EG UK Computer Graphics & Visual Computing (2021)
K. Xu and M. Turner (Editors)

Design guidelines for virtual neurological procedures

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Abstract

The role of technology has become more and more preponderant for educational purposes in schools, in universities and for training. It is also applied in healthcare and neurology training thanks to the proven effectiveness and the rising demand inside hospitals and medical schools. The necessity to outline design guidelines is increasing hand to hand with the aforementioned phenomenon. In this paper we will discuss some key aspects of a healthcare teaching application such as the fidelity of the learning environment, the target platform of the application with a particular focus on Virtual Reality, and the learning strategies that can be implemented within the program. We will also illustrate some results of our stroke assessment training application, where we proved the effectiveness of the proper implementation of some design aspects that we addressed inside the guidelines section. (see https://www.acm.org/publications/class-2012)

CCS Concepts

• Applied computing** → **E-learning; • Human-centered computing** → **Virtual reality; • Computing methodologies** → **Simulation environments;

1. Introduction

E-learning approach to teaching has been proven as a valid alternative to standard education. Browser, tablet, desktop and Virtual Reality teaching applications and serious games can lead to promising results also when compared to face-to-face lectures [FAH20, HKQ*18, MDC15, OCMMA19]. Thanks to the reduction in the price of devices capable of running complex applications and thanks to the internet connection improvements of the last years, the increasing use of these solutions requires the definition of viable and practical guidelines to obtain such good results. The choice of platform, type of application and learning strategy is meant to be taken considering factors such as target user, academic field and price range. For example, we will see that Virtual Reality applications are particularly functional and effective for surgery training but can be expensive for teaching to big groups of students at the same time. We also want to focus the attention to guidelines and features that can be adopted in healthcare treatment training, in neurology in particular. Many applications and serious games have been proven to be very effective [LLG*17] therefore we will support this statement by exhibiting the results of the application such guidelines.

2. Application design guidelines for healthcare

2.1. Fidelity and engagement

Fidelity, intended as similarity with the real procedure in the real world, is a characteristic that can be achieved at various levels if we consider it as a combination of visual realism and accuracy with respect to the standard procedures that are objective of the training. Sarmah et al. [SVH*17] expressed the advantages of a high over a low fidelity simulator. In their specific case the realism of the anatomy of the patient allows the refinement of skills required for the medical procedures they are describing. Furthermore, future improvements such as realistic movement with breathing of the patient, its positioning and the operating room environment with equipment will play an important role for the engagement of the trainee.

Engagement is defined as the heart of the learning process by Choi et al. [CDC*17] who also explains how fidelity, realism, accounting for the skills, attitudes and motivations of the learners during the training, could create an ideal engaging simulation. Also computing power improved significantly during the last years, leading to more sophisticated imaging technology. And however noticeable the differences with the real world are, current simulations can provide encouraging options for training in healthcare [KFS17]. Fidelity and engagement are very distinguished features that can positively affect the learning outcome of our application. They can help make the user feel inside the lesson while keeping a high level of attention.

2.2. Target platform

The choice of a proper platform for the application is key for multiple reasons. Depending on the type of application, simulation, environment and interaction we can add different features which could lead to different results depending on the type of training we

DOI: 10.2312/cgvc.20211311

are providing. For example, if we consider mobile applications it is trivial to say that the biggest benefit is the population we can reach since almost everybody has a smartphone today. But it is also true that the type of interaction, the dimension of the screen and the computational power of this kind of device is not suitable for a complex simulated environment. Those kinds of applications are also called 3D Virtual Learning Environments (VLEs), defined as "computer-generated, three-dimensional simulated environments that are coupled with well-defined learning objectives" by Schmidt [Sch10]. On the complete opposite pole, we can find Virtual Reality (VR) applications. VRLEs, or Virtual Reality Learning Applications can achieve higher levels of attention and immersion, but VR headsets are not cheap, and they often need a powerful workstation to run complex simulations. Cheaper than VR setups are desktop and laptop computers. We can find at least one of them in almost every house and they can run applications that need processing power that cannot be found in smartphones. However, they are also limited if compared to VR. The use of head-mounted displays and handheld controllers helps giving the user a sense of immersion that cannot be easily achieved with standard displays. For instance, Zizza et al. tested the response of users to two different versions of the same learning application. Preliminary subjective tests confirmed that the VR version was more enjoyable and immersive while not being distracting [ZSH*18]. We could say that the choice of the platform depends on the population you need to reach, the complexity of the environment, the visual quality you want to achieve and the type of interaction the user must perform in order to use the application(Figure 1).

2.3. Virtual reality learning

The immersive approach to Virtual Reality extended the possible applications, the type of interactions and the quality of the experience. Corrêa et al. researched how a realistic 3D environment in conjunction with immersive VR is perceived. Performing an evaluation on interactive archaeometry, they concluded that it is possible to represent a Virtual Environment as realistically as the real one [CBL*17].

Virtual Reality has become more and more a tool capable of stepping up possible features and interactions within simulations and training applications. Being able to move freely inside the virtual scene permits more accurately illustrated processes as well as extreme close-up inspection of objects and people. VR also permits learning by using a constructivist approach and helps keeping focused the user since active participation is required by changing the way a learner interacts with the subject [CRGMOAMA20].

It is important to give the users time to get used to the way they can interact with the application. If they are required to perform specific actions, follow ordered lists of tasks or pay attention to elements of the scene they should know what they must do and how to do it beforehand. Otherwise, they would possibly try various combinations of keys to find the correct one while losing the attention span needed for completing the task. We also do not want to overwhelm the users with too much information, especially if the tutorial does not explain thoroughly what they are facing. In the case study presented by Byl et al. we have an example of the problems caused by a missing tutorial. Their spatial cognition training VR game for medical ultrasound imaging showed some difficulties during the user test because the participants needed time to figure out how to use the scanner. Also, the absence of feedback did not help to understand when they succeeded performing designated tasks , which is something that could have helped mitigate the mistakes caused by the lack of previous information [BST18].

An accurate User Interface (UI) is also essential to show the essential information to the user without covering too much space of the screen. This is very important because with head-mounted displays the eyes cannot be focused on another direction the same way we do with conventional displays. The field of view is still very limited also on the most expensive VR headsets available on the market hence it is preferable to keep an essential UI and to adopt visual metaphors inside the environment, such as books or blackboards.

Another useful guideline is the use of proper devices according to the training we want to simulate in order to take advantage of as many features as possible. Navigation devices, haptic devices and instruments used in real healthcare settings could help to provide a fully immersive simulated world. There are many examples of real equipment operated during simulated training. In blood clot removal neurosurgery with stroke cases for example. If those tools are not available, it is possible to introduce haptic devices capable of providing similar tactile responses as substitutes for them. The accuracy of the simulation, and thus the quality of the training, is deeply connected with the conditions the trainee is working in. Adding appropriate haptic feedback, immersive visual and audio technologies could also help reaching that level of quality [LYS*17].

The type of approach to the user is also important, Cardona-Reyes et al. [CRGMOAMA20] listed several categories such as video-game based approach, object recognition approach, combination of real elements with virtual approach and user-centered approach. The first consists of a specific integration of entertaining features within the learning application, which helps to engage users' motivation to achieve the desired instructional goals [GNPA12, PCY*06]. The object recognition approach means that the manipulation of objects inside the environment is performed as a primary procedure for its recognition [JHV*02]. The third approach is similar to object recognition but involves the adoption of real existing objects that in some cases corresponds to what will be used in a real situation [YCC10]. Lastly, the user-centered approach is derived by the definition of user-centered design given by Abras et al. as "a broad term to describe design processes in which end-users influence how a design takes shape" [AMKP04]. In our case it means that the learning environment involves the user in every aspect of the training including design and feedback.

We also need to consider the level of user interaction and control. In a Passive Level we have a low interaction and control of the user. The simulation will be more like a 3D movie with more degree of freedom for the point of view of the trainee. If we add the possibility for the user to move inside the virtual world and a few more control over the environment we will have an Exploratory Level of interaction and control. Lastly, the Interactive Level involves a high interaction with the VR environment which means deep exploration and even modification of the virtual world. In this case the freedom could be also extended to the interactions with objects and even other users inside the simulation [VRL17].

2.4. Learning strategies

During the development of an educational application, it is important to decide which approach is more suitable for teaching the target subject. There are learning strategies that obtain more results in some fields than others and their actual implementation inside the application could be easier or more difficult than applying them in real case scenarios. For example, it can be easy to group together students inside a real classroom and take advantage of the collaborative learning. Unfortunately, if we want to implement this strategy a multiplayer application could be necessary. In that case we need to consider all the inherent difficulties we could face when introducing all the necessary features into our teaching tool. Therefore, a preliminary step in which design benefits and disadvantages of the learning strategy are taken into consideration is mandatory. In this chapter we will present a list of four of the most common and effective strategies that can be applied to teaching(Figure 2).

2.4.1. Role-play

Role-play learning involves the use of specific characteristics and personalities for the students. This approach makes the student feel more involved in the actions and decisions that will be taken during the training. This happens because (especially younger) learners tend to become very familiar with those representations of themselves and tend to express what they think and feel through the characters, stimulating creativity and imagination. This approach is very effective when applied to education integrated with computer games also because it is very similar to what we usually find in many successful videogames, which helps to create a more engaging and motivating learning environment. To maximise the effect it is important that the role-play is created in a way that makes it believable in order to facilitate the immersion in the exercise [HRL10, MJ00].

2.4.2. Collaborative learning

Collaborative learning in an educational application means offering the students the possibility of sharing lessons, thoughts and exercises with each other inside the same learning environment. Sharing the responsibility of the assignments by giving a different task to each student of the group is a great way to develop teamwork, leadership, communication and conflict-management skills. The use of shared lecture and text-chats opens to the possibility of increasing the interest of the student and promoting critical thinking, as well as improving social skills which lead to a more effective group processing [CRGMOAMA20, HRL10, HLT12].

2.4.3. Problem-based learning

Problem-based learning's first aim is the improvement of problem-solving skills. In this case it is necessary for the student to learn how to outline the problem, study the case and then design a solution. This method has proved to be an effective tool for improving thinking skills learning by using scientific method, systematic and logical thinking. Five phases define the Problem-based learning model, and they are:

- Student orientation to the problem including purpose of the learning and motivation of the student.
- Organise students defining learning tasks related to the problem.
- Individual and group research guide to an appropriate information gathering and experimentation aimed at explaining and solving the problem.
- Develop and present the work with reports or models.
- Analyse and evaluate the problem-solving process.

In our case the VLE is the tool that will be used to simulate the situation that the student will observe and in which the student will operate to solve the problem [HS04, HRL10, SSS17].

2.4.4. Creative learning

Creative learning aims to strengthen the creativity of the student by teaching new ways of visualising different ideas and concepts that may not be immediately recognised by the senses. In fact, creative thinking is often an important resource for problem solving and often problem solving, creative thinking and creative learning are correlated. The use of a creative visualisation of the information we want to impress in combination with the help of the imagination of the student (for example via imaginary play) is a very effective catalyst for the knowledge [AP18, HRL10]

3. Case study

Here we present a case study we are developing. Our VR training application has the primary objective of training students and healthcare workers how to assess stroke cases. A stroke is a medical condition where the blood supply of a part of the brain is cut off. The diagnosis is usually performed by doing physical tests and studying images of the brain produced during a scan. The assessment is very complex, and our simulation is limited to the assessment of a specific severity grade of the stroke based on physical movement, facial expressions, speech and other actions necessary for the evaluation but not currently possible to replicate using a mannequin.

The assessment procedure we are simulating is the National Institutes of Health Stroke Scale (NIHSS). "The NIHSS is a 15-item neurologic examination stroke scale used to evaluate the effect of acute cerebral infarction on the levels of consciousness, language, neglect, visual-field loss, extraocular movement, motor strength, ataxia, dysarthria, and sensory loss. A trained observer rates the patient's ability to answer questions and perform activities. Ratings for each item are scored with 3 to 5 grades with 0 as normal, and there is an allowance for untestable items. The single patient assessment requires less than 10 minutes to complete. The evaluation of stroke severity depends upon the ability of the observer to accurately and consistently assess the patient."(http://www.nihstrokescale.org/)

This application simulates the presence of a patient on a hospital bed who needs immediate assessment of the stroke condition. The simulation guides the student through all the steps of the NIHSS above-mentioned then helps to decide the correct subsequent prognosis.

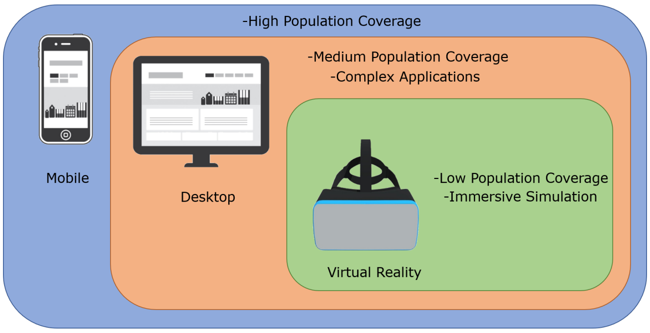

Figure 1: *Most features can be inherited from mobile to desktop and from desktop to virtual reality while achieving new ways of interaction and more complexity thanks to the increased computational power. The number of people owning more performing and expensive devices, however, is inversely proportional to said performance.*

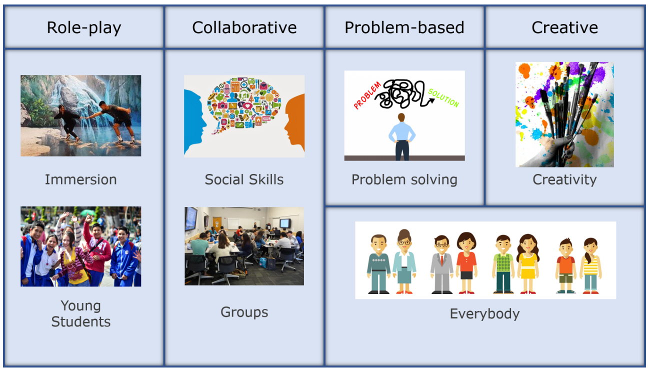

Figure 2: *Different strategies have different features and are more suitable for different targets. Role-play gives an immersive and engaging learning experience with better results on young students. Collaborative learning is more appropriate for teaching social skills to groups of students. Problem-based and creative learning strategies are more adequate for strengthening problem solving skills and creativity. Unlike the first two strategies, problem-based and creative do not have a recommended target.*

4. Preliminary survey

We performed a preliminary survey to study the benefits of a well simulated virtual environment with respect to simple simulations and real videos. The potential of different approaches to e-learning for medical students was the primary objective of the survey. We considered factors such as device type and quality of the teaching material to highlight advantages and preferences of the users.

The survey starts with a series of questions related to personal experience with e-learning, then we divided the questionnaire in two sections. The first section shows 3 videos illustrating different versions of the simulation of a stroke patient while performing an arm movement that should be evaluated by the senior medical consultant. These versions are minimalist, realistic and real, respectively. Each video is followed by several questions regarding realism, accuracy and smoothness of the simulation. The second section includes a poll on which those different types of simulation are compared according to the preference of the participant.

The survey was attended by 30 participants, 17 of which are males and 13 females from 19 to 64 years old with an average age of 28.2. Most of the participants (83.3%) studied, attended a lecture or have been trained using e-learning applications. They never used Virtual Reality as a tool for learning or training but 23.3% of the population believe it would be the second-best media for this purpose after the personal computer (56.7%). The first part of the survey contains five questions for both minimalist and realistic simulation video. They can be answered giving a number from 1 to 5 rating appearance, likeability, accuracy of the movements, realism and smoothness. We noticed a significant improvement from the minimalist to the realistic simulation (lower number means better result). In fact, the results have a mean value of $3.09(\sigma = 1.02)$ for the minimalist against a $2.5(\sigma = 1.0)$ for the realistic. The second part pool contained a video taken from an official video-guide used as reference for the two previous simulations. The objective of the poll was to get the preference for training on how to recognise the correct execution of the movement. As we expected, 23 out of 30 participants voted for the real video as a first choice but 6 out of 30 preferred the realistic simulation even over the real video. The realistic simulation has been chosen as second best choice with 22 votes leaving the minimalist simulation as the least favourite by 27 participants.

It is clear how all the aspects of the animations are perceived in a different manner when we compare the two given examples. These results clearly lean towards the preference of the realistic version of the simulation, giving a similar importance to each improvement made from the minimalist version to the realistic one.

5. Conclusions

In this paper we have defined some of the many key notions that are essential for the design of a learning application. We placed emphasis on the simulated environment approach for healthcare including some design guidelines for Virtual reality. We also listed some of the most used learning strategies that can be adopted inside the application we want to design while explaining key aspects and effects of said strategies. The case study we illustrated shows the results of the application of some of the above-mentioned guidelines. For example, the use of two different types of graphical accuracy has resulted in two very different perceptions of the same type of simulation. This experiment validates what we expressed about fidelity, confirming the correlation between quality of the virtual environment and engagement of the user.

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