Serious Games: An overview of the game designing factors and their application in surgical skills training

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***Abstract*— Serious game is a promising tool for interactive teaching and training. The serious games are applicable to a wide variety of scenarios ranging from school education to training of professionals. The serious game design is different from normal game designing as there is a learning objective involved. The perfect blend of learning and entertainment along with promising results is a challenging task. In the case of specific applications like skills training in surgery, assessment methods and validity measures are the additional inevitable requirements. The main focus of our paper is to provide an overview of design factors for skills training applications in surgery.**

Keywords*— *e-learning, serious games, skills training, surgery, virtual reality

I. INTRODUCTION

The education scenario has experienced major revolution after the emergence of computers and internet technologies. Surgical education is also leaping into simulation-based training from the existing apprenticeship methods. There have been physical, synthetic, virtual and mixed reality based simulations developed for skills training in surgery [1-5]. Neurosurgery being one of the delicate and complex surgical specialty, the development of simulations need to consider factors like; whether the design of simulations is actually considering the pedagogical concepts, anatomical constraints, workspace or real surgical circumstances. The operative skills competence includes technical and cognitive skills and requires deliberate practice.

The skills training using physical simulators like box trainers or bench models have shown efficiency in training surgeons with basic technical skills [6-9]. The virtual reality and mixed reality simulators are the other potential training techniques that reduce patient risks and provide high fidelity [10-15]. These are suitable for advanced technical and procedure based skills training. Another important skills training and educational tool that may include both technical and cognitive skills training are serious games (SG) [16, 17]. Serious games; as the name indicates include gaming technology or environment to accomplish a serious learning objective.

The use of serious games for education includes a learner-centered approach and provide a fun based environment to learn at own pace. One of the serious games definitions is as given; "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" [18].

Our objective is to review the serious game frameworks and the perceptual and cognitive basis for designing them. Another objective is to review the application of serious games in

978-9-3805-4421-2/16/$31.00

surgical skills training and identify the assessment methods of the gaming "trainee" and the games.

II. Serious Games And Other Technology-Enhanced Learning

The serious game has several overlapping features with edutainment, e-learning, game-based learning, and digital game-based learning. Digital game-based learning (DGBL) is education using computers/ game consoles and can be considered as a subset of serious games [19, 20]. The serious game contains a blend of entertainment, multimedia and experience. The growth of serious games is noted to be exponential in both research and industry in recent years [21].

The computer game spectrum shows that skills training using simulators/virtual reality simulators are purely dedicated to training with no entertainment. On the other hand, games are completely dedicated to entertainment. The serious games fall in the mid-way of these and can be considered as an effective training platform in the current scenario [22]. The major difference in the case of traditional virtual reality simulators and serious games include the factors like entertainment, development costs, development time and deployment costs [23].

The technological advancements reveal that education using games is no longer a quandary and people from all age groups enjoy playing games. Casual/social gameplay on mobile devices and online has increased significantly over the past years [24].

The studies show that digital game-based learning is more effective than the traditional pedagogy techniques [25]. But the acceptance of a serious game in this era demands it to be compatible with various platforms (online and offline) and should be tailored to the needs of today's students and workers [26].

III. Review Methodology

The main aim of our research is to describe the various factors involved in the design of serious games and narrowing our attention to the existing serious games for surgical skills training. The related articles were searched using IEEE Xplore, Scopus, Pubmed, Google Scholar. The keywords used for search include "serious games" AND/OR "design", "cognitive factors", "medicine", "skills training", "surgery". We included review papers and their cross references as well as books and reports on the design of serious games and study. We focused our review on the surgical skills training papers that explicitly mentioned serious game paradigm. The review shall describe the classification, designing factors, skills training serious games, evaluation and assessment methods.

IV. Review On Serious Games

A. Classification of serious games

Serious games can be developed in any genre, using any game technology, for any platform and can target any age group. The classification of these games has been done based on various factors like domains, markets, target group, content, and platform. The major applications of the serious game include education, healthcare, public policy, corporate, defense and training [19–21, 27]. By reviewing over 612 games, Ritterfield.et.al [28, 29] have provided an elaborate classification of the serious games. The games have been categorized as Primary educational content, Primary learning principle, Target age group, and Platform.

B. Design Factors of Serious Games

Designing of the serious games has four important considerations: (i) cognitive and perception models that guide the preparation of the learning content, (ii) providing multimedia contents with reduced cognitive load, (iii) the entertainment components of serious games guided by motivation, storyline and interactive features, and the (iv) assessment methods for the game and the gamer.

1) Learning content incorporation - Cognition and perception models

The adult learning is different from that of a child and they always try to apply the concepts learned from various experiences. Table I describes how serious games satisfy Knowles' elements of adult learning and can be used for training adults [30].

TABLE I. Serious Games and adult learning

Knowles' elements of adult learning	Features of serious games facilitating learning
Independence in learning	Active learning by the learner-centered approach.
Learn through their past experience.	Learning at each level can be used as clues for next level.
Motivated by goal setting.	The presence of levels or newer task provides goal-oriented motivation.
Problem-based learning is easier than content-orientated learning.	The gaming scenario can provide realistic problems facilitating learning experiences of the gamer.

The games for education have been found beneficial in many cases like language, arts, history, military, business, and industry; but the level of educational content and entertainment and its blending is still undefined [31-32]. There are many cognition methods or models that can be considered while developing a serious game. The RETAIN model is one of the widely accepted cognition based designs for serious games [33].

a) RETAIN model

The most relevant instructional design models considered for inclusion in the serious game design are Gagne's Events of Instruction, Bloom's Taxonomy, Keller's ARCS motivational model and Piaget's schema [31]. Gunter et al proposed a Relevance Embedding Translation Adaptation Immersion & Naturalization (RETAIN) model by a combination of the appropriate elements from these cognition designs that fit into a game design scenario. It can also analyze any game by giving a

score from these rubric content and weight is defined according to the importance of the design factor in the RETAIN [32].

b) Learning-Game mechanics (LM-GM) model [34]

This model uses Bloom's theory to link the game mechanics to the learning mechanism. The game elements are directly related to the learning pedagogy and this model can be used for game design and analysis.

2) Reducing cognitive load by proper multimedia delivery

Designing of serious games involves interaction with the human mind. The information reaches the brain through various sensory pathways. Appropriate sensory perception of the input helps in information processing with optimal cognition load. If visual graphics, textual and auditory inputs are provided simultaneously, rapid attention shifts are required to perceive all of them. This could lead to increased cognitive load and diminished processing [35]. There are different hypotheses about how mind works when provided with multimedia content:

a) *Dual channel*: There are separate information processing channels for the multimedia content; say visual and audio.
b) *Limited capacity*: There involves limited processing capacity dedicated to each channel of information.
c) *Active processing:* The learning of any content requires a suitable amount of cognitive processing involved for the channel [36].

There are three types of cognitive demands for processing: essential processing; that refers to the processes involved to make sense of the presented material, incidental processing; these are processes which are not related to making sense but primed by the design of the content delivery, representational holding; refers to the processes necessary to hold the mental representation in the working memory before getting vanished out [37]. The design of the serious games should take into account these cognitive overloading scenarios and must provide the multimedia content to rightly engage the learner or the gamer.

3) Entertainment component of serious game

The essential factors for designing serious games include:

a) Motivation: The education and entertainment paradigm in the interactive technology are not clearly defined, but the relation between them can be theoretically said to be linearly positive, linearly negative or inverse-u-shaped [28]. The education and entertainment paradigms can be the following:

a. *Motivational:* Entertainment provides ways to educate the person and help to develop an interest in the educational content.
b. *Reinforcement:* Entertainment is given as a surprise or rewards for the successful completion of learning.
c. *Blending:* Learning is blended with entertainment in such a way that it is indistinguishable. The person enjoys the game and masters it to master the educational content as well.

b) Interactive features: A game with good technical capacity will load fast and will work smooth. The game design includes the GUI and the interaction with the game environment. Aesthetics include the visual and audio effects and it should be 3D or immersive for better attention. The narrativity includes having a storyline that is revealed as the game progresses. There can be various levels of the game, which get more challenging and intuitive. The social experience is another feature that creates a social impact, interaction, and teamwork with the fellow players.

4) Assessment methods

Assessment of Gamer: The gamer is assessed by game-metric parameters. These should be able to differentiate an expert from novice and be able to trace the gradual improvement of the gamer. There are various metric available for finding the similarity or dissimilarity among experts and novice and scores can be provided [38, 39].

The assessment of the effectiveness of the serious games is of concern and due to the open-ended nature of games, collecting data on student learning is difficult [40].

As in regular teaching paradigm, the serious game domain has assessment methods like completion assessment (summative) and in-process assessment (formative). In addition, teacher assessment of SG user provides predictive validation. Indirect assessment of learning include correlation of psychological state and the physiological signals like facial Electromyography (EMG), cardiovascular measures, Galvanic skin response (GSR), electroencephalography (EEG).

The techniques for assessing the learner can be assessment management systems that support the instructor to create, assess and analyze tests like Questionmark Perception (QP), Assessment Tools for Teaching and Learning (e-asTTle), Assess By Computer (ABC). It can be tools that assess answers marked in free text like Short Answer Marking Engine (SAME) or classroom response system like SMART response, 2Know!. In-game assessment tools are considered appropriate for serious games as it is incorporated in the game itself in such a way that progressing to next level need knowledge from basic levels like Immune Attack, CancerSpace [41].

Assessment of Game: The game can be assessed by the game models which are used to design them (RETAIN, LM-GM model). The assessment can also be done using the validity measures.

V. SERIOUS GAME APPLICATION: SURGICAL SKILLS TRAINING

The surgical skills training based serious games are:

A. Serious Game for Total Knee Arthroplasty (TKA) [42]

Total Knee Arthroplasty refers to a surgical procedure in which the arthritic joints are replaced with artificial

components. The designed serious game includes the surgeon as the first person (avatar) and a sequence of steps to complete the game. The gamer can progress in the game if they know the correct order of steps involved in the real surgical scenario and if they select the specific tool required. An OpenGL-based 3D game engine is developed and it is a multimodality game with other avatars like nurses, assistant. The trainee is corrected in case of mistake with the help of playing a video corresponding to correct approach. There is no validation study reported in the paper.

B. Blood Management based serious game in orthopedic surgery [22]

This game progresses on three levels. First level and second level include "stopping the fountains" on a plane and curved surface respectively to improve the eye-hand coordination and the third level includes the orthopedic surgery game. This level includes three modes: *training* mode in which the trainee has to stop the bleeding spot by performing the correct steps, *time-attack* mode with a time limit of action if exceeded the virtual patient will die, a *collaborative* mode in which players work together in a network. The simulation of bleeding is done by considering physiology and smoothed-particle hydrodynamics (SPH). The interaction is using a haptics device and the performance of the game on Parallel Processing Unit (PPU) and Central Processing Unit (CPU) is also studied. The user performance is measured using time, off-target contact error. The evaluation study is performed on a group of undergraduate students with subgroups of two. One group was allowed to go through all the levels and the other group directly to the orthopedic surgical game. The first group was reported to show significant improvement compared to the other. The questionnaire was also provided to know the opinion of the gamer.

C. Serious Game for Laparoscopic Suture Training [43]

The serious game is targeted for laparoscopic surgeons and uses a pair of haptics devices. The tissue deformation model is represented as a 3D grid of point masses connected by spring. The surgical thread is modeled depending on "Follow-the-leader" approach with the help of spherical joints connected by cylinders. OGRE 3D engine is used for rendering, NVIDIA PhysX for computation, and HAPI library for haptics. The assessment of the suturing task is done based on objective elements.

D. Serious Game for decision making in surgery [44]

The serious game Medialis is developed to train decision making (diagnosis and management) of biliary tract disease. The game included quiz levels from around 97 cases. An image, description of the problem and possible solutions are provided in the game. 10 seconds are given to solve a problem and game mechanics included time, competition by sharing high scores in a network. The evaluation study involves 41 members in 5 different groups. The study describes validation for face, content, and construct validity.

E. Serious Game for Off-pump coronary artery bypass grafting cardiac surgical procedure (OPCAB) training [16], [17]

OPCAB technique does not use heart and lung machine instead stabilize the segments of heart for bypass grafting. This game includes a first person perspective with other avatars and steps are to be correctly followed for better performance. They also present a framework for serious game designing surgical cognitive education and training framework (SCETF) and emphasizes the cognitive learning using the serious games. OpenGL based game engine is developed and provide technical details regarding the shaders and game sound design. There is no validation study reported in the papers.

VI. DISCUSSIONS

For surgical skills training, the focus mainly lies on psychomotor skills and cognitive ability. Depth perception and eye-hand coordination should be a training objective. The interaction should address the fact that the motor skills imparted should be relevant to a real scenario. Sustained attention and reasoning need to be trained for the long stressful surgical operative scenario. The learning can be provided linearly with endogenously delivered didactic content. Involving various personnel from dependent specialties to play the respective roles in the game (Massively Multiplayer Online Games- MMOG) will improve the social interaction and naturalization of the game. Appropriate artificial intelligence allows the framework to learn the attitude and intention of the trainee and provide individualized game experience and assessment of the gamer. Relevant handshakes in the learning and gaming will provide good immersive training leading to better healthcare.

A. Assessment of the game and gamer

Serious games are proven to be helpful in military training and high school education. Their use in medical education and surgical skills training as a part of the educational curriculum will be an innovative approach. The assessment of the game and the gamer is important to identify the reliability and validity of the learning environment. The main hindrances for integration into the mainstream curriculum are the identification of assessment parameters (game-metric) requirement for assessing the trainee's performance and their validation [45]. The parameters, which are assessed, should be able to predict the learning curve as well as the level of mastery of the trainee. The assessment can be a comparison of the outcomes and decisions against the ideal or recreating the answer of experts.

For the validation of serious games for medical education the validity measures like content, face, construct, concurrent and predictive validity need to be proved: [46]

1) *Content validity*: Medical experts check for quality of game content and associated assessing parameters.

2) *Face validity*: Tested by the gamers and the medical experts for the degree of resemblance between medical constructs featured in gameplay and in reality.
3) *Construct validity*: Inherent difference in the outcome of experts and novices on gameplay outcome parameters. Outcome differences should be significant between players of the different medical specialist level of skill.
4) *Concurrent validity*: Outcome parameters should show significant correlation between game and an alternative, established training method.
5) *Predictive validity*: It is the correlation between outcome parameters of a game and performance results of the game-trained-user in real life.

B. Individualized learning experience

The surgical skills training games should provide individualized experience. Even in team-based games, each player should be provided with individual experience with customizable avatars.

VII. CONCLUSION

The serious games have enormous potential for entertaining as well as educating. The appropriate blending of game design and learning design would be key for efficient technology-based education. Cognition and perceptual models like ARCS and RETAIN enable to design these games with scalability. Serious games are accepted training method in various fields like military, commerce, school education, health education and environmental conservation. This powerful training method should be used for routine medical personnel training and education. Building these games on virtual reality platform would be safest and best training methods for surgical skills. The emphasis while doing so should be to develop validated assessment methods incorporated into the games.

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