nursing”, “games for education”. Over the years, the technology associated with serious games and training has become broader, as well as their definition, and therefore the types of games developed vary from quizzes using cards to complex video games. In parallel to the games’ design evolution, there has been some development in their evaluation with respect to training Fig. 2.1.

After serious games were introduced within nursing, the concept of game integration carried forward into other professional training scenarios [11, 12]. Role-playing, with someone taking on the role of a patient, interacting with the trainee, was one of the first types of serious games introduced in nursing education. For example, role-playing was used for training in mental health and psychiatry nursing, or in nursing for older patients [13–15]. However, to be considered as a game

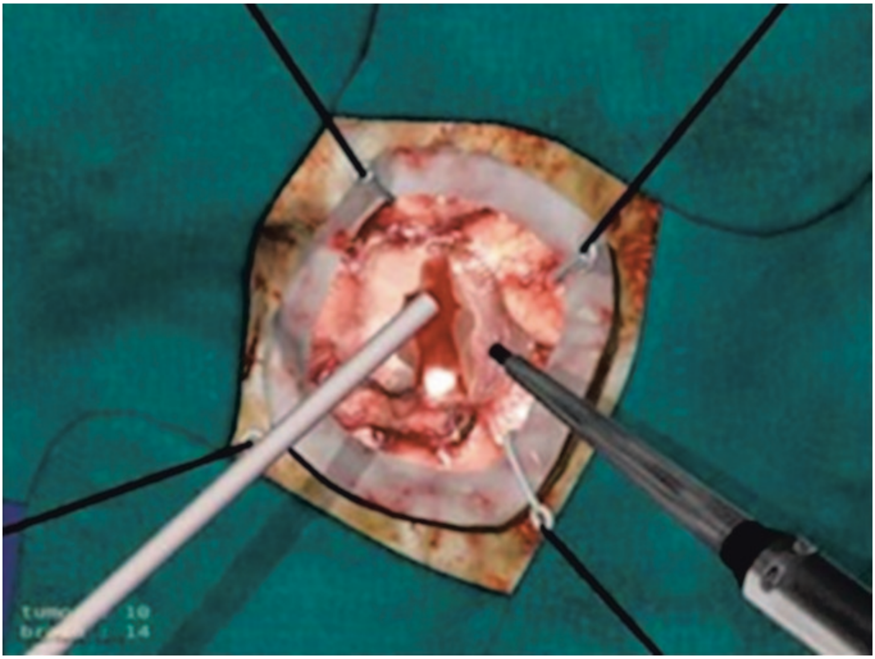

**Fig. 2.1** Screenshot from the neurotouch designed by the National Research Centre Canada. The task of the trainee is to remove the whole tumour without removing the brain around it, and to minimize the blood loss

instead of just a role-playing experience, one has to introduce more structure or rules, and a better theoretical framework. Studies showed that there was an increased active participation and motivation when the skills where learned in a game environment [16]. Role-playing games where followed by scenarios gravitating around mannequins for cardio-pulmonary resuscitation [17], first only focusing on technical skills with low-fidelity mannequins, but increasingly more complex scenarios were developed, with higher fidelity mannequins (Fig. 2.2).

Game-developers attempted to implement quiz-based educational games using different strategies such as card picking and wheel turning, among others, in an attempt to make learning more attractive. Some researchers were also inspired by TV game shows. For example, “Pediatric Jeopardy” was based on the TV show Jeopardy [18]. Games have been applied to a variety of medical education topics. For example, games have been developed for medical trainees to learn about neonatal care [19], cardiovascular drugs [20], and abnormal blood clot formation [21]. Games have also been employed to educate medical students about basic principles such as physiology [22], microbiology [23], cancer genetics [24] and psychosocial aspects in paediatric [25] or geriatric calls [26], clinical practice guidelines [27], and even how to maintain a medical practice [28]. The same designs have also been used to teach specific treatments, such as starting an insulin treatment

**Fig. 2.2** Example of an OR setting in a virtual reality world (second life) [96]

for diabetic patients [29], or the treatment of stroke [30], with learners showing a higher level of satisfaction with similar knowledge retention.

In general, studies examining appreciation of serious games and comparisons of serious games (quizzes, web-based or role playing) in nursing or medical students, have showed that students favour a serious game approach [1, 23, 24, 31–34], even if their scores were usually similar to "traditional" (non-serious games-based) teaching methods. At the resident level, junior residents were more interested and engaged within a serious game than the senior residents [35], indicating that serious games might have more effect early in the training rather than towards the end.

Despite the promise and potential of serious games to address many of the shortcomings associated with the current educational system, particularly with respect to addressing the learning needs of today's generation of learners, there is a lack of studies that have methodically assessed learning via games and this has prompted some to challenge the usefulness of game-based learning in general [4, 36, 37]. Further complicating matters are the results from a number of past studies that have reviewed the literature and conducted meta-analysis on "instructional games" focusing on empirical research on instructional effectiveness, which have questioned the effectiveness of game-based learning [38, 39]. Many of these reviews related to the effectiveness of simulations and games were conducted several years ago and the studies they focus on date back several decades. However, even in the last 10 years, there has been unprecedented development within the videogame field and it has been suggested that games more than five years old are "old news" [7]. That being said, there are also many examples of studies that have demonstrated that when designed properly, "learning games", do facilitate knowledge and skill acquisition (and plenty of it), while also engaging players [40–42].

Learning in general is a complex construct and difficult to measure. Thus, determining the effectiveness of a serious game (that is, determining whether the serious game is effective at achieving the intended learning goals) is a complex, time consuming, expensive, and difficult process [43, 44]. While most studies have shown more engagement of students and a higher satisfaction level among trainees when a game strategy is used to teach, a review in 2012 showed that in the 25 articles describing serious games for medical personnel training, none had a complete validation process [2]. Therefore more scientific and systematic ways of evaluating the satisfaction of the learners and the knowledge retained through this pedagogical approach needs to be incorporated into future studies, in order to have a more concrete view of how serious games can be implemented into the curriculum of health professionals. In addition, one should not forget that such games must accomplish specific learning goals that complement existing training methods. Debriefing must occur after the game, using the experience to point out meaningful events (especially errors made) and the correct approach that should be taken in future attempts.

It has also been shown that not all serious games result in improved learning [45, 46], which raises an important issue: without a good evaluation, one cannot be sure that 'negative learning' is not arising from the game. As stressed earlier, the content of the game as well as the objectives must be well thought of and recognized before and during the development of the game. It must then be tested on a pilot group, to of learners be sure that there are no misconceptions on the students' part since their understanding of the game and procedures to be done might not be the same as for the experts. This phenomenon has been well demonstrated in some medical simulator studies, as well as in other disciplines [47–49].

Example of serious game involving decision-making in surgery:

Total knee arthroplasty (TKA) is a commonly performed surgical procedure whereby knee joint surfaces are replaced with metal and polyethelene components that serve to function in the way that bone and cartilage previously had. Motivated by the fact that by clearly understanding the steps of the procedure and the underpinning surgical decision making processes, when placed in real operative environment, trainees will be able to focus on the technical aspect of the procedure, we recently developed a serious game for TKA procedure training (see [50]). The TKA serious game focuses on the cognitive aspects of the TKA procedure (i.e., the ordering of each of the steps in the procedure, and the various tools used at each of the steps). Users begin the serious game in the operating room taking on the role of the orthopaedic surgeon, viewing the scene in a first-person perspective (see Fig. 2.3a). Several other non-player characters (NPCs) also appear in the scene including the patient, assistants, and nurses (currently, the NPCs are not animated and are not user controllable but future versions will allow them to be controlled remotely by other users or controlled using artificial intelligence techniques). A cursor appears on the screen and the trainee can use this to point and interact with specific objects in the scene. "Selectable objects" include the NPCs (assistants and nurses) in addition to the surgical tools. When a highlighted object is clicked on, a menu appears providing a list of selectable options for this particular object. The surgical tools are also selected using the

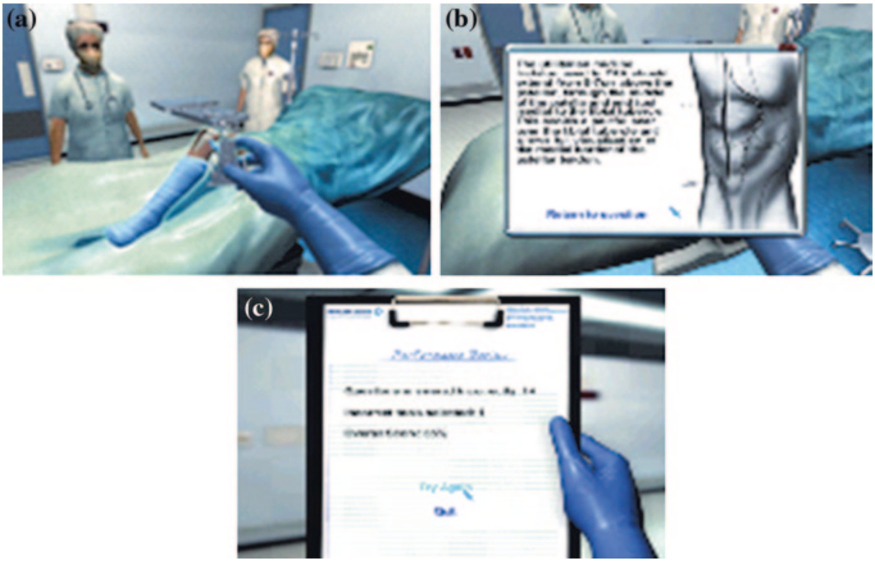


**Fig. 2.3** Arthroplasty game: sample screenshots. **a** (*left*) The patient's leg glows to show that it can be interacted with. **b** (*right*) A pop-up window explaining why the user's answer was incorrect. **c** (*lower row*) The performance review screen shows the number of questions answered incorrectly and the number of times that the wrong tool was selected

cursor and once a particular tool is selected, the tool appears in the hands of the user's avatar. Once the tool has been chosen, if the patient's knee is selected using the cursor, a menu appears providing the user a list of options corresponding to that step. For instance, if the user chooses the scalpel and then clicks the patient's knee, a menu appears prompting the user to choose how big the incisions should be. Once the correct step is chosen, users are asked a multiple-choice question to test their knowledge of that step. Answering correctly results in a number of "points" earned, which are added to an accumulating score. If the user answers the multiple-choice question incorrectly, they are corrected in the form of text and/or illustrations (in a pop-up window) to ensure they understand why their answer was incorrect (see Fig. 2.3b). If they answer the question correctly, they are presented a short video segment illustrating a surgeon performing that particular step on a "real" patient with the surgeon narrating the details of the step). If the user chooses an incorrect tool for the corresponding step or performs a step out of order, they are corrected by a pop-up text-based monolog from an angry assistant surgeon. When the procedure is complete, the player is shown a score card listing the number of questions answered incorrectly, the number of tools selected out of order, and the overall score as a percentage of correct responses (see Fig. 2.3c).

A usability study conducted with both orthopaedic surgery residents and game developers revealed that the serious game was adequate with respect to allowing users to learn how to operate it, to learn advanced features, to explore and discover new features, and to remember previously used commands [50]. Moreover, participants believed that the serious game was properly designed to provide a logical sequence to complete tasks and that it provides feedback on the completion of particular steps. Recently, user-based experiments with orthopaedic surgery residents were conducted and results indicate that the game is effective with novice trainees.

Given the positive experimental results of the TKA serious game together with the positive feedback regarding the game in general, particularly from the medical/surgical community, we are in the process of applying serious games for the cognitive training of several other surgical procedures including the technically challenging and difficult off-pump coronary artery bypass surgical procedure [51], and the z-plasty, plastic surgery procedure training [52].

For example, Z-Doc was developed for training plastic surgery residents the steps comprising the Z-plasty surgical procedure. Z-DOC employs touch-based interactions and promotes competition amongst multiple players/users thus promote engagement and motivation [52]. Qin et al. [53] describe a serious game for the management of blood loss and replacement in orthopaedic surgery. Further examples include a serious games for total knee replacements education whose goal is to educate orthopaedic surgery residents about the steps of the procedure and the tools required for each step [50], a serious game for the off-pump coronary artery bypass (OPCAB) grafting cardiac surgical procedure [51], and finally, a serious game that was developed to examine needle placement under ultrasound guidance amongst radiology residents [54]. Serious games have also been used in CPR pre-training for medical students before a session using a simulator (mannequin) and have resulted in an improvement in CPR skills [55].

Moreover, we are also in the process of generalizing the application of serious games to cognitive surgical skills training through the development the serious game surgical cognitive education and training framework (SCETF) [56]. Domain-specific surgical modules can then be built on top of the existing framework, utilizing common simulation elements/assets and ultimately reducing development costs. The SCETF focus is on the cognitive components of a surgical procedure and more specifically, the proper identification of the sequence of steps comprising a procedure, the instruments and anatomical/physiological knowledge required for performing each step, and the ability to respond to unexpected events while carrying out the procedure. By clearly understanding the steps of a procedure and the surgical knowledge that goes along with each step, trainees are able to focus solely on the technical aspect of the procedure (i.e., the actual execution) in higher fidelity models or in the operating room thus making more efficient use of the limited available resources. Adequate cognitive skills can accelerate the understanding and planning of a particular procedure, and lead to a reduction in the training time required to become proficient with the procedure, thus creating more effective learning while making more efficient use of the limited training time in the operating room [57]. The SCETF is also being developed as a novel research tool, whereby simulation parameters (e.g., audio, visual, and haptic fidelity, stereoscopic 3D (S3D) viewing) can be easily adjusted, allowing for the systematic investigation of simulation fidelity, and multi-modal interactions with respect to learning. This will also allow us to build upon our current work that is examining perceptual-based rendering, whereby rendering parameters are adjusted based on the perceptual system to limit computational processing. Ultimately, this will lead to a better understanding on fidelity and multi-modal interactions on learning.

## 2.2 Does Video Game Proficiency Correlate with Surgical Skill?

Another focus of study over the last decade is whether video games have an effect on surgical skills or other health-related skills. Researchers have argued that playing video games may help in the eye-hand coordination, visual perception, visual memory, [58] and even fine motor control.

According to a recent review, 46 % of the studies examined showed an improvement in clinician skills outcomes and 42 % in health education outcomes—but the author identified that the study quality of those 38 articles as "generally poor" with few blinded researchers [59]. An example of those studies investigated whether good video game skills translate into surgical skills demonstrated that laparoscopic surgeons who played video games made fewer errors [60] or were faster in laparoscopic performance than their counterparts who did not play video games [61, 62]. The same results were replicated for endoscopic/gastroscopic surgery [63, 64] and robotic surgery. However, a number of studies have shown no difference in performance between video game players and their peers [65]. It is clear from this conflicting evidence that further research is required in this area.

## 2.3 Serious Games for Patient Education

In addition to training health care professionals, serious games can be used in different aspects of health care, such as to educate a patient, their family, and the general public about a disease or a medical/surgical procedure. There are different aspects of serious games for health that can be developed. The first category focuses on distracting the patient from their condition in an attempt to treat anxiety [66], nausea during chemotherapy [67], or pain during debridement of a burned wound [68] or other chronic painful treatment (www.breakawaygames.com/serious-games/solutions/healthcare/). The effectiveness of virtual reality and games used in the treatment of phobias and in distracting patients in the process of burn treatment or chemotherapy has been scientifically validated with the use of functional MRI (fMRI), which has shown differences in brain activity in patients who were experiencing pain with and without the use of virtual reality and games [69].

The second category (referred to as “exergaming”) promotes physical activity through game play, using Wii, Kinect or even a joystick or special equipment (such as in GameWheels, which was developed for patient in wheelchairs) [70]. These games can be used to promote fitness or rehabilitation and have been used in traumatic brain injury [71–73], stroke [74], or limb deficit after trauma or stroke [75, 76].

The third category involves teaching the patient or the patient’s family about the patient’s condition and how to manage it more effectively. For example, in a game designed to teach children about asthma, Bronkie the Bronchiasaurus needs to avoid triggers, or the child creates an avatar of a secret agent spying about asthma management [61]. As a further example, consider the games designed for diabetes, where the user is provided with tricks regarding the management of insulin and general nutrition, in order to influence patients’ dietary choices [77]. Case scenarios, and other games have been developed to explain surgical procedures to patients. For example, there is an interactive tool to describe deep brain stimulation surgery, or an aneurysm repair to children in a classroom, which could be used for patients [6, 53].

## 2.4 Games and Play: Structured Learning Versus Entertainment

The mechanisms underlying the educational benefits of serious games lie in their capacity to improve the enjoyment, engagement, and motivation of learners as they engage with educational content that they are required to learn. “Serious Games” are generally proposed as a potential solution to the fact that receiving education formally is often seen as requiring hard work, and work is not necessarily enjoyable. The typical distinction made between activities that are ‘work’ and ‘play’ hinges on the motivational aspects behind these activities: play is done spontaneously or by choice and work is typically imposed, prescribed, or done for remuneration.

There are important definitive characteristics of all games: they are activities in which a player works, through interaction with an environment, towards a goal. In the process, a player conquers challenges in an attempt to achieve the specified goal, without any certainty that it will be attained. If more than one player attempts the goal independently in order to show better performance than others, then it is a competition. If players interact within the framework of the game in a way that can interfere or interact with the other’s performance, then it is a multiplayer game.

In common use, the word “game” refers to an activity that has no consequence in the real world. Despite this, consider “Game Theory”: the study of rational decision making under conflict or cooperation. Interestingly enough, game theory is conceived to model and explain the interactions of agents in the real world. Game play can be enjoyable, and, at the same time, allow the player to practice a set

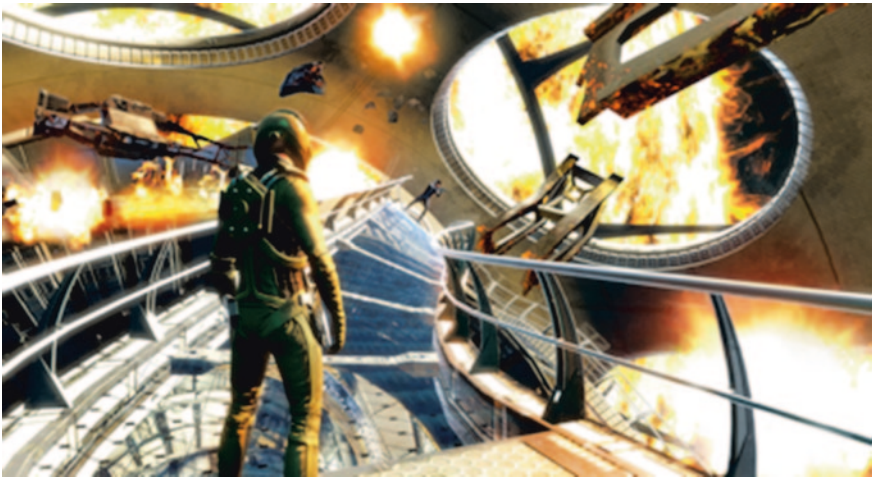

**Fig. 2.4** Example of an engaging game with realistic images (image courtesy of digital extremes, Inc)

of skills; in a relatively constrained and risk-free version of reality. In this sense, 'game play' can have a bearing on the real world, as the player can improve skills that can lead to better performance on related tasks in the real world—a concept known as transfer [69, 78]. Certain aspects of gaming and playing should be examined with regards to learning:

- Games are goal-driven activities
- Games involve interaction between the player(s) and a represented world
- Game interactions are constrained or governed by rules
- During a game, progress towards the goal can be evaluated, even though there is no certainty that the goal will be attained
- Games are adaptive to the level of the player
- Games and play are enjoyable and engaging
- Play, when appropriately designed, results in the learner developing a skill or knowledge that can be applied to the real world.

There is a fanciful sense in which games might be proposed as an ideal mode for teaching. Squire and Jenkins (2003) note that in the science-fiction novel, Ender's Game [79], in which the earth is threatened by an alien invasion, the response is to raise a group of specially selected children,

"…trained through a curriculum that consists almost entirely of games—both electronic and physical. Teachers play almost no overt role in the process, shaping the children's development primarily through the recruitment of players, the design of game rules, and the construction of contested spaces" [80] Fig. 2.4.

In this way, open game play serves as the substrate for curriculum delivery, in accordance with current constructivist theories of learning, where the learner is in the "driver's seat" and the traditional role of the teacher or the instructor is replaced by that of a facilitator. Psychological constructivist learning theory argues that learners actively construct meaning of phenomena through interactions with their environment, in a process where what they already know contacts ideas and knowledge that they are exposed to [81]. "Card's school is a constructivist utopia—in that nobody teaches kids what to do in these games; they are left on their own to experiment and solve compelling problems" … "And the games automatically adjust to the skill level and objectives of each student" [80].

The concept of 'unconstrained play' also brings into sharp focus the necessity of a clearly articulated curriculum and well-designed instructional content for these games. This raises a number of important questions, including: If a set of games allow for engaged yet risk-free training, then who selects the games? Who ensures that they are sequenced in a useful order for the learner? How are the games adapted to the current level of the learner to ensure the optimal degree of challenge without cognitive overload [82, 83]? And if the games are so engaging, then who stops the gameplay to ensure that the trainee does not over-learn one small fragment of a necessarily broad skillset? In other words, who plays the role of instructional designer and facilitator?

Constructivism has always emphasized the role of the teacher as a guide, and the importance of the staging of the curriculum [84–87]. This is clear when we examine Piaget's levels of development [88]. First, individuals need to learn at a sensorimotor level, followed by a more abstract level in which symbolic information may be acquired through learning about objects and their properties, or through verbal instruction. The third stage is 'operational' in the sense that external rules and behaviours can be used within a framework of logical reasoning. Finally, the formal operational stage corresponds to a level of expertise in which alternative plans and hypotheses can be formulated and evaluated, and combined with general abstract knowledge [89]. Although these stages are regarded typically as being applied to general learning from infancy, Piaget's incremental learning process fits equally well to the abstract levels of complex task analysis [90], as applied to a set of levels of abstraction in complex task learning [91] for surgical training or within a broader healthcare context.

Constructivist theories emphasize the necessity of staging learning in a way that spans these levels, and recognize that one level of learning is predicated on scaffolding upon other levels. The notion of 'scaffolding' educational experiences is seen among many social constructivist curriculum designs that are applicable to serious games, including the spiral curriculum model [77] and Lev Vygotsky's model of training within the "Zone of Proximal Development" of a learner [92]. Thus, to the extent that 'games' may be appropriate forms of activity for learning, the set of games needed to teach complex clinical and surgical skills, and the order in which they are presented to a learner, need to reflect these levels [93]. What remains, therefore, is to examine how the set of games can be mapped onto the set of sub-tasks, which comprise an overall complex task from its hierarchical task decomposition.

## 2.5 Hierarchical Task Analysis for Game Scenario Design

To introduce the notion of Hierarchical Task Analysis within a clinical setting, let us consider the phases of any clinical or emergency situation: situational assessment, decision making, task selection and sequencing, followed by the task activities. For example, in an emergency medical response situation, first responders arriving on a scene begin with a situational assessment. This is followed by some cognitive, problem-solving processes, towards a decision making to stabilize the situation. Finally, based on their decisions, the responders will take action performing a variety of tasks or direct actions.

The characteristic of all tasks that are accomplished in a real or virtual world is that they are comprised by low-level sensori-motor actions. Examining the surgical task in detail, we recognize a kinematic level (kinematics of reaching, grasping, cutting, and piercing) and a dynamic level (control of forces needed for pulling, cutting, piercing, and probing). This descriptive account can be defined in terms of a Surgical Skills abstraction hierarchy [91], including:

- 'Knowledge Level' or Cognition (assessment)
- Decision-theoretic (reasoning, planning)
- Sequenced 'Action Scripts' or tasks (rehearsed responses to typical scenarios)
- Sensori-motor Kinematic Skill (targeting, positioning, grasping, moving)
- Sensori-motor Dynamical Skills (forces, balance, pressure).

Using these levels, we propose to decompose the concept of a 'training scenario' into layers of abstraction [91]. This hierarchy is similar to those posed by Albus [90] to describe the abstract levels of control that need to be considered when controlling a complex mission using telerobotic control of a remote robot.

At the lowest levels, the training aspect is at the skill level, where movements and actions involving hand-eye coordination are converted to visual-motor programs. The skills are evaluated by measuring the speed/accuracy of the movements (Fitts' paradigm [94]). As we move upwards through the hierarchy of levels, training involves skills that are composites of skills at the lower level. In effect, tasks, like suturing, are skills that are comprised by low-level movements: grasping and pulling, and are repeated and controlled with a set of rules, which initialize, iterate, and complete the movement. In composite actions, the notion of 'task time' and 'accuracy' can be specified in terms of the individual task times of the composite movements, or as the overall sum. Similarly, for accuracy, the objective score for, a row of sutures as an example, can be based on an assessment of the individual positions of the run of stitches, or by an overall measure of the uniformity of the pattern [95]. Pursuing this argument further, as we move upwards through the hierarchy, the skills being trained are posed in a vocabulary that may include tasks like opening or closing (which in themselves comprise sub-tasks). In opening, the surgeon will cut the skin, achieve hemostasis, and reach their target; while for closing: the surgeon will finalize the hemostasis, close the incisions with sutures and apply a dressing.

We assume that objective measures of the skill level of the trainee will be posed in terms of some speed and accuracy measures—yet these become overall scores typically. In surgical assessment, these are often reported as ‘outcome measures’, and can be a mixture of subjective and objective scores. However, whether training is performed using serious games or VR simulators, these outcome measures can be determined objectively if the training software is designed to measure the movements and response times of the trainee. If the evaluation can only be posed in terms of ‘speed and accuracy’ at any one of the levels of abstraction, the scores for evaluating the effectiveness of training at any particular level of the task hierarchy can be composed by aggregating the objective measures of the subtasks at a lower level of abstractions.

## 2.6 Knowledge Level, Procedural Levels, and Basic Skills Level

Let us now discuss the levels of knowledge and skills involved in the surgical process, how they relate to each other and how they may be assessed.

*Domain Knowledge* At this level, we include the knowledge and skills relevant for diagnosis, namely the logical reasoning necessary for evaluation of the situation and the patient. One must assess the patient, bringing to bear all of their relevant medical knowledge, applying it specifically to that situation, while integrating the patient’s history and the various laboratory and imaging results. It is therefore an integration of current information on a patient with previous knowledge in order to obtain a differential diagnosis. One will confront different working scenarios and hypotheses arising from the patient’s condition to previous knowledge to try to construct this diagnosis.

*Planning and Decision Making* Here, we incorporate the decision processes arising during the care of a patient. For example, when a patient arrives in the emergency room, the triage nurses have to decide whether the patient needs to be lying down and has to be seen immediately or whether some wait time is acceptable. While the full diagnosis is not needed, some key words will trigger different responses. One can plan to lay the patient on a stretcher, to start an intravenous fluid infusion, to call the emergency physician. The decision making involves grouping, coordinating and communicating a number of tasks among several individuals and diverse disciplines to achieve a result. Evaluation at this level may include considerations of time and agreement of the enacted plan with those of experts.

*Task-level activities* occur within a small time frame involving a motor action and may also require a basic decision. At this level, we include activities such as starting an intravenous infusion (one looks for a good vein, prepare the skin with an antiseptic solution, open the iv packet, then pierce the skin with the needle, advance it in the vein, etc.). Tasks may be simple with no decisions involved (such as tying a knot) or composed of sub-tasks (for closure, the surgeon or trainee must decide how far apart to make the stitches, or what type of suture (single, continuous running etc.)). Tasks can be difficult to assess, since there may be no explicitly "true or wrong" task executions, so timing can still be examined (especially in simple tasks), but accuracy is more important than error rate (not binary but scaled).

*At the movement level (kinematics*), we examine aspects such as the displacement in space with surgical instruments to reach a target, the movement needed to cut a tissue or to grab an organ to displace it. For example in endoscopic surgery, the surgeon has to reach the target with the forceps while looking at the screen. At this level, assessment involves calculation of the speed and accuracy of the movement.

Finally, at the *dynamics level* (forces, etc.) we examine physiological control, such as the force with which a surgical instrument is grasped. One can look at the amount of pressure exerted on scissors to cut a tissue, the force with which a needle driver is handled, the pressure exerted on the forceps handles and therefore to the forceps tip in order to use them. Repeated use of tools and training might change the handling of instrument, and therefore experience and decreased stress level during a procedure might also explain the differences between novice and expert.

Therefore when analyzing a scenario, one has to take into account the layers mentioned above in order to decompose the task hierarchically. Objective measures based on speed and accuracy at all levels of the abstraction hierarchy provide for an evaluation mechanism of the learning process, and also serve as the 'scores' for this serious gaming activity.

## 2.7 Conclusions

When considering the definitions and differences between the terms "game", "play", "work", and "task", it becomes clear that games and tasks are almost synonymous, except for the notion that one is typically perceived as enjoyable and the other as tedious. The fact that games are scored and quantifiable (just as task performance), is what makes them well suited within an educational context. The scoring in a game gives immediate feedback to the users, but usually only reflects a small portion of their performances. While it is useful to keep the trainee engaged, and helps them strive to achieve a better score, the scoring systems currently developed are usually not giving enough information on what was done correctly and incorrectly to help the user improve as efficiently as with a formative feedback.

To make a successful serious game, one must first evaluate the needs of the envisioned learners, and decide what are the skills or knowledge than one want to teach. The learner's profile will be part of the constraints. Domain experts as well as educators will have to be part of the development and work in collaboration with the computer software or game developers. In addition to its domain-specific content, the game must be fun and challenging, with some type of story adapted to the trainee. The interactive nature of the game will help the user become immersed in the game. The age of the subject that one wants to train is also important, to decide on how long one can maintain the subject's attention, whether we want to make it in a fantasist or realistic world, since the motivation to play the game will vary with age. Last but not least, after the game has been designed, it needs to be evaluated to study the retention (short and long term) of knowledge/skill acquired by the subject playing the game. Objective measures based on speed and accuracy at all levels of the abstraction hierarchy not only provide an evaluation of the learning process, but serve as the 'scores' for these serious gaming activities for healthcare education.

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