# Lecture notes
# Theoretical part

Emmanuel Fokides

YG02. Workshop on Virtual Reality Applications and Emerging Technologies

# Contents

Learning is not compulsory... but neither is survival.

~Dr. William Edwards Deming (1900-1993)

# Introduction. Technology, learning, and education

It is generally acknowledged that the successive technological revolutions and, especially the digital revolution, have led to the necessity of broadening the concepts of learning, as well as to the revision of the methods followed in what is called "teaching", or, better, the educational process. Teachers and, in general, all those involved in education, now have a plethora of -technological- tools at their disposal, which allow them to carry out their work more effectively, but also make the whole process more interesting and enjoyable for those who learn.

The truth is that technology has early on acquired a special relationship with education. The term 'educational technology' essentially describes the coupling of technological tools and teaching and was first used in the late 1940s (Saettler, 2004). As already mentioned, in addition to providing new teaching tools, the introduction of technology into schools paved the way for new teaching methods and practices. Thus, it was quickly assumed that, as a medium, technology facilitates learning and, therefore, should be used to a small or large extent to support teaching. Others, seeing the rapid technological advances and the changes that were brought to all aspects of human activity, argued strongly for the transformative role of technology, speaking of an educational (e.g., Seidel & Rubin, 1977).

However, a number of papers, emphasized, supported by empirical findings, that at first glance are convincing, the failure of technology to benefit students. A typical example is a report by the Organization for Economic Co-operation and Development -widely publicized and reproduced by many media- which concluded that the use of technology in education, in the end, did not have the expected positive and spectacular learning outcomes (Organization for Economic Co-operation and Development, 2015). The report stated that students who use computers, but not intensively, tend to have somewhat better learning outcomes compared to students who rarely use computers. However, students who use computers too often in school have worse learning outcomes in most subjects, even when socio-demographic characteristics and background are taken into account. Also, the results did not show any noticeable improvement in students' performance in reading, mathematics or science subjects in countries that had previously invested significant funds in bringing technology into education. Perhaps the report's most disappointing conclusion was that technology ultimately offers very little in bridging the skills gap between privileged and disadvantaged students, which is a key argument of educational technology advocates.

The notion that educational technology is not capable of improving learning outcomes is, indeed, at first glance, both a well-founded view -as long as it is based on serious research- and gives a strong basis for arguments to those who oppose the integration of technology into the school environment. However, to dwell on learning outcomes, separating them from how, why, and under what circumstances they were achieved, is a mistake. The big picture, which is multi-dimensional and complex, should be taken into account.

The first point worth noting is the digital divide between teachers and students. Indeed, research shows that in addition to the well-known digital divides between economically underdeveloped and developing areas and between those with access and those without access to technology, there is another divide that has to do with how teachers perceive the use of technology and how students expect it to be used in the classroom. In fact, this is true across all levels of education (CDW-G, 2010). For example, 75% of teachers reported that they regularly use technology in their classrooms.

However, only 40% of students reported that technology is used in the classroom, while 86% reported using technology more at home than at school. At the same time, an overwhelming 94% of students reported using technology to do their homework, while less than half of teachers (46%) appear to have incorporated technology into the assignments they give students. It is reasonable to assume that the term "regular use" is defined differently by children and adults.

The point to be explored is how much technology is actually used in the school environment. Van Broekhuizen (2016) in his 3-year study involving 144,000 classrooms in 39 states in the US and 11 other countries concluded that few students use technology and digital tools in a meaningful way in their classrooms. Indeed, teachers have been trained on how to use, for example, interactive whiteboards, and many do, but there is little use of technology by students themselves during lessons. Children use technology outside school all the time for personal and recreational purposes but are not pushed or asked to use the same technology in the classroom for learning. Typical findings from the above research were:

- In more than half of the classrooms, there was no evidence of students using technology to collect, assess, or use information for learning.
- In two-thirds of classes, there was no evidence that technology was used to help students solve problems, conduct research, or work collaboratively.
- The problem is not that schools lack access to technology. More than eight out of ten teachers have access to personal or laptop computers in their classrooms. At the same time, little variation was found in the availability of technology in different types of schools.
- Many teachers have an uncomfortable relationship with technology. They see it as a "necessary evil," tolerated when it is strictly limited. Teachers have the -understandable- fear of losing control of their classroom and their students. Teachers also reported that they find it difficult to engage their students' interest when smartphones, tablets, and laptops are brought into the classroom.

A third point to analyze is how technology is used in the classroom. Devices such as tablets and laptops in all shapes and sizes provide opportunities for students to organize their notes and assignments, explore their interests, communicate with teachers and peers, prepare presentations, collaborate on projects, and connect with experts. However, even as digital tools become more portable, more sophisticated, and more "ubiquitous." for some reason, they have not become the dominant, everyday learning tool. Both of the studies cited above concluded that technology is being used as a teaching tool rather than being used by students themselves as a means to learn. Additionally, asking them to write their assignments on the computer, or make a presentation is simply a meaningless use of technology, and students (who are already familiar with technology) realize this mistake. Typically, only 4 out of 10 students felt that they were satisfied with their use of technology at school (CDW-G, 2010). What is really happening is that children are still doing exactly what older generations did when they went to school. The dominance of photocopies and worksheets continues to exist, transformed or "dressed up" in a digital wrapper.

In addition, there are two widespread myths about technology that hinder progress in research and the application of innovations in practice. The first myth concerns the problematic relationship between digital and non-digital media (e.g., digital and printed books) (Kucirkova, 2014). A consequence of this myth are practices where technology and analog media are in opposition rather than in a complementary relationship (Edwards, 2013). The second misconception is related to technological determinism and in that many see technology as a panacea. Thus, they argue that technology can be a driver of change in education, without acknowledging the powerful role of the context in which it is implemented and the individuals who implement it, namely the teachers (Livingstone et al., 2013).

Apart from the above, a common criticism of projects aimed at introducing technology in education (whether they are research projects or not) is that either the software that will support the material is inadequate, or there is insufficient technical support, or the training is minimal to non-existent. It is perfectly understandable that teachers are at a standstill. How to cope with the speed of technological developments? With so many technology systems available, what technology to use and how can they know ways to integrate into the educational process? Teachers are without meaningful support. It is common knowledge that the slow pace at which important training activities are being implemented. One such example, in Greece, is the Training in Information and Communication Technologies (ICT) Level 2, the completion of which is at least ten years overdue. The relationship between teachers and technology and, ultimately, its good use, is again based on education as a process. However, such a *modus operandi* is unlikely to create the right conditions for educational resurgence or change in practice; it is more likely to replicate the dominant models of teaching. Another mistake is to ignore the systemic/institutional nature of educational practice (Crook & Lewthwaite, 2013). For example, what would happen if children's technology skills, social influences, culture, or economic context were taken into account? This wider context is closely linked to the ways in which technology can support learning (Crook, 1991).

In conclusion, there are serious problems in both how and how much technology is used. Logically, there are problems related to learning outcomes. However, as indicated above, technology *per se* is not responsible. Its limited use for learning is neither an issue of students' access to technological tools in school nor an issue of technological infrastructure. But what do we have to do? Van Broekhuizen (2016) argued that schooling has never really tried to harness or integrate technology to personalize and deepen learning. Unfortunately, the educational establishment is not responding quickly to change and this is not just about technology. At the same time, technological advances are pushing for even more change.

Technological pressure has led to a profound contradiction. Today's learners are digital natives, i.e. they are familiar with a wide range of digital tools and services. This contrasts with their teachers, who are digital immigrants (Prensky, 2001) and, as mentioned, are reluctant to integrate technology into their daily teaching practice. As a result, outside the classroom, students are largely engaged in using technologies (some of which are even considered cutting-edge technologies), many of which could easily be exploited by schools. Inside the classroom, these technologies are excluded.

However, whether some people like it or not, whether schools are ready or not, technology will eventually find its way into the classroom and into the hands of students. This is because, at some point, the use of digital tools will be such an integral part of society that its invasion will be inevitable. Most likely, this has already happened. In short, it's too late to keep technology out of classrooms or children's lives. Some may think they are protecting students when they keep them locked in a technology-free "bubble" during school, but in the end, they go home, graduate, and get jobs. Everywhere they can or need to use technology. If they are blocked from using it in school, it may, eventually, turn out to be a problem. So, children need to be engaged in dynamic, adaptable technological environments at school in order to be successful later on. It is, therefore, imperative that teachers integrate technological tools into their teaching so that they not only keep pace with the needs of teaching but also make their teaching more attractive to their digitally native students. It goes without saying that teachers should become capable of making wise choices about what technological tools to use and how to use them.

In the above context, given the pace of technological developments on the one hand and the ever-changing pedagogical perceptions on the other, it is logical that many people wonder which technology, in the near future, will generate the same interest and debate as the introduction of the first educational applications of ICTs some years ago. In other words, what might be the new "New Technologies" in education? An even more important question is whether these new "New Technologies" will be able to reverse the unfortunate situation mentioned earlier regarding the degree of penetration and the way technology is used in education, paving the way for its substantial transformation.

Trying to predict the future is a practice that often -if not always- leads to wrong conclusions. In fact, any analysis can be considered a balancing act on a tightrope. If it is conservative enough, it may fail to detect the changes to come. If it is sufficiently radical, it can be called "science fiction." The question, however, remains the same: which technology can play a major role in shaping the school of the future? One way to answer this question is to examine the potential -or rather the untapped potential- of existing technologies and their applications, and then speculate on whether this potential is sufficient to initiate and sustain a new educational transformation.

So, what are the existing technologies that have wide educational use? The answer is easy enough: the Internet (including applications that run online) and multimedia/hybrid applications. Both are the most common forms of computer use at every educational level and are so interrelated that they can be considered as a single form. Indeed, any multimedia application can, without particular difficulty, expand its potential by exploiting Internet resources, and any Internet application incorporates multimedia elements to varying degrees.

But what is the potential of these applications that has not yet been fully exploited? Firstly, their spread. One way to achieve this is to reduce the cost of acquiring either an electronic device, an application, or an Internet connection. Secondly, there are already available (at a reasonable cost) technologies that greatly improve the speed of the average user's Internet connection (e.g., fiber optics). Indeed, 5G technology is available, which exponentially increases wireless Internet access speeds. Although its cost is still high, it is expected to decrease significantly in the coming years. Both the reduction in cost and the increase in speed will have a huge impact on the volume and type of data that can be moved in a short time, across a large number of users. In other words, existing technologies, in addition to enabling the implementation of even more complex and demanding applications, can make them even better at realizing the democratic ideal of "access to knowledge by all."

On the issue of the application of new pedagogical theories, it seems that constructivism is the prevailing view. Indeed, the study of the ways in which students interact with each subject has led to the view that knowledge is not simply the result of transmission from teacher to student but is constructed by the latter. Constructivism, although not a single theory, supports this view, acknowledges that individuals construct their own representations of reality, recognizes that they learn through active participation and action and, finally, states that learning is a dialectical and interactive activity with the social environment. As will be discussed in a later chapter, constructivism provides several ideas on how to achieve the above using computers, notably by developing applications that do not set limits on the type and form of interactions that users can have. Many argue that all this is already being implemented with existing technological applications. Indeed, the terms "interaction," "free and non-linear navigation," "collaboration," and "learner control over the subject matter," are frequent in the literature that studies and supports the use of web and multimedia applications in education.

However, the question must be asked whether multimedia applications and the Internet have really brought significant changes in the way students are taught or whether they are just tools to assist teaching. Arguments about collaboration have been around since long before the advent of computers. The same is true for the concepts of inquiry learning, peer interaction, and other student-centered teaching approaches. In some ways, it could be argued that what computers have actually achieved is to provide an easier way of doing these things.

Are multimedia applications and the Internet very different from the media available to a teacher thirty, forty, fifty, or even a hundred years ago? Not really. The blackboard, books, TV, and video are compressed and beautifully presented on a device called "computer." So, instead of teachers and students having books at their disposal, they can be provided with laptops containing everything necessary for the school year. Although such a development would be very important, it does not fundamentally change education.

But isn't distance education a major innovation brought about by computers and the Internet? Probably not. Again, what is happening is that computers are providing, in a different way, solutions that existed long before. Students in Finland, Australia, Canada, and other parts of the globe were using distance education long before the advent of computers. Again, it should be recognized that digital media are enabling distance education to be implemented more effectively and in more complex ways.

All the findings presented above, lead to the conclusion that the technology already widely used in education provides a more flexible, probably more economical, and arguably better form of "traditional" education. However, it is argued that it has not radically transformed education. In order to speculate about which technology might cause a radical educational transformation, more fundamental questions need to be answered. One should seek what is wrong with both textbooks and computers and what is wrong with technologically enriched and traditional ways of teaching.

The answer lies in the fact that someone (the teacher) or something (the blackboard, the book, the computer) is interposed between the information and knowledge and the person who wants or needs to learn. The learner does not have direct access to knowledge, but an indirect one. The data has already been processed by the teacher, the author of the book, the developer who built the application, or the web pages. But this way, students are cut off from perhaps the most important way that people learn, namely first-person experiences. Although this concept will be discussed in another chapter, at this point it should be mentioned that first-person experiences refer to the direct experiences that a person gains from their everyday contact with the world around them. Such experiences are immediate, personal, and subjective. To a large extent, this type of experience is related to what is known as "hands-on experiences." Similarly, "third-person experiences" are indirect, unprocessed experiences. A simplified example, illustrating the contrast between first and third-person experiences, is the significant difference between watching a movie and having it narrated, albeit very vividly, by someone else. Little or much of the experience one would have had, the emotions one would have felt, and the knowledge one might have gained, is "lost" in the latter case.

But there is a technology that could provide a solution to the above problem and, by extension, transform education. It is 3D virtual environments or, in other words, VR (VR). As the term suggests, these are digital environments created using 3D graphics (Freina & Ott, 2015) and aim to create realistic, rich, and "first-person" experiences for users. In fact, a variant of VR, the Immersive VR (ImVR), is of even greater interest. Although VR is not a recent technology, its development in recent years has been significant and so has the rate of its diffusion. It could be argued that with the emergence of 3D virtual environments, a whole new world for learning has emerged, offering even more innovative tools that can be used in education (Taiwo, 2010). Research has demonstrated that applications of VR, and 3D simulations in general, enhance intrinsic motivation and creativity (Brown et al., 2008), due to the type of experiences they provide (Fokides & Atsikpasi, 2018). As will be seen at another chapter, studies demonstrated that it can have highly positive learning outcomes in many disciplines.

# Chapter 1. Virtual Reality, definition, and history

The following sections present definitions of VR and a brief historical review of its evolution, so that the reader has a better understanding of the evolution of this technology over time.

## 1.1. Definitions of VR

Several definitions of VR have been given, many features have been attributed to it, and its use has been extensively explored in several areas. As a term, it was attributed to Lanier in 1987 (Lewis, 1994). Until then several terms were used for this technology. For example, Krueger (1992), in the 1970s, described it as "artificial reality," meaning technology that allows users to physically participate in a simulation created by a computer. Gibson, in 1982, introduced the term "Cyberspace", i.e. a parallel universe created by computers (Doherty, 1994).

From the above, it can be seen that VR offers a way of simulating reality. It is not quite as "real" as physical reality, but it works best in the space just below what might be called the "reality horizon." For example, if a virtual car hits a user, there is no physical injury, but, nevertheless, one may feel anxiety. On the other hand, as pointed out by Lanier, the real power of VR is to go beyond what is real, it is more than simulation, as VR allows the user to step outside the boundaries of reality and experience situations that would otherwise be impossible.

Basically, the term "Virtual Reality" is contradictory. The term "virtual" also has the meaning of "fake," something that does not exist in reality. The noun "reality" refers to something real, not imaginary, that has real substance. In the term "Virtual Reality" these two meanings come together and are unified. This means that anything that can happen in reality can be programmed to happen but only "virtually." However, the basic goal of this technology is to reproduce reality so well that users cannot distinguish between "fake reality" and "real reality" (Sutherland, 1968). In other words, it tries to make the fake look real.

Usually, researchers define VR from their perspective. For example, some state that VR is a medium that allows people to visualize, manage, and interact with both computer systems and highly complex data in a virtual environment (Aukstakalnis & Blatner, 1992). Pimentel and Teixeira (1993) defined VR as an immersive, interactive experience created by a computer. Another definition states that VR is a closed system consisting of a virtual environment, a physical environment, and software and hardware, which allows for mutual interaction between humans and computers (Zaho, 2002). According to others, VR is a technology whereby the user can interact with a virtual, non-real world and directly manipulate its objects (Ihlenfeldt, 1997). Others have stated that VR is a set of hardware (computer and special devices) and software (e.g., special programs for building virtual worlds) with which individuals are able to visualize and interact with highly complex data in three dimensions (Fokides & Tsolakidis, 2011). Thus, in essence, VR can be defined as a high-tech medium that involves real-time simulation and interactions through multiple sensory channels.

The above definitions attempt to describe, as best as possible, what VR is. What emerges is that VR, with the computer (or any other electronic device) as its main tool, creates visual, auditory, or other types of sensory stimuli for users in order to immerse them in a virtual world. With regard to the concept of interaction (mentioned in one of the above definitions), it defines the ability of users to select, shape, and construct 3D objects and ultimately their own virtual worlds. The "user" factor seems to play an important role in VR. That is, this technology takes into account their actions in this illusory world and their ability to realize what exists within it (Sherman & Judkins, 1992). In conclusion, the definitions mentioned above consider VR as a technology that aims to realistically simulate real or imaginary environments.

However, realistic simulation does not seem to be a necessary condition. The perception of the immediate environment depends on the data collected by the sensory systems (vision, hearing, touch, taste, and smell). However, research evidence suggested that individuals focus on a very small number of key points in space and then the eyes scan paths that tend to follow perceived patterns (Noton & Stark, 1971). In reality, then, although people perceive a small percentage of what they need to see, their brains create a complete model of space. It has even been argued that the model of space tends to drive eye movements rather than the other way around (Chernyak & Stark, 2001). According to Stark (1995), this is the reason why VR works even if the representation of the virtual environment is simplistic or even poor. It seems that VR provides enough evidence for the brain to assume "this is a room" and then, based on an internal model, create a model of that room using a perceptual completion mechanism. Thus, it might be more apt to argue that the goal of VR is to replace the perception of reality with computer-generated perception.

If sensory perceptions are effectively replaced, then the brain has no other choice but to extract the perceptual model from the stream of sensory data given by VR. Hence, the perception of the virtual becomes the perception of the real, despite the individuals' certainty that what they see is not real. The factors critical to the above sensory substitution have been known for several years, such as the wide field of view, tracking of head/arm/body movements, low system response time (latency), and high resolution (Barfield & Hendrix, 1995; Ellis, 1996; Heeter, 1992; Held & Durlach, 1992; Loomis, 1992; Sheridan, 1992, 1996; Slater & Wilbur, 1997; Steuer, 1992).

Thus, taking into account the human factor, the term "VR" can be extended by adopting the definition given by Macpherson and Keppell (1998) that VR is a situation created in the mind that can, with a varying rate of success, engage a person's attention in a way similar to that in the real environment. The devices used contribute to the creation of this state. In other words, VR is not just a new technology. It is primarily a mental state in which the subject-user is immersed -partially or totally- in an artificial environment, which may have great similarities or differences from reality.

Turning to the technological approach to the term, Figure 1 presents Milgram's and Kishino's (1994) "Reality-Virtuality Continuum". From this, it can be seen where VR is placed in relation to the superset of Mixed Reality. Mixed Reality ranges from the completely real with no digital elements to the completely virtual that contains no real elements at all. Also, Mixed Reality includes Augmented Reality and Augmented Virtuality that overlap in several places. In both cases, the real world is enriched with virtual objects (2D or 3D objects that provide information) and users coexist and interact with them (Milgram & Kishino, 1994).

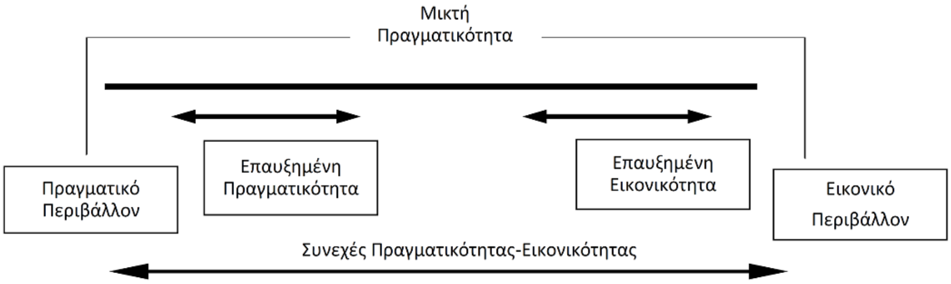


**Figure 1.** The reality-virtuality continuum
(Milgram & Kishino, 1994)

## 1.2. Historical background

In order to make it more understandable, a brief historical review is presented, including indicative stages of VR's development with references to the pioneers and those who contributed to its formation until today.

*Panoramic murals*

The panoramic frescoes (or panoramic paintings) of the 19th century are the precursor of VR. The paintings gave viewers an evocative, intense, and very vivid experience, making them feel that they were actually in the place where the event or scene took place. Figure 2 shows the Battle of Borodino (1812) painted by Franz Roubaud and exhibited at the Borodino Panorama Museum. It is indeed a huge circular painting, with a circumference of about 116 meters.

**Figure 2.** The Battle of Borodino

*Stereoscope*

Wheatstone, an English inventor, in 1838, published his discoveries on the perception of three-dimensional (3D) objects. He observed that distance reduces the perception of the depth of an object; an object that is closer to an observer appears different to each eye. He invented the stereoscope (Figure 3), a device capable of presenting two separate images of the same object in each eye, fooling the brain, which perceives that it is seeing a 3D object (Wheatstone, 1838). Essentially, Wheatstone demonstrated how we perceive 3D objects (VR Society, n. d.).

**Figure 3.** The stereoscope

*Link trainer*

$^{o}$Moving into the 20th century, Link, in 1929, built the "Link trainer" (Figure 4) which simulated, very realistically, a flight. It was controlled by motors connected to the rudder and steering wheel to simulate pitch (propulsion, up and down) and roll (rotation). It also had a small motorized device that simulated turbulence. It later became commercially available and, in fact, during WWII, over 10,000 Link Trainers were used by more than 500,000 pilots to train and improve their skills.

*Sensorama*

The Sensorama was built by Heilig in 1950. It was a device that could stimulate the senses (sight, hearing, and smell) (Alqahtani et al., 2017). It contained stereo speakers, a 3D stereoscopic screen, fans, odor generators, and a chair that produced vibrations. The Sensorama was designed to fully immerse a person in a film (Figure 5). Heilig created, in total, six short films for his invention.

**Figure 4.** Link trainer

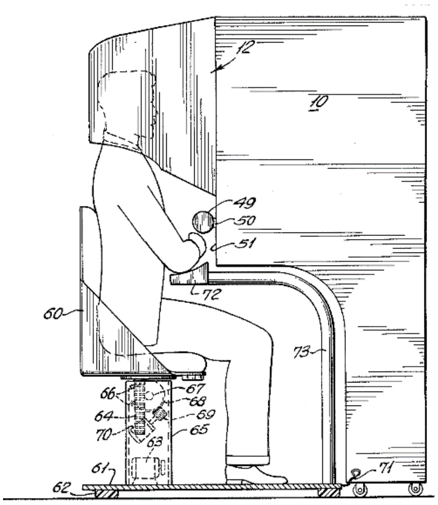


**Figure 5.** Sensorama

*Telesphere Mask*

Heilig's VR invention was the "Telesphere Mask", one of the first head-mounted displays (HMDs) (Figure 6). It provided stereoscopic and wide-angle vision with stereo sound, although it was not interactive and could not track the user's movement (VR Society, n. d.).

*Headsight*

In 1961, two Philco Corporation engineers, Comeau and Bryan, built the Headsight, a precursor to today's HMDs, with the ability to track the user's movement (Alqahtani et al., 2017). This incorporated a display for each eye and a magnetic motion tracking system, which was connected to a closed-circuit camera (Figure 7). It allowed the viewing of dangerous situations and was used by the military. Head movements moved a remote camera, allowing users to physically look at the environment.

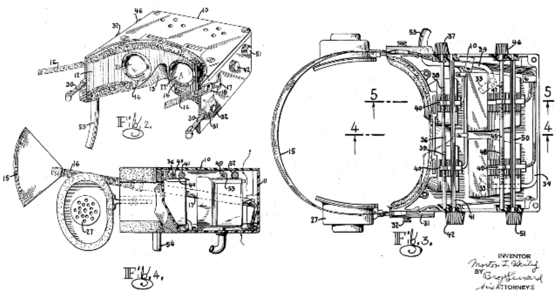


**Figure 6.** Telesphere Mask

**Figure 7.** Headsight

*Sword of Damocles*

Sutherland and Sproull, in 1968, created the first Virtual/augmented reality display, the Sword of Damocles, which was connected to a computer (Sutherland, 1968). The device was large in size and heavy in weight (Figure 8). The basic idea was to reproduce a 3D image in the user's field of view that changed each time the user's position changed. To achieve this, it projected a 2D image into each eye so that the brain could combine both into one 3D image. When the user moved, the position and orientation of the head could be detected and the corresponding image could be altered.

Despite all these inventions, there was no common term that clearly described this evolving field of technology. In 1987, Lanier (Figure 9) introduced the term "Virtual Reality" (Lewis, 1994). His company developed a range of VR tools, including Dataglove (with Zimmerman) and the HMD EyePhone, a precursor to modern HMDs.

Room-scale systems were also developed, such as vehicle simulations and the CAVE Automatic Virtual Environment (CAVE) (Figures 10 and 11). Vehicle simulations have evolved technologically a lot compared to the Link trainer and an example was the simulation of a school bus. The first CAVE system was created in 1992 by Cruz-Neira et al. (1992). It is a room with projection screens on the walls, floor and ceiling, projectors, speakers, stereoscopic glasses, and a controller, all synchronized with each other. CAVE systems also provide photorealism, stereoscopy, and guided interaction. A large number of participants can watch the virtual world when the CAVE is in the form of a dome/theatre/cinema. There are disadvantages related to high implementation costs, maintenance, and space requirements (Havig et al., 2011).

**Figure 8.** The Sword of Damocles

**Figure 9.** Jaron Lanier

**Figure 10.** Vehicle simulation

**Figure 11.** CAVE

In the late 1980s and early 1990s, the enthusiasm for the future of VR was high and everyone thought that similar systems would soon be massively available at low cost. This enthusiasm was clearly seen at the SIGGRAPH '89 (Conn et al., 1989) and '90 (Barlow et al., 1990) conferences. However, by the mid-1990s, one by one the companies of commercially available VR devices were either closing down or turning to other products, having as a result few to remain active. The market for HMDs began to collapse for a number of reasons, primarily because it could not give users what it promised in VR entertainment.

Indeed, the cost of the devices was disproportionately high for the experience they provided. For example, the entry-level HMDs started at around $500 (such as Sony's Glasstron Lite PLM-A35), but had a very low screen resolution. Other devices were as high as $5,000 (such as Liquid Image's MRG 3C), which had better resolution. In fact, commercial HMDs had a cost as high as $100,000, such as Kaiser Electro-Optics Inc.'s SimEye SR100A (Figure 12), which was used by the US Air Force. Thus, VR, which at one point, was synonymous with the future, began to fade in people's minds. Simply put, there were no "value for money" devices. The *coup de grâce* to VR was given in 1995 with the advent of the Internet. Suddenly, everyone wanted to be "connected" in this new "space," which could not (yet) be rivaled by VR.

**Figure 12.** SimEye SR100A

Coming to the present day, thanks to technological developments, there has been a renaissance of VR. For example, in 2012, a young entrepreneur, Palmer Luckey, created an HMD, the Oculus Rift, which became commercially available at a cost of about $300 and with very good technical features (Figure 13). Later, in 2016, HTC's HTC Vive and Meta's Oculus Rift CV1 became commercially available (Figures 14 and 15). In 2019, the Oculus Quest was released (Figure 16). Oculus Quest 2 followed a year later; both devices were widely accepted by consumers (SuperData, 2020), with a slew of other HMDs in development (such as Meta Quest 3, released in 2023 and Apple's Vision Pro, also released in 2023). Thus, it is predicted that devices with displays offering higher resolution and featuring more powerful processors will become available. VR will also incorporate AI and connectivity to the Internet at the speeds offered by 5G. Perhaps, in the future, holograms will replace these devices entirely.

It's worth noting that there are several very expensive HMDs that are commercially available. One such example is the Vision 8K X, from Pimax (Figure 17) used by car companies, surgeons, and architects. Vrgineers' XTAL and Varjo's XR-1 are similar. These types of devices will be discussed in detail in the next chapter.

**Figure 13.** Oculus Rift DK1

**Figure 14.** HTC Vive

**Figure 15.** Oculus Rift DK1

**Figure 16.** Oculus Quest

**Figure 17.** Vision 8K X

# Chapter 2. Head-mounted displays

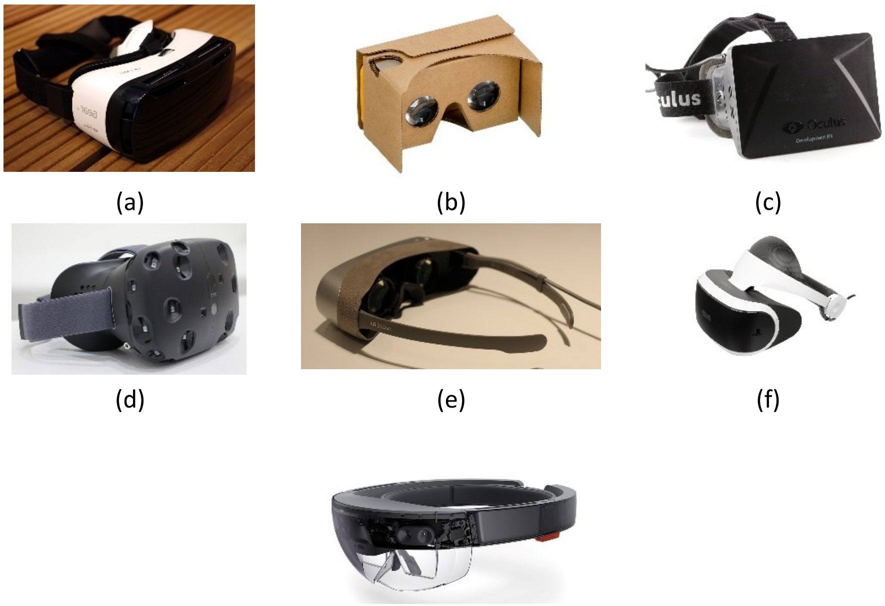
It is a fact that, since the beginning of the 21st century, there have been quite significant technological developments regarding the devices and, in general, the electronics used in VR. A notable portion of these developments concerns HMDs. They encompass a wide range of devices, depending on whether they are related to Virtual, Augmented, or Mixed Reality. Thus, in this chapter, HMDs related to VR are examined in detail, analyzing their function, technical characteristics, and application areas.

## 2.1. Conceptual framework for Head Mounted Displays

HMDs are imaging devices that are worn on the head, have lenses, and, in most cases, small screens for displaying images (Gartner Glossary, n.d.). HMDs differ in whether they can display only computer-generated images or combine images from the physical world and computer-generated images (Figure 18). The first case concerns VR while the second concerns VR augmented or Mixed Reality.

HMDs have found application in several VR disciplines, such as Mathematics, Physics, Architecture, health sciences, but also for entertainment (Schneps et al., 2014; Shibata, 2002). For example:

- Entertainment. It could be said that the pioneer in games using HMDs is Sony who created the PlayStation VR supported by the PlayStation 4 gaming console. Most applications for HMDs are games.
- Engineering. Engineers use HMDs to project stereoscopic images in order to create drawings/views (e.g., Wheeler, 2016).
- Health sciences. Health sciences is a field that has been positively influenced by this technology. As an example, HMDs have been used in the training of surgeons and anesthesiologists (Liu, et al., 2010).
- Army. There are many examples of research that addressed military training, with the main aim of developing skills related to technical and procedural issues (e.g., Song & Song, 2019; Taylor & Barnett, 2013). The military, police, and fire departments use HMDs to provide these professionals with information such as maps or thermal imaging data. One of the first applications involved the use of HMDs for paratroopers (Thompson, 2005).
- Training and simulation. HMDs are also applicable to education. They are widely used in Mathematics, Physics, Architecture, and, in general, in fields related to the study of physical phenomena (Freina & Ott, 2015). They simulate situations that are either economically unfeasible to do otherwise or safer to study through a virtual world (e.g., electrical engineering education) or impossible to study otherwise (e.g., planets).



(a) (b) (c)

(d) (e) (f)

(g)

**Figure 18.** Various HMDs
(a) Samsung Gear VR, (b) Google Cardboard, (c) Oculus Development Kit 2, (d) HTC Vive, (e) LG 360VR, (f) Playstation VR (PS VR), and (g) AR Hololens

## 2.2. Principles and operating elements of Head Mounted Displays

All HMDs, in general, work in a similar way, which is none other than to transmit images and sound to the person's respective sensory organs, with the help of lenses, screens, speakers, and sensors (Figure 19) (Ezawa et al., 2016). In terms of sound, all HMDs use the same technology (headphones) to enable someone to hear what is happening in the virtual world. However, this is not the case for the image, as there are different approaches to this issue, but they have an impact on the quality of the generated image. The method that will ultimately be chosen to be embedded in an HMD depends on the manufacturer. It could be said that it is a matter of commercial policy and strategy, as, for example, a company may choose to incorporate a low-quality display in device A in order to market a product more affordable to the average consumer, whereas it may choose to incorporate a high-quality display in device B because it wishes to market an advanced device, believing that it will make a profit because of this quality feature. Also, the lenses used in HMDs are not all the same. The same applies to processors in autonomous systems, as well as in controllers. It is therefore necessary to present some basic principles of operation and characteristics of HMDs, in order to provide a more complete picture of how they are built and operate.

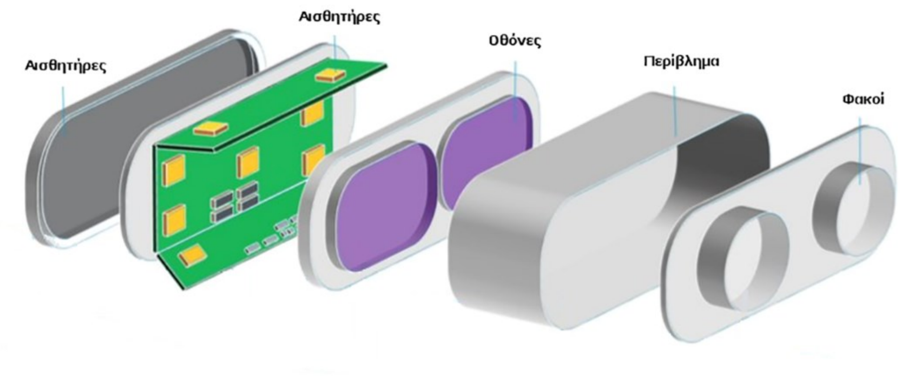


**Figure 19.** The basic parts of an HMD

*The position on the head and near the eyes*
An HMD is a device that is placed on the user's head. This position seems to have originated from the first devices made, such as the Headsight (Alqahtani et al., 2017), which enabled the user to move their head and, at the same time, remotely move a camera to physically look at the environment. The position of the device on the user's head means close proximity of the screen to the user's eyes. This close viewing distance was chosen by the manufacturers for practical and substantive reasons discussed below.

*The weight and fit*
The weight of the HMDs and whether they can be fitted to the head plays an important role in each individual's experience. Given that the display lenses and computing components are located in front of the user's eyes, that's where the most weight is found. Thus, pressure is usually exerted on points such as the nose and cheekbones, resulting in some discomfort. Indeed, when a person takes the device off, after a certain period of time (e.g. half an hour), red marks appear on his face. Most HMDs have a special foam material around the user's eyes and nose to make them as comfortable to use as possible. Also, due to the direct contact with the user's skin, sweat is produced and the pad should be washed regularly. For this reason, special disposable masks (similar to simple surgical masks) have been created that have an opening for the eyes, but protect and keep dry the rest of the rest of the face that comes into contact with the device.

Placing electronic components inside HMDs in a balanced way is very important, otherwise, the center of gravity may shift in one direction (left, right, or forward). Furthermore, when it is a type of HMD that requires the use of a mobile phone (see Chapter "2.3. Presentation of different HMDs"), then the weight of the second device should be taken into account. Furthermore, the fit of HMDs also depends on whether they include adjustable straps at enough points to allow each user to adjust them accordingly, to their face and head. Furthermore, those users who wear glasses should check whether there is enough space for them on the HMDs and, in special cases, an order can be placed with such lenses built-in.

*Use of lenses*
Viewing through a lens shows a distorted object. Taking simple glass as an example, when a beam of light passes through it, it bends and changes direction. Lenses bend light in a specific way depending on their type. The properties of a lens are derived based on Snell's Law of Refraction of Light (Encyclopaedia Britannica, 2020):

- The refractive index describes how much a material can bend the light that enters it. Curvature indicates the slowing of light; as it enters the material, the more it slows down, the more it bends. For example, in air, light bends very little, whereas in water and glass, it bends quite a bit.
- The angle of the material in relation to the angle of light. Light bends depending on the direction of the light and the shape of the lens, the time it takes for the light to exit the lens (lens thickness) and the wavelength of the light.
- Chromatic aberration separates the colors of light as it bends through a lens.

In all HMDs, for image viewing, there should be two lenses (one for each eye) and one or two small projection screens in front of the user's eyes (Takala, 2017). The lenses, in essence, magnify the image of the small screens and thus, the feeling of a large (virtual) screen is created (Figure 19).

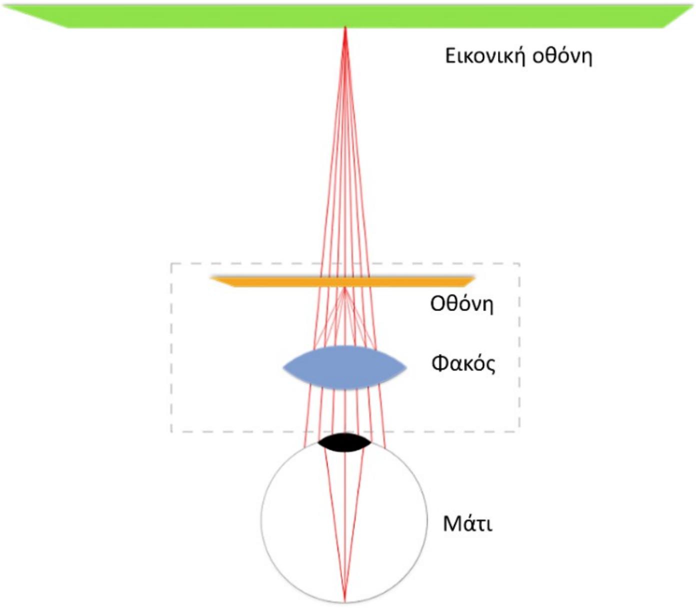


**Figure 19.** Creating a virtual screen on HMDs

It should be noted that the size of the virtual screen plays an important role in a virtual experience, as the larger it is, the larger the projection; thus, the experience becomes richer. To make it bigger, larger lenses and larger projection screens are required, resulting in an increase in the weight of the device. Not only that, but human eyes cannot focus well at close range and the field of view is reduced. The result is like trying to see around wearing blinders. Lenses, or rather, a series of lenses can provide a solution to this issue, creating devices that work in a similar way to that of cameras.

However, multiple lenses, apart from the cost, add, as already mentioned, weight, making it impractical to use them in the case of HMDs. Thus, in most HMDs Fresnel lenses are used. These lenses have a series of concentric circles that curve the light rays differently depending on the point of the lens they hit. Beyond this, as much material as possible has been removed from the lens, while still maintaining the curvature of the surface (Davis & Kühnlenz, 2017) (Figure 20).

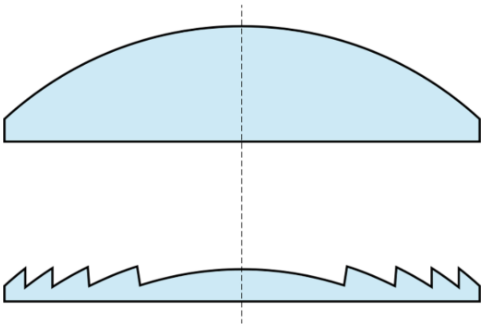


**Figure 20.** Fresnel lens construction

The idea belongs to the French physicist Augustin-Jean Fresnel, in the 18th century. He was the first to construct and install such a lens in a lighthouse to upgrade its function. Such lenses are often used as magnifying lenses and for image-making (Edmund Optics, n. d.). They can be made out of various materials. The earliest of this kind were made of glass, where sharpening and grinding were done by hand. Later, molds were used in which the glass was injected. Today, they are made of high-quality plastic, acrylic, polycarbonate, polycarbonate, and vinyl. Acrylic is the most common material, while polycarbonate polymer is used in specific cases where resistance to wear, harsh conditions, and high temperatures is required. Thus, although these lenses have a similar function to conventional lenses, they have a number of advantages, such as thin and lightweight construction, satisfactory concentration of light, and are available in various sizes.

In addition, HMDs with Fresnel lenses achieve a wide field of view without chromatic aberrations. However, because of them, a problem called barrel distortion occurs (Figure 21). This issue can be corrected by software, which creates an inverse distortion. In this way, the final image/view is distortion-free (Tom's Hardware, 2018). Many companies are designing even better lenses to provide a better solution to the latter problem. These lenses are pursuing better focus, better magnification, weight, and thickness reduction, so that HMD designers can place the HMDs screen even closer to the user's eyes, reducing the size of the devices.

**Figure 21.** Barrel distortion

*Pixels and screen resolution*

A pixel is the smallest controllable element of an image displayed on the screen (Foley & Van Dam, 1982). Each pixel can display colors and different levels of brightness. The pixel density, expressed as the number of pixels per inch, determines the quality of the image on an electronic device (e.g., computer screen, television, mobile phone, and HMD). Obviously, the higher the pixel density, the better the image quality. Another way of determining image quality is the product of the horizontal and vertical pixels on a screen, also known as screen resolution. Again, the higher the resolution, the better the displayed image. In recent years, the resolution provided by HMDs has been satisfactory. For example, a computer monitor can reach 4K (3840 x 2160), while the resolution on HMDs ranges from 2K to 8K overall (for both eyes). However, the use of lenses on HMDs creates the so-called screen-door effect. In essence, there is an empty space between the pixels that separates them, which, due to the lenses, is noticeable to users, especially when the pixel density is not high.

*Field of view*

The field of view is the area (space) that can be perceived when the eyes are fixed on a point and is measured in degrees (Strasburger et al., 2011; Strasburger & Pöppel, 2002). Each human eye has a field of view of 80 to 90 degrees on the horizontal axis, with both eyes together about 120 degrees, and if peripheral vision is included, about 210 degrees (Figure 22). The field of view of both eyes overlaps largely in the central visual field (i.e., the binocular field of view) (Aprile et al., 2014). The larger the binocular field of view, the better the focus on an object and the better the sense of space and depth (stereoscopy).

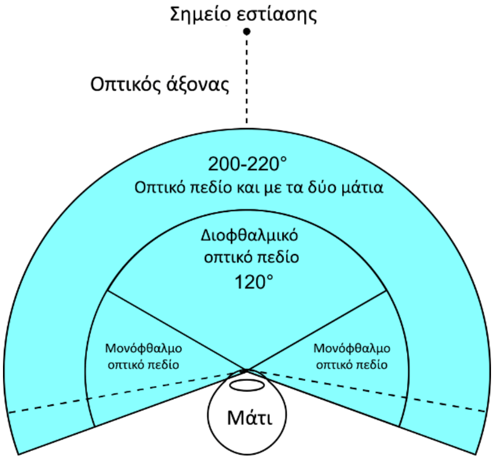


**Figure 22.** The human field of vision

Animals that are considered predators, such as tigers and owls, have similar and/or better stereoscopic vision than humans, whose eyes are also pointed in the same direction (forward). This trait (good stereoscopic vision) was retained in these animals and passed on to subsequent generations, as it enabled them to be more successful predators, enabling them to live and reproduce. In contrast, animals that are considered prey, such as rabbits and birds, have a field of view approaching 360 degrees (in some cases) and their eyes are positioned in the opposite direction (facing left and right). Their field of view is very wide for the reason that these animals need to escape quickly from predators. This feature was passed on to the generations precisely because it was functional. Some examples of the binocular and monocular fields of view of the pigeon (prey) and the owl (predator) are presented schematically in Figure 23.

Something similar to the field of view is the field of view of electronic systems. As a term, it refers to the area of space that is visible to users in real-time through devices that project an image. The field of view is also measured in degrees. It is an important feature in HMDs for the experience they offer and is usually more than 80 degrees. It is desirable to have a field of view that approximates that of the field of view of humans.

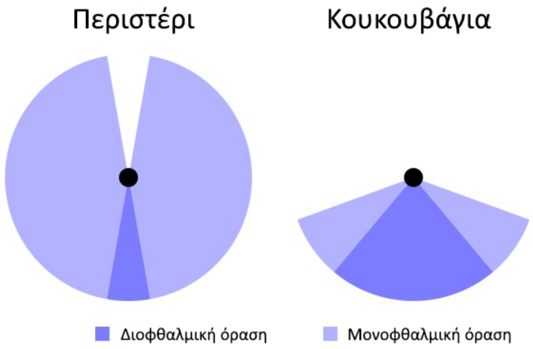


**Figure 23.** The field of view of the pigeon and the owl

*Refresh rate, response speed, and frames per second*
As mentioned earlier, the image on the screen is formed by pixels. However, the image is created by continuous scans of the screen. This process is described by the term "refresh rate". Typically, the refresh rate is in the range of 60 to 72Hz (i.e., the image is refreshed 60-72 times per second). In modern HMDs the refresh rate is in the order of 90Hz or more. The refresh rate depends, on the one hand, on the electronic components that have the role of image processing (graphics card or processor). On the other hand, it also depends on the display itself. This concerns both whether it is capable of updating the image with high frequency and whether it is capable of responding with high speed to the data coming to it from the Processor. This is known as "response time" and is expressed in milliseconds.

In videos and, in general, wherever there is a moving image, the (false) sense of movement is created by showing successive static images at a certain rate. The human brain, through the phenomenon of "afterimage,", perceives these images as motion. The rate at which the images are projected is described by the term "frames per second" (FPS). Usually, at 25 frames per second, people do not perceive interruptions and irregularities in the motion (which, obviously, is perceived below this value). However, some people are able to perceive such problems even at higher values; for this reason, the American NTSC television signal standard uses 29.75 frames per second. A computer system, including HMDs, should be able to process moving images at such a speed that the frames per second value is always kept above 25 to 30. The problem arises from particularly demanding applications (such as digital games), which, due to the heavy computational load they cause, lead to significant fluctuations in the number of frames per second.

*Visual calibration*
Optical calibration is the operation in which the lenses of HMDs are adjusted to the users' eyes. Most HMDs allow users to adjust the lenses based on the interpupillary distance of their eyes. The purpose is to provide good image quality during viewing, as long as the lenses are adjusted to the individual's measurements. This distance is measured in millimeters from the center of the eye sockets and averages between 51 and 77 millimeters in adults (slightly shorter in children).

*Display type*

Most HMDs use liquid crystal displays (LCDs). The main disadvantage of these displays is that the colors are not vivid and the black color is not exactly black, but very dark grey. For this reason, in some cases, displays with organic light-emitting diodes (OLEDs) are used. These have a layer consisting of organic plastic molecules that emit light when electricity is applied. Such displays have better color rendering, faster switching, and true black. All of these features drive richer visual experiences. There are HMDs, such as Vision 8K, that use customized low-persistence liquid displays, which have higher pixel density, as well as faster response and higher refresh rate (Engadget, 2017).

*Motion and position monitoring*

Motion/position tracking in VR is important because the user can turn their head and the scenes they see in the virtual world can change accordingly. Furthermore, they can walk in the virtual space, grasp virtual objects, and interact with them. Thanks to technology, information about the user's position and orientation is constantly provided, which helps to optimize the user's experience. In electronic devices there are three main types of technology for tracking the movement and position of a body, active, passive, and hybrid (Takala, 2017):

- Active consists of devices that emit a signal. Such monitoring systems are, for example, mechanical, magnetic, and ultrasonic monitoring. Usually, they require a wireless network connection, a Global Positioning System (GPS), or a mobile phone network.
- Passive monitoring uses devices that receive a signal from sensors, such as the gyroscope, accelerometer, and compass.
- Finally, hybrid monitoring consists of devices that are active and passive at the same time (as in mobile phones that combine computer vision and inertial monitoring).

More specifically, some of the types of active and passive monitoring used in devices are as follows (Takala, 2017):

- Mechanical tracking, active. It involves special arms, is highly accurate, and has haptic feedback, but is expensive and the devices are relatively difficult to use.
- Magnetic tracking, active. It is fairly accurate but requires a cable connection, is very expensive and has limitations on the movement.
- Inertial tracking, passive. This type of tracking measures the angular rate of orientation of a body using sensors such as the accelerometer, gyroscope, and magnetometer. The accelerometer, often used in inertial navigation systems for airplanes, measures acceleration forces (either static, such as the acceleration of gravity, or dynamic, caused by changes in velocity or direction of motion) (Christiansen & Shalamov, 2017). The gyroscope, which is also often used in inertial navigation systems for airplanes and missiles, is a device that can maintain a constant orientation through the rotation of its parts and the principle of conservation of angular momentum. Gyroscopes oscillate at a relatively high frequency (they are among the most energy-intensive motion sensors) (Christiansen & Shalamov, 2017) and are excited, relatively easily, by a loud sound or a vibration. A magnetometer (the simple compass) is an instrument used to measure the direction of a magnetic field. Furthermore, the magnetometer in electronic devices measures the Earth's magnetic field along the three vertical axes and gives data on the course of, for example, an airplane when in autopilot mode (Acar & Shkel, 2008). VR supports rotational tracking of HMDs and other input devices. Advantages of the sensors are that they do not need a transmitter, they

are low cost and small size since they belong to the microelectromechanical systems (Clarke, 2016), which are from 20 micrometers to one millimeter in size (Gabriel et al., 1988).

- Optical tracking, passive. It works through image processing and computer vision.

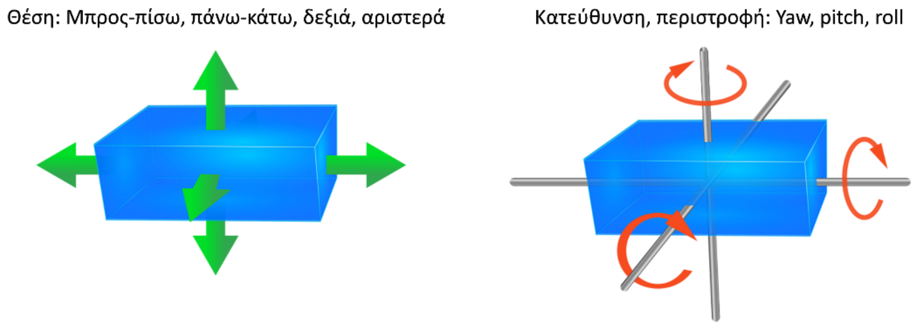
More generally, there are various types of motion/position monitoring/recording on HMDs that use some of the above methods, alone or in combination:

- Outside-in tracking: external sensors and/or cameras are used to accurately track the position of the HMD within a defined area, usually on a room-scale. For greater accuracy, users should install more than two sensors.
- Inside-out tracking: an HMD uses one or more cameras to track its position, with or without the help of markers. This type of tracking is generally less powerful and accurate than outside-in tracking.
- Hand tracking. Another type of motion tracking is that of users' hands. Most HMDs allow hand tracking either through the controllers or through sensors (e.g., Leap Motion). This enables users to interact accurately and more "freely," i.e. in a relatively natural way with the content of the application.
- Eye tracking. Another type of tracking is that of the user's eye movement which is a function of HMDs that tracks the user's gaze. Few HMDs have this feature as the technology is still complex.
- Full body tracking. This type of tracking usually consists of a very sophisticated system with many detectors and is not aimed at the average user because of its high cost. It is usually used for the production of motion pictures.

*Degrees of freedom*

Degrees of freedom (DoF) express the number of ways a rigid object can "move" within 3D space, by turning human/physical motion into motion within the virtual environment (Pennestri et al., 2005). HMDs and input devices (e.g., controllers) have 6 or 3 degrees of freedom (6DoF and 3DoF). The six degrees of freedom describing each possible motion of an object are as follows (Figure 24):

- Position: three for movement along the axes that can be considered as forward or backward, left or right, and up or down.
- Direction: three for rotational movement around the x, y, and z axes, also known as "pitch" (pitch, up-down), "yaw" (yaw, right-left), and "roll" (pitch/roll).


Θέση: Μπρος-πίσω, πάνω-κάτω, δεξιά, αριστερά

Κατεύθυνση, περιστροφή: Yaw, pitch, roll

**Figure 24.** Position and direction in HMDs

3DoF HMDs allow tracking of the user's rotational movement, but not their movement. That is, individuals wearing an HMD, only whether they are looking left or right, turning their head up or down, and whether they are turning left or right can be determined. It should be noted that by using the mouse or controller there is the possibility of six degrees of freedom, which are not real but simulated.

6DoF HMDs allow for the tracking of both motion and rotation. Thus, it can be determined whether a user has rotated their head and whether they have moved.

Degrees of freedom are important for virtual experiences, as they give the user the freedom to explore places, process details and experience real-life experiences. It is worth noting that 3DoF HMDs are typically cheaper than 6DoF HMDs. With 3DoF HMDs, it is possible to watch 360° videos or images and view the interior of a house before buying it. On the other hand, with 6DoF HMDs, in addition to the above, there is, for example, the possibility of disassembling the mechanical parts of a vehicle, simulating the preparation of a meal, and having fun with action games where the user has to avoid objects.

*Central Processing Unit-CPU*

The CPU is a central component included in almost all electronic devices. Its role is to process data, control, and perform basic system functions. CPUs in computers are much more powerful than those found in simpler and smaller devices. The evolution of the processors of stand-alone HMDs (see Chapter "2.3. Presentation of different HMDs") has been significant in recent years. A typical example is the Snapdragon XR1 which can support high image quality without high power consumption (Qualcomm, n. d.). Furthermore, this processor, in addition to VR and Augmented Reality, can also support Extended Reality (eXtended Reality). Its successor, Snapdragon XR2, supports 5G networks, tracking of user movement by cameras, 3K screen resolution in each eye, artificial intelligence, and high-quality 3D audio (Road to VR, 2019).

*Ways of viewing the virtual experience*

A user, wearing an HMD, can choose three different positions (styles) to experience a virtual experience (Blurbusters, 2019):

- Sitting position (sitting down). A user sitting in a chair, or other fixed point can enjoy experiences such as movies, 360° videos, driving, and flying while lying down. This feature is available on all HMDs.
- Standing up (static) position. This position makes users immerse themselves in the virtual experience more than the previous position. Furthermore, they can participate in virtual games, play sports, and compete with other players. This feature is also present in all HMDs.
- Room-scale. This mode allows users to be fully immersed, as they can move freely in physical space, and, therefore, in the virtual environment, in all directions, without the constraints of the previous positions. In this case, a kind of security is provided. To avoid accidents, when the user approaches an object (such as a piece of furniture or a wall) in the real world, a "grid" appears in the virtual world. This is a virtual wall to demarcate the application space. Room-scale exists in the 6DoF HMDs, while the presence or absence of wires provides a different user experience.

*Latency (latency)*

Latency refers to the processing speed and the system's response time to a change observed in it (Stackpath, 2019). On the Internet, it is also referred to as lag, the delay that exists between sending a "packet" of information and receiving it. The term lag is also used in digital gaming to convey the delay that occurs between a user action and the system's response to it, due to the high computational load. In a virtual experience, especially in HMDs, it goes without saying that the latency should be as short as possible. For example, between 20 and 25 milliseconds is considered good enough. The lower it is, the more natural the user's movements in the virtual environment, resulting in greater satisfaction, usability, and a better experience. Note that low latency depends on the speed of the particular processor.

*Cooling*

The temperatures generated during the operation of computing components in HMDs are quite high. For this reason, manufacturers have usually made sure that there is enough ventilation, and some have created special cooling systems.

*Audio*

Sound in electronic devices is produced either by the users or by the devices. Just as a good speaker system in a cinema or television plays a big role in the viewers' experience, in HMDs, sound plays an equally important role in a remarkable immersive user experience (Headphonezone, 2020). HMDs have built-in speakers, headphones, and a microphone. The microphone in HMDs enables users to communicate with other people in a virtual game or use voice control.

The way people perceive sound in real life is binaural audio, i.e. it is perceived by both ears (AR VR Journey, 2017). Something similar is being attempted by those involved in creating software to produce sounds on electronic devices. The aim is to simulate the way people perceive sounds. In particular, the sound produced by an electronic device depends on concepts such as spatialization and localization (Takala, 2017). Spatialization is the processing of sound signals to make them appear to come from a specific point in space (e.g., left, right, back, and front). On the other hand, localization is the ability of people to identify the source of a sound, which is not equally strong across individuals. As a result, 3D sound is generated, which gives sound information in the x, y, and z axes. Given that simple stereo headphones are used in HMDs, a simulation of 3D sound is performed. In any case, this type of sound increases the possibilities of interoperability between the user and the system (Upload VR, 2017).

*Controllers*

The function of the input devices is to (continuously) transmit information to the virtual application in question. They are, usually, tangible objects (such as controllers) that "bring" information from the outside (the user's movements) to the inside (the system) (Takala, 2017). There are devices that record information and do not require tangible objects (such as inertial systems, that have already been mentioned). At this point, however, the interest is focused on user-operated devices and, in particular, the controllers.

The controllers can be (Takala, 2017):

- Fixed, like those for vehicle simulations.
- Non-tracked handheld controllers, with which the user can focus on an object and point-and-click on it.
- With motion tracking (tracked handheld controllers), which the user holds in his hands, and can have great freedom of movement.
- Hand-worn devices. Typically, these are special gloves with which the user can enjoy haptic feedback and a rich interplay of gestures. Previously, gloves were wired while, today, most are wireless (VR Times, 2020). An extension of these devices are full-body suits that, among other things, provide haptic feedback to many parts of the body.

- Bare hand input (bare hand input). There are two ways of generating this type of data: (a) through a special device attached to the HMD, such as Leap Motion, which records hand movements, and (b) through the HMD's cameras combined with computer vision. This technology is discussed in detail below.

The most widely used controllers have small buttons for various functions (such as the main menu and rotation), grip and triggers for item selection or object throwing, a joystick, and a touchpad or trackpad (Figure 25). All of these, with slight differences depending on the manufacturer, support 6 degrees of freedom. Usually, there are two in number (one for each hand), giving users great freedom of movement and a pleasant experience. On the other hand, there are also controllers that support only 3 degrees of freedom. In this case, there is usually only one controller, which acts as a pointer. Users can focus on an object and point-and-click it in, for example, to turn it on, move it, or stop it. This type of controller is used for simple applications and conventional use, such as watching a 360° video, and for non-complex games and applications. Naturally, this controller does not provide much freedom of movement and limits the users quite a bit.

On an HMD the controllers may be absent and users may have to focus the device itself on a point on the screen (e.g. in the center) in order, for example, to change room or area. This is often used in 3DoF HMDs.

**Figure 25.** 6DoF controllers

Furthermore, in 6DoF HMDs, in addition to the controllers, there can be an alternative way for users to mediate with the virtual environment. In particular, some enable users to interact with the virtual environment using only their hands and without any controllers (bare-hand input). In this case, the HMD receives data either from an external device adapted to it (e.g., Leap Motion) or from its built-in cameras and, in combination with computer vision, tracks the hands in real-time (Vrscout, 2019). This creates a 3D model of the user's hands, predicting their position and joints. Users can control content, type text, do "screen scrolling," and, almost everything they would do with their real hands.

This feature is still being refined, as there are some issues in fast-paced applications (e.g., in games) resulting in losing motion tracking. There can be a strange sensation for users when they "grab" a virtual object but have no feeling in their hands, so the lack of the sense of touch is a challenge.

*Simulator sickness*

Simulator sickness (or virtual reality sickness, or cybersickness) is a kind of motion sickness (or transportation sickness) that some users of HMDs may experience to an intense or less intense degree.

It was first observed in pilots during their training in flight simulators. It is manifested by symptoms of nausea, headache, and vertigo, which can be particularly severe.

There are two theories about how it is created. The first argues that it occurs in VR because the moving images do not keep up with the (real) movement or stillness of the body (Kasahara et al., 2014). While the eyes convey the information to the brain that the body is moving, but the inner ear (and specifically the labyrinth) that controls balance conveys the information to the brain that the body is still. The second theory argues that unfamiliarity is the determining factor. This means that the situations that produce simulator sickness are those with which individuals are least familiar. For example, seasickness on a boat is, for many, a transient problem that resolves itself once they have traveled several times in that mode. Thus, the experience of a "different" motion, such as that in a virtual environment, is thought to lead to an inability to maintain orthostatic control, and this lack of control causes simulator sickness until the user adapts. Experiments have demonstrated that the onset of orthostatic instability precedes other symptoms (Stoffregen et al., 2000).

At present, neither theory seems to be able to explain adequately the phenomenon. What is certain is that simulator sickness, in addition to being individual dependent (not everyone manifests simulator sickness with the same intensity either) may be due to several factors, such as, the time of HMD use, low refresh rate, increased response time, and unadjusted lenses. In any case, it can have a particularly negative impact on the experience of using HMDs (e.g., Bradley & Newbutt, 2018; Jensen & Konradsen, 2018; Snelson & Hsu, 2019). One way to reduce the chances of a person experiencing simulator sickness is by reducing the image quality at the periphery of the field of view by simulating people's peripheral vision being more "blurred" than the central vision (foveated rendering). At the same time, this technique achieves the reduction of the computational load.

## 2.3. Presentation of various HMDs

HMDs can be divided into categories depending on whether they are:

- Tethered HMDs. In this category, HMDs function as peripheral devices that are connected by a cable to a powerful computer, which handles the processing of the graphics. Examples of devices that fall into this category are the Oculus Rift and the HTC Vive.
- Console VR. In this category, HMDs function as peripheral devices that are connected by a cable to a game console. An example of such devices is the Sony VR connected to the PlayStation.
- Based on mobile phones. In this category, HMDs do not include any electronic components. They consist of two lenses and a space into which a mobile phone can be inserted. Typical examples are the Google Cardboard and the Samsung Gear VR. The phone's screen is used to display the image, which can be quite low quality if the phone's processor is not powerful enough. Therefore, the quality of the experience is low compared to the other categories.
- Untethered HMDs. In this category, HMDs do not function as peripherals to another electronic device, but operate autonomously. These HMDs consist of two lenses and have a 'small' computer that resembles in its capabilities a very sophisticated mobile phone. Depending on their capabilities, their cost and the quality of the experience they offer varies. Typical examples are the Meta Quest 1, 2, and 3.

Table 1 shows the technical characteristics of some 6DoF HMDs and Table 2 shows the technical characteristics of some 3DoF HMDs.

**Table 1.** Comparison of specifications of 6DoF HMDs

| **Device** | **Oculus quest 2** | **Oculus quest** | **Oculus Rift CV1** | **HTC Vive** | **StarVR One** | **PIMAX 8K X** |
|---|---|---|---|---|---|---|
| **Type** | untethered | untethered | tethered | tethered | tethered | tethered |
| **Circulation** | 2020 | 2019 | 2016 | 2016 | 2018 | 2018 |
| **Screen type** | LCD | OLED | OLED | OLED | AMOLED | CLPL |
| **Visual field** | - | 90° | 110° | 110° | 210° | 200° |
| **Screen resolution (total)** | 1832X1920 every eye | 2880X1600 | 2160X1200 | 2160X1200 | 2928X1830 | 7680X2160 |
| **Pixel Density** | - | 538ppi | 450ppi | 461ppi | 426ppi | 801ppi |
| **Refresh rate** | 72-90 Hz | 72Hz | 90Hz | 90Hz | 90Hz | 120Hz |
| **Latency** | - | 13.9 ms | Depends on the processor | Depends on the processor | Depends on the processor | Depends on the processor |
| **Processor** | Snapdragon XR2 | Snapdragon 835 | computer | computer | computer | computer |
| **Lens settings** | IPD 64mm | IPD 64mm | IPD 58-72mm | IPD 60.8-74.6mm | IPD 60.8-74.6mm | IPD 55-75 mm |
| **Lenses** | Virtuclear | Fresnel | Fresnel | Fresnel | Fresnel | Fresnel |
| **Cameras** | Yes | Yes | No | Yes | No | No |
| **Tracking** | Inside out | Inside out | Outside-in | Inside out | Outside-in | Outside-in |
| **Weight (excluding cable)** | 403gr | 470gr | 470gr | 563gr | 450gr | 450gr |
| **Site** | 128-265Gb | 64-128Gb | - | - | - | - |
| **Cost** | 299€ | 399€ | 200€ | 399€ | 3200 € | 1.300€ |

*Notes.* C/meter = Gyroscope, VR/meter = VR accelerometer, M/meter = Magnetometer

**Table 2.** Comparison of specifications of 3DoF HMDs

| **Device** | **Oculus Go** | **Goblin** | **Pimax 4K** | **Gear VR** | **Google Cardboard** |
|---|---|---|---|---|---|
| **Type** | untethered | untethered | tethered | untethered | untethered |
| **Circulation** | 2018 | 2016 | 2017 | 2015 | 2014 |
| **Screen type** | LCD | LCD | LCD CLPL | Mobile device | Mobile device |
| **Visual field** | 100° | 92° | 110 ° | - | - |
| **Screen resolution (total)** | 2560X1440 | 2560X1440 | 3840X2160 | Up to 2960X1440 | Up to 2960X1440 |
| **Pixel Density** | 538ppi | - | 403ppi | - | - |
| **Rate of renewal** | 60-72Hz | 70Hz | 60Hz | Up to 60Hz | Up to 60Hz |
| **Processor** | Snapdragon 821 | Snapdragon 820 | computer | mobile device | mobile device |
| **Lens settings** | No | - | Yes | No | No |
| **Lens Lenses** | Fresnel | - | - | - | - |
| **Built-in camera** | No | No | No | No | No |
| **Tracking** | Head movement | Head movement | Head movement | Head movement | Head movement |
| **Weight (excluding cable)** | 468gr | 440gr | 499gr | 345gr | 96gr |
| **Battery** | Yes | Yes | No | Yes | Yes |
| **Site** | 32-64Gb | 16 Gb | 10 Gb | SD card | SD card |
| **Cost** | 283€ | 243€ | 409€ | 130€ | 5€ |

# Chapter 3. The main features of Virtual Reality

Several characteristics have been identified in the literature as important for VR. However, there are conflicting views on three very important ones, those of immersion, presence, and interaction, both in how they are defined and how they shape the user experience in the context of VR. For example, there is much debate about the extent to which immersion affects the sense of presence. Further, immersion, while relatively easy to describe, is nevertheless difficult to define. When children are "glued" to a television show, one can say that they are immersed. In fact, if they do not answer the questions asked of them (or are indifferent to answering them), it is a way to measure the degree of their immersion. However, the above example is obviously not a coherent definition of immersion. On the other hand, it can be an indication of how complex the phenomenon is, since a similar experience is created by reading a book or watching a film. Furthermore, regarding the sense of presence, there are researchers who have argued that it depends solely on the equipment used (e.g., North & North, 2016). Others have argued that presence is largely dependent on the personality of the individual (e.g., Bindman et al., 2018; Nunez, 2004).

Furthermore, users entering a virtual environment, in order to get the sense of being somewhere else (which, as will be analyzed below, constitutes immersion) and that the virtual world is real (which is an element of presence), need, first of all, to give value to what they are doing/experiencing. Thus, in order to have a positive experience in a virtual environment, they need to develop their mindfulness. Mindfulness is the awareness of the present in which individuals are "open" to experiencing the feelings and sensations of the present without judgment (Brown et al., 2007; Davis & Hayes, 2012). In a virtual environment, users need to be able to observe the environment and its elements without going on "autopilot" and simply act because the application asks them to. In other words, they should be convinced from the outset that they should be able to let themselves be drawn into the experience and, under no circumstances, see it as a "chore," especially if it includes educational content. Usually, mindfulness is considered in research on issues such as reducing anxiety through VR, where it was found to have an inverse relationship, i.e., when mindfulness increases, then anxiety decreases (Crescentini et al., 2016).

Thus, this chapter will attempt to identify important terms/concepts related to VR that affect and, in essence, define the user experience, starting, first, with a brief reference to the 3Is of VR.

## 3.1. The three Is of VR

Burdea and Coiffet (2003) introduced the term "3Is" (interaction, immersion, imagination-3Is), which, in essence, identifies the characteristics required to ensure that users feel engaged in a virtual environment. The authors described these three attributes as the triangle of VR (Figure 26).

In particular, they argued that:

- Interaction refers to the communication and connection between the user and the VR system.
- Immersion relates to the user's sense of being in a virtual environment.
- Imagination refers to the user's ability to perceive non-existent things and to believe that the virtual environment in which he or she finds himself or herself is real.

Furthermore, according to them, the levels of interaction and immersion can directly influence users' imagination, which, in turn, depends on other characteristics (e.g., type of equipment, degree of realism, and motivation) (Burdea & Coiffet, 2003).

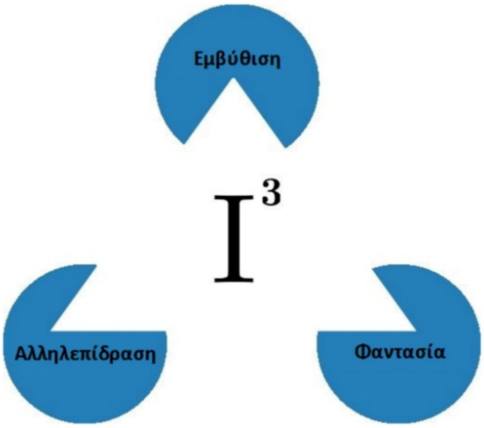


**Figure 26.** The 3Is of VR
(Burdea & Coiffet, 2003)

## 3.2. Immersion

According to Mikropoulos and Bellou (2006), an immersion system includes 3D spatial representations, multi-sensory interaction channels, and intuitive interaction with real-time physical manipulations. Extending what Mikropoulos and Bellou mentioned, it can be argued that immersion is the ability of the VR system to provide users with stimuli (visual, audio, and tactile) and a sense of being somewhere else (MacLeod & McLeod, 1996). In this sense, immersion is technical, as it depends on how sophisticated the VR devices used to create this sensation for users are. Therefore, using a less sophisticated HMD offers less immersion than using a more sophisticated one, due to the lower resolution and field of view. Therefore, in a fully immersive state, users either receive the same sensory information as in the real world or the perception of reality is replaced by the computer-generated perception; in either case, the brain cannot capture the difference between virtual and real environments.

Furthermore, immersion, in psychology terms, refers to the state in which individuals are fully engaged in something while acting (Muhanna, 2015). In other words, during immersion, users are attracted to and involved in a virtual activity where their minds are separated from the physical space they are in. Furthermore, immersion is the sense that individuals have of being surrounded by a completely different reality that requires their attention and interest (Murray, 1997).

According to Natsis and Zacharis (2008), an immersive system is described as a VR system in which the virtual environment is displayed on special devices (e.g. HMDs) and does not include the conventional screen, which does not help to disconnect users from the real world. In particular, HMDs, stereoscopic glasses, gloves, and/or full-body suits are used to achieve a sufficient degree of immersion. However, it is not necessary to combine all devices; usually, stereoscopic glasses or HMDs alone can provide sufficient isolation from real-world stimuli.

The level of user immersion in a VR system, from a technical point of view, depends on a number of key elements, such as the degree of separation of users from the physical environment, the degrees of freedom of movement afforded to users, the mode of display, and the degree of interaction with the virtual world. In addition, to enhance the level of immersion, elements such as the performance of the software of the VR system, haptic feedback, and sound play a role. This is in line with the views of Bowman and McMahan (2007), who reported that the degree of immersion depends on many factors related to vision, such as field of view, display size and its resolution, stereoscopy, and the refresh rate of the image (these terms were discussed in the previous chapter).

It should be noted that for a virtual world to be considered immersive, it must be able to suspend participants' disbelief about whether it is "real" for a certain period of time, but without requiring it to be as real as the physical one (Pimentel & Teixeira, 1993).

Other authors (e.g., Zhou & Deng, 2009) have approached VR according to the degree of immersion and flow. Regarding the degree of immersion, when it is too low, the authors refer to it as a virtual world. When users are partially immersed in the virtual world, then it is considered moderate VR. Finally, when they are fully immersed, the authors consider VR to be achieved. Flow is a mental state where users are fully engaged, focused, and enjoying an activity either work or play, in which the challenges of the activity and the skills required are in balance (Csikszentmihályi, 1990, 2017). In fact, users in such a state lose track of time while they are focused on their task, while, at the same time, feeling pleasure.

Some of the basic types of immersion are:

- Haptic immersion. It is the experience of users in a virtual environment when performing tactile operations involving skills (Adams, 2004). For example, users can experience haptic immersion when using the controllers to perform a skill-intensive activity. In fact, the more they learn to use the controllers, the more they develop the corresponding skill and get better results.
- Technical immersion. It refers to elements that direct users' attention so that they consider themselves part of the virtual environment (Elmezeny et al., 2018). Furthermore, technical immersion was discussed by Sheikh et al. (2016). According to them, directing users' attention in a virtual environment is achieved through the combination of audio and visual information (technical immersion elements), while using only visual information does not bring the desired effect. One element they considered important is the recognition of users by the characters in the virtual world. This can occur through looks, gestures, and words that the characters direct towards the camera. Also, Sheikh et al. (2016) argued that participants need to be directed to look around or move to follow the story and immerse themselves in it.
- Narrative immersion. It occurs when users are "surrounded" by a story that unfolds in a virtual environment. In particular, narrative immersion resembles what one experiences when reading a book or watching a movie (Adams, 2004). Elmezeny et al. (2018) argued that narrative immersion is influenced by the settings, as well as by the interaction of the story and characters with the users so that they become part of the story. They also considered that it is related to technical immersion, that one genre supports the other, and that they reinforce each other. Ryan (2015) divides narrative immersion into four subcategories; (a) spatial, (b) temporal, (c) spatio-temporal, and (d) emotional. Spatial immersion concerns the environment, i.e. the setting and the time and place of the story, in other words, the way the (virtual) world is created. Temporal immersion

relates to the structure of the plot and the creation of suspense, action, and expectation that have a classical structure (i.e. beginning, middle, and end). Spatio-temporal immersion is influenced by the narrative perspective and integration of the audience within the story, and finally, emotional immersion relates to the emotions created to the participants by a story.

- Mental immersion. It is the state in which users engage with a virtual environment without distrusting it, because they experience it as believable/realistic (Sherman & Craig, 2003). For example, when a person reads a novel, they feel transported and belong to a fictional world, they become emotionally involved with the characters; they forget the real world and their environment. Something similar occurs through watching a film, listening to music, or even daydreaming.
- Imaginative immersion. It refers to the absorption of users thanks to the plot/story of the virtual environment, resulting in emotional involvement with the characters, the development of their imagination, or simply the enjoyment of the virtual environment (Ermi & Mayra, 2005).
- Sensory immersion. It refers to the concentration/attraction of users in a virtual environment induced by the sounds and images it offers (Ermi & Mayra, 2005).
- Sensory-motor immersion. It occurs when users enter a virtual environment and are mentally stimulated. There is harmony of space and time as users merge with the medium, which affects their opinion about it and their consciousness (Bjork & Holopainen, 2004).
- Emotional immersion. It occurs when users confuse the virtual environment with real life (Bjork & Holopainen, 2004). Furthermore, according to Cohen (2001), emotional immersion results in a decrease in users' self-awareness which, at the same time, is replaced by increased emotional and cognitive engagement with the characters in the virtual environment.
- Cognitive immersion. This type of immersion involves the users' abstract thinking. It is achieved through solving complex problems (Bjork & Holopainen, 2004).
- Strategic immersion. It is more cerebral and related to mental challenges (Adams, 2004). For example, chess players experience strategic immersion when they choose a solution from a wide range of options. Also, according to Ermi and Mayra (2005), this is also called challenge-based immersion, which occurs when applications require users to think strategically or solve logical problems.
- Spatial immersion. It occurs when users feel that the virtual world feels real and convincing and that they are "there" (Bjork & Holopainen, 2004).
- Physical immersion. Physical immersion occurs when people feel that they are physically involved in an experience. Those who achieve physical immersion are called participants (Sherman & Craig, 2003). For example, in a flight simulator, the user enters a simulated cockpit to be able to interact with different objects to fly a virtual plane and, in the future, a real one.
- Passive and active immersion. Nakatsu and Tosam (2005) proposed these types of immersion, which are distinguished by the lack or presence of interaction. Active immersion involves users interacting with objects (creating a scene), while passive immersion presents only information (watching a movie). According to Nakatsu and Tosam (2005), a virtual experience should contain active immersion.

### 3.3. Presence

Presence is created when users are engaged to such an extent that they feel themselves "living" in a virtual world (Schubert et al., 2001; Slater, 1999; Witmer & Singer, 1998). Furthermore, it can be said that presence is the sense of being in a virtual environment as a distinct entity (Mikropoulos & Natsis, 2011), as well as the subjective sense of "being" in it (Bulu, 2012). The above definitions imply that presence is synonymous, in a way, with the illusion of being in a (virtual) place (being there) (also referred to as place illusion). However, Slater and Sanchez-Vives (2014) added the attribute of plausibility, i.e. experiencing events as if they were real. Thus, to achieve the first element (place illusion), head tracking and/or body tracking are required. Ideally, eye tracking should also be present. These allow users to participate more naturally in the virtual environment by using the natural movement of their bodies (e.g., crouching, watching the surroundings, and listening by turning the head towards the source). On the other hand, for the second element (plausibility) to occur, three factors must be taken into account: (a) the degree to which events in the environment are specifically addressed to the participant, (b) the degree to which there are events responsive to the actions of the person (e.g., the participant smiling at a virtual person who, in turn, smiles at him), and (c) the overall response of the environment to the user's expectations (Slater & Sanchez-Vives 2014).

Furthermore, according to Lombard and Ditton (1997), presence is a psychological state in which virtual objects are perceived by users as real and also creates the illusion that the mediated environment is not mediated. A mediated experience in VR is one where in order to experience it, users have to use "mediating devices" such as a computer, HMD, controllers, and input devices (keyboard/mouse) (Kaye & Giannachi, 2011). Since these devices mediate between users and the experience, they should, logically, be "aware" of them at all times and remind them of "where" they are and "what" they are doing. However, the sense of being present in a non-mediated VR experience makes users have the illusion that there is nothing interfering between them and that experience, that they are experiencing something real. This is the main goal of VR, namely to create unmediated experiences (Schafer, 2016).

At the same time, presence is about the characteristics of the experience of VR as experienced by users (Bindman et al., 2018). That is, if the plot/story is compelling, then users will be fully absorbed by it. If the virtual world offers social interactions, as well as interactions with other users that feel real, then the virtual world will feel more real. If the interaction with the virtual world is easy and natural, then it creates an excellent presence. In this respect, presence indicates the degree to which the user feels engaged with the VR experience and how much it feels like a real experience. In essence, presence is a subjective feeling and therefore depends on the state of mind, the user's experience in the virtual environment, and other psychological factors.

Presence consists of a number of dimensions/subcategories that vary according to the purpose of the context in which they are applied. Each dimension is considered to contain the same fundamental principle, namely that users feel "present" in a virtual environment, perceiving the virtual content as real (Schubert et al., 2001). The different dimensions, however, reinforce the further distinction of the context or situation in which presence occurs. These contexts or states, which are often used interchangeably, are as follows (Zhao, 2003):

- Self-presence. According to Lee (2004), users feel self-presence in a virtual world, i.e. they experience their virtual self as real. Furthermore, according to Heeter (1992), it is also called personal presence, meaning that users feel part of the environment.
- Spatial presence. It is the sense of being in an environment (Schubert et al., 2001). It relates to the verisimilitude of presence within the mediated space, i.e. it is purely experiential. Steuer (1992) argued that in any mediated communication there is an overlap with physical presence, i.e. the real world. Furthermore, according to Heeter (1992), this kind of presence is also called environmental presence. In addition, some have further divided spatial presence into self-location and possible actions (Wirth et al., 2007). The first kind relates to the sense of being in an unmediated environment and the second relates to the perceived possibilities of action in it. Also, Kim and Biocca (1997) considered presence to consist of two concepts, arrival (the feeling that users are in a virtual environment) and departure (the feeling of being separated from the physical environment), which seem to be related to the concept of spatial presence.
- Natural presence. It refers to the extent to which the virtual environment is in agreement with reality (Witmer & Singer, 1998). Furthermore, according to Lee (2004), natural presence is a psychological state in which virtual objects are experienced by users as real objects in sensory or non-sensory ways.
- Tele-presence. It stands out because of its original context, namely the various tele-operations/tasks that can be performed (Sheridan, 1992). Steuer (1992) considered tele-presence as a distinct concept from presence, suggesting that the former refers to the experience of a secondary environment (such as the virtual) through a communication medium. Given both of these distinctions, telepresence, as related to the context of teleoperation, suggests that perceptions relate to the experience of a virtual environment in which work (i.e. interaction) can occur using a communication medium.
- Co-presence. It is a similar concept to tele-presence, but with a different dimension. Nowak and Biocca (2003) noted the distinction between these concepts in relation to connecting with other people. While telepresence can occur without the participation of another person, co-presence depends on the presence of another person who is also connected to the same medium. It is this human connection that distinguishes co-presence from telepresence, i.e. it focuses on the relationship that develops between two individuals (Zhao, 2003). Indeed, when there is a high degree of immersion, this helps users to feel co-presence with others and facilitates mutual understanding between them when, e.g., conducting collaborative research (Heldal et al., 2007).
- Social presence. Another dimension of presence is related to co-presence, but it requires the connection of a group of people (Nowak & Biocca, 2003). At the same time, Gunawardena and Zittle (1997) considered that social presence is about how reality is perceived in mediated communication and that it depends on two factors, intimacy and immediacy (Gunawardena & Zittle, 1997). According to Lee (2004), social presence in a virtual world is the interaction of people with (artificial) social characters that look very real or with the representations of other people who are connected in the same virtual environment.

## 3.4. Interaction

Interaction seems to be a somewhat simpler and less difficult concept to define than immersion and presence. As mentioned above (see Chapter "3.1. The Three I's of VR"), according to Burdea and Coiffet

(2003), interaction is about communication and connection between the user and the VR system. There are many types and technologies that contribute to and enhance human-computer interaction and communication. One of the main goals of VR is to have, to the highest degree, natural interactions of users with the virtual environment and the virtual objects it contains (Rebelo et al., 2012). Thus, the dimensions of the interaction between the user and VR system are as follows:

- Navigation. Whether or not navigation is available.
- User interface. This refers to the way in which the various interactions are implemented. There is the composite user interface which involves interaction with two or more senses. When it involves vision, it is called a graphical user interface, and when it involves sound, it is called a multimedia user interface. The interface in a VR system belongs to the latter case. The aim of VR is to involve other senses in the interface to create a complete interaction, i.e. as if the users were in the real environment.
- Modality. Modality, in human-computer interaction, refers to the use of sensory input/output channels between the human and the computer (Karray et al., 2008). In some ways, it is therefore related to the interface. If there is only one channel it is called unimodality and if there is more than one it is called multimodality (Karray et al., 2008). Also, there are two forms of modality (Palanque, 2001). The first is the computer-human modality, where the output devices of the VR system to give information to the users stimulate their senses (sight and hearing and more rarely touch, taste, smell, heat, pain, and balance). The second is the human-computer modality (Bainbridge, 2004), where VR systems are equipped with input devices to receive information from users. Such devices are often the keyboard, mouse, touch screen, and more rarely computer vision (a branch of artificial intelligence) and speech and motion recognition.
- Human agency, which could be related to navigation, but could also be a criterion of how much a user is able to interact with and/or manipulate a particular environment.

Furthermore, the types of interaction that users can have with a virtual environment are:

- Physical interaction. This is an interaction beyond the simple use of a keyboard/mouse, usually using controllers or just the user's hands or special gloves (Jha, 2018). It allows users to experience an activity as they would in the real world (e.g., playing tennis), i.e. very realistically.
- Magical interaction. This is an interaction that could not happen in reality (Bowman et al., 2012). Users, with this interaction, can gain superpowers or interact with fictional characters in a non-real environment (there are no restrictions on this type of experience).
- Active interaction. It refers to the interaction caused by users towards the VR system, such as clicking the mouse or selecting content with the controllers (Ferguson et al., 2020). Furthermore, they are free to choose what to see from the virtual environment without a specific viewing order being necessary.
- Passive interaction. This is the interaction that is not performed by users through input devices, but by the system itself through the detection of their location. If, in fact, the system can also track eye movement (eye tracking), then an improved interaction is achieved (Schönbrunner, 2000).
- Intuitive interaction. Intuitive interfaces are less easy to implement but easier to use. Intuitive interaction recalls past experience, is fast, accurate, and often users do not think before they act (they act unconsciously) (Blackler et al., 2019). Users can interact with interfaces and systems intuitively when they are able to apply prior knowledge to a new context of use (Naumann et al., 2007).

- Embodied interaction. This type of interaction provides the possibility for one's (physical) body to interact with the technology in a natural way, e.g. through gestures (Hartson & Pyla, 2012). Furthermore, it relates to how users perceive/understand the world and the interaction that comes from themselves in a physical and social world with embodied agents (Dourish, 2004).
- Tactile interaction. It is related to embodied interaction and, in a way, they complement each other. Tactile interaction refers to the interaction between users and objects (Ishii & Ullmer, 1997), in which some form of haptic feedback has been included.

### 3.5. Relationship between immersion and presence

The literature seems to be more concerned with the relationship between immersion and presence, while, usually, interaction is part of them. However, one can argue that the concepts of immersion and presence are not so separate and there is a grey area between them. The nature of presence is highly subjective, which makes it more difficult to define than the concept of immersion. Nevertheless, presence seems to be directly related to immersion, as several studies have demonstrated that the immersive capabilities of VR affect the subjective sense of presence (Balakrishnan & Sundar, 2011). Furthermore, as mentioned previously, immersion is a technological feature of VR systems that contributes (along with others) to the creation of the sense of presence (Natsis & Zacharis, 2008).

Immersion is important for creating presence. If a virtual world is technically sound, but experienced through a low-end HMD (e.g., one that does not allow for social interactions, has no physical feedback, and has low resolution), then the users will not be able to feel that they are actually there and, thus, the sense of presence is destroyed. This is not always the case. Even with a low-end HMD, if the plot is compelling, with great characters, and engages the users, who stay there long enough to get used to the graphics, they could feel present, because they will feel like they are living in that world. So, a user can be given a sense of presence even without a high degree of immersion.

Also, Witmer and Singer (1998) defined presence as the subjective experience of being in one place or environment, even if one is physically in another. Presence refers to the experience of the virtual environment rather than the physical location. The necessary conditions for experiencing it are participation and immersion. According to them, participation is the psychological state experienced by the individual as a consequence of a set of stimuli received, the focusing of energy and attention on important activities and events. Thus, involvement is related to other concepts similar to engagement such as "the flow state." Similarly, immersion is a psychological state of the individual characterized by the perception of being surrounded, included, and interacting with an environment that provides a continuous flow of stimuli.

However, Slater (1999), in response to Witmer and Singer, argued that immersion refers to the technical characteristics of the medium and that these characteristics affect the various senses of the user. Slater did not give immersion the psychological dimension that Witmer and Singer gave but defined it purely from a technological perspective. On the other hand, Slater (2002) agrees with Witmer and Singer in his interpretation of the concept of presence, i.e. that users feel that they are part of the virtual environment.

Presence and immersion seem to occur when the user's attention is so focused or absorbed that they participate in the digital environment and engage with the content (Oprean, 2014). This allows for the development of a framework to measure the influence one concept has on the other. For similar reasons, and as previously mentioned, Witmer and Singer (1988) argued that both immersion and participation are prerequisites for an individual to experience presence in a virtual environment.

Some have combined immersion, presence, and mediation, stating that presence is defined as the psychological state in which a user feels lost or immersed in a mediated environment, feeling physically "present" in it (Schubert et al., 2001). At the same time, according to Mikroopoulos (2016), the sense of presence is the (false) sense of non-mediation created by 3D representations, intuitive interaction, and immersion.

It is worth noting that, when researchers consider presence as a subjective sensation, they also consider immersion as an objective characteristic of technology, which refers to the extent to which a technological medium can provide the user with the (false) sense of being in a real environment (Slater & Wilbur, 1997). In conclusion, it could be said that the core of VR is presence and it operates within the boundaries set by immersion (Slater, 2009), and that VR can only be considered a sufficiently realistic experience when users feel both immersion and presence at the same time (Eichenberg, 2011).

On the other hand, the relationship between interaction and immersion can be seen through the following continuum (Figure 27), where it can be seen that low interaction and immersion exist when users use simple devices, while high when using sophisticated ones (Oprean, 2014).

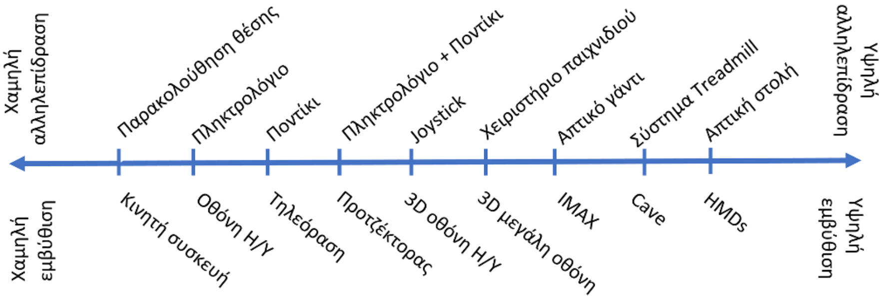


**Figure 27.** The interaction and immersion continuum
(Oprean, 2014)

In summary, Table 3 shows the types of immersion, presence, and interaction.

**Table 3.** The types of immersion, presence, and interaction

| Types of immersion | Types of presence | Types of interaction |
|---|---|---|
| Haptic immersion | Self-presence | Physical interaction |
| Technical immersion | Spatial presence | Magic interaction |
| Narrative immersion | Natural presence | Active interaction |
| Mental immersion | Telepresence | Passive interaction |
| Imaginative immersion | Co-presence | Intuitive interaction |
| Sensory immersion | Social presence | Embodied interaction |

| | | |
|---|---|---|
| Sensory motor immersion<br>Emotional immersion<br>Cognitive immersion<br>Strategic immersion<br>Spatial immersion<br>Physical immersion<br>Active immersion and<br>Passive immersion | | Tangible interaction |

## 3.6. General comments

This chapter presented immersion, presence, and interaction, which are considered the main characteristics of VR, and discussed the relationships between them. Subcategories of these characteristics were identified. In general, immersion is a more technical feature while, on the other hand, presence is considered a subjective attribute related to how much users feel that they are in a virtual environment. Finally, interaction is related to the communication and connection between users and the virtual environment.

Thus, by convention, the following definitions can be given for these three terms:

- Immersion refers to how complete/rich the sensory information provided to the user by the virtual environment. The more closely it resembles that of the real world, the higher the immersion. That is, immersion is more of an objective phenomenon and should be investigated with technical tools (e.g., technical questionnaires) and VR devices (different ones to show different levels of immersion).
- Presence refers to the extent to which users feel that they are in a virtual environment and have the illusion of non-mediation, i.e. it is more of a subjective phenomenon and should be investigated with psychometric tools (psychometric questionnaires).
- Interaction refers to the communication and connection between users and the virtual environment.

# Chapter 4. Taxonomies of Virtual Reality systems

As mentioned in the previous chapters, VR has taken a variety of forms, while keeping pace with technological developments. Despite the variations that have occurred, its main purpose has remained unchanged, which is to create rich experiences for users. VR systems vary depending on the software as well as the hardware used (Levin, 2011). When talking about software, it means the programming part (the programming platform) with which the system in question is created and supported. For example, a virtual environment may be built with the Unity platform. The hardware is the means by which users interact with the software. Typically, this consists of output devices, such as the computer screen, HMDs, and even an entire room, as well as input devices, such as the keyboard/mouse and controllers. Thus, this chapter presents some of the existing taxonomies of VR systems and proposes a new taxonomy. Also, reference is made to the different types of VR.

## 4.1 Existing classifications of VR systems

Mikropoulos (2016) proposed a taxonomy based mainly on the visual interface, including all cases win which users can perceive a virtual environment with their eyes.

Thus, he proposed the following categories of VR (Figure 28):

- Desktop VR. The computer screen (and its peripherals) is the medium of this system, it has simple 3D graphics, high resolution, and limited interaction.
- QuickTime VR-Telepresence. It is a tool that supports many types of graphics, movies and sounds, providing high-resolution images (panoramic, 360°) with limited interaction, and stereoscopy.
- Partial immersion (CAVE, CUBE, FLEX, PLEX). This category includes VR systems that provide photorealism, stereoscopy, guided interaction and allow for a large number of participants.
- Mixed and Augmented Reality. These are technologies that embed virtual objects/information in physical space. Indeed, in Mixed Reality, they coexist and interact with physical space in real-time.
- Multi-user Virtual Environments/Virtual Worlds/Distributed VR. In these environments, there is multi-user interaction, synchronicity, and a sense of presence.
- Fully immersive VR. There is a high degree of interaction and medium to high screen resolution.

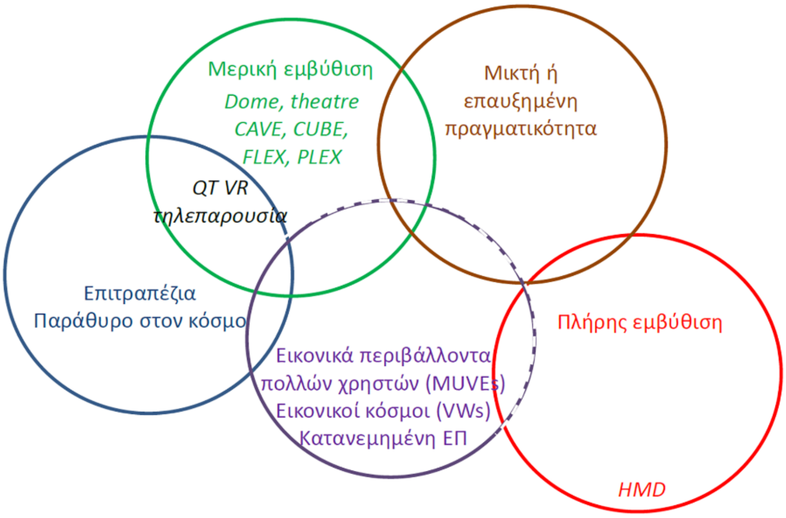


**Figure 28.** A taxonomy of VR systems
(Mikropoulos, 2016)

Muhanna (2015) set out two criteria for creating her taxonomy. The first was the type of technology used to build each system, i.e. the need for special input/output devices to experience VR. Systems that do not use such special devices were termed "basic," while those that require them were termed "enhanced." The second criterion on which it was based was the level of mental immersion of the user in a virtual environment. Immersion, as discussed in a previous chapter (see Chapter "3.2. Immersion"), is indeed a psychological phenomenon, but it is caused by the use of specific devices. Furthermore, Muhanna used the term mental immersion, i.e. something purely subjective. Thus, she considered that VR systems vary based on the degree of mental immersion they provide to users (Figure 29).

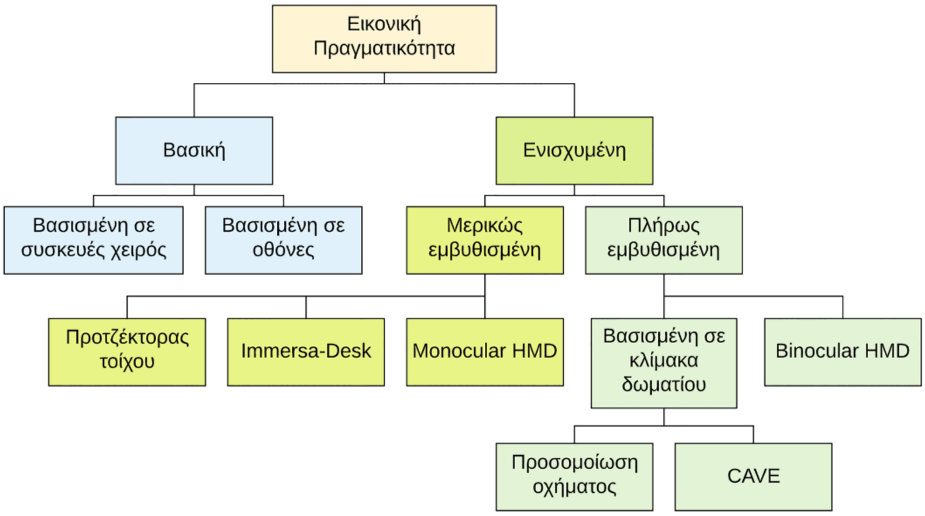


**Figure 29.** Another taxonomy of VR systems
(Muhanna, 2015)

Basic VR includes screen-based (computer-based) and handheld-based VR. Both provide very low intellectual immersion. On the other hand, Enhanced VR is divided into Partially Immersive VR and Fully Immersive VR.

Partially immersive VR includes:

- Wall projectors. In this system, no stereoscopic glasses are used and interaction with virtual objects is done through special gloves. It should be noted that it does not project objects in three dimensions.
- Immersa Desk. The user wears special glasses to view the content (3D object) on the projection screen.
- Monocular HMD. The user is able to view, in combination, virtual and real objects through transparent screens. Alternatively, they can view them with one eye and see the real world with the other. It touches on Augmented Reality.

Fully Immersive VR includes:

- Binocular HMDs. These are HMDs that provide a view from both eyes of the user that can give either six degrees or three degrees of freedom (for more details on this topic, see. Chapter "2.2 Principles and operating elements of Head Mounted Displays").
- VR based on room scale. This is further branched out to vehicle simulations and CAVE systems.

## 4.2 Proposed classification of VR systems

Regarding the first taxonomy of VR systems (Mikropoulos, 2016), the category "Mixed-Augmented Reality" includes two different technologies, which are classified together, because they have almost similar functions (since they both embed virtual objects/information in physical space). Mixed and Augmented Reality have elements of VR but are not purely VR (Milgram & Kishino, 1994). They were probably included in the taxonomy because the classification criterion was the vision interface.

Regarding the second taxonomy of VR systems (Muhanna, 2015), it is observed that the category of basic VR includes handheld-based VR, which involves the display of virtual content on the screen of a handheld device. This is an older form of VR that has been replaced, thanks to technological advances, by Augmented Reality. Furthermore, it appears that the category of partially immersive VR includes monocular HMD, which is more related to Augmented Reality, a technology, as mentioned, which is different from VR. Therefore, it should perhaps be included in another taxonomy. Furthermore, in this taxonomy, room-scale VR (vehicle simulation and CAVE) is included in the fully immersive VR. However, these systems do not completely cut off the user from the physical environment. Therefore, it should perhaps be placed in another category, for example, in the partially immersive VR, which is the case in the first taxonomy.

In any case, as demonstrated in the above taxonomies, a user can experience VR through a variety of forms and modes of presentation. Specifically, Mikropoulos' taxonomy was based on the visual interface, i.e. what the user sees, while Muhanna's taxonomy was based on the hardware and mental immersion, i.e. how much the user feels belonging to the virtual world, emotional engagement with the characters, and disconnection from their environment. Perhaps, the important criterion is immersion, as it encompasses all of the above elements.

Therefore, taking the above taxonomies as a starting point, the VR systems can be redefined, creating a new taxonomy that ranks them in terms of user immersion. It should be stressed that it was considered preferable to focus on the technical aspect of immersion, because it is difficult to identify and quantify its subjective dimension, as in Muhanna's taxonomy. Also, the proposed taxonomy includes systems related only to VR. That is, it differs from the two previous taxonomies, which included systems partially involving VR, such as Augmented and Mixed Reality, which might have to be removed altogether.

Since immersion (from a technical point of view) is considered the criterion for the proposed classification of VR systems, it should be indicated on which elements the degree of immersion depends. Thus, based on what was mentioned in Chapter "3.2. Immersion," it was considered to be a function of (a) the degree of separation of the user from the physical environment (none, partial, complete), (b) the degrees of freedom of movement granted to the user (three or six), (c) the mode of display (low-high quality), and (d) the degree of interaction with the virtual world. Note that the interaction factor was added because of its close relationship with immersion (see Chapter "3.5. Relationship between immersion and presence").

Specifically:

- Disconnecting the user from the physical environment. It has to do with the extent to which users feel disconnected and have "forgotten" the natural environment. Usually, there is no disconnection from it when using a computer screen and keyboard/mouse. This is because, simultaneously with the virtual experience, users are aware of the physical space in which they are in, and, as a result, they receive stimuli from there as well. Partial disconnection occurs when users, because of the equipment they use, are to some extent disconnected from the physical environment, but nevertheless retain the perception that it exists. Finally, full immersion cuts users off from the physical environment to such an extent that the actual space and time do not concern them. In other words, users in full immersion receive sensory stimuli only from the virtual environment. However, it should be noted that with today's technological standards, this mainly involves vision and hearing, partially touch, and little to no sense of smell and taste.

- Degrees of freedom. Degrees of freedom refer to the number of ways an object or person can move in 3D space (Pennestri et al., 2005). As presented in Chapter "2.2 Principles and operating elements of Head Mounted Displays," the degrees of freedom can be divided into two broad categories (6DoF and 3DoF). In 3DoF there is only rotational motion. Using the mouse there is the possibility of 6DoF, but these are simulated ones.
- Viewing mode (low-high quality). Here, many factors can be included such as image resolution, projection type, refresh rate, frames per second, and field of view. Image resolution in a simulation plays an important role in immersion. In recent years very good resolution has been provided, but there is room for improvement. For example, a computer screen can reach 4K (3840 x 2160). The resolution on an HMD ranges from 2K to 8K in total (for both eyes). The view can be 2D or 3D (stereoscopic view). Stereoscopy or stereoscopic vision is the blending of two images into one, resulting in the perception of depth (McIntire et al., 2014). On a computer screen, simple projection is usually found, while stereoscopic projection is found on HMDs as well as other systems. The refresh rate refers to how fast the image is formed, while frames per second refers to the quality of the moving image. Finally, the wider the field of view offered by a device, the more likely it is that users will perceive the activity they are performing as more realistic.
- Degree of interaction (low to high). Interaction with the virtual world depends on whether the developer has intended to give users the ability to manipulate and modify some or all of the objects in the virtual world. Also, interaction depends on the devices used to implement it.

Another point to consider is the following. A system A is more immersive than a system B if A can be used to simulate the perception provided by B, but not vice versa. Hence, an HMD is more immersive than a CAVE system, since the former allows the virtual representation of the user's body. In contrast, in a CAVE system, the user sees his/her actual body. Moreover, the virtual body can be designed to resemble the real one. Sound could be included in the criteria, but it was chosen not to use this criterion, although in several taxonomies it is mentioned as a characteristic of VR systems because 3D stereoscopic sound can be achieved in any system. Based on the above, the taxonomy of VR systems presented in Figure 30 is proposed.

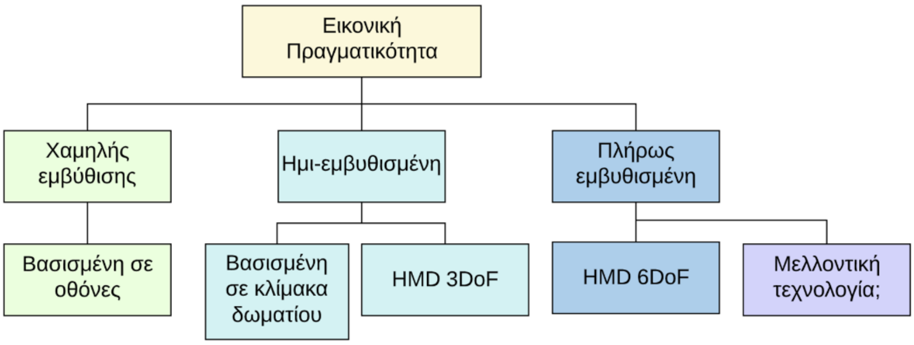


**Figure 30.** Proposed system taxonomy VR

Based on Figure 30, three main categories of VR can be distinguished:

- Low immersion. This category of VR includes all systems that present the virtual environment on a screen. It has 3D graphics (the projection can, but not usually, be stereoscopic with the use of special glasses), high resolution, high refresh rate, and a large field of view. On the other hand, however, the degree of immersion is very low, because the user is not cut off from the physical environment at all and 6DoF are simulated. The same applies to the interaction with virtual objects because they are not usually manipulated in a way that simulates the physical object, but mainly by means of the keyboard and mouse.
- Semi-immersive. Semi-immersive VR includes two main types of systems. The first type includes systems that project the virtual environment on a room-scale (e.g., vehicle simulation and CAVE). In this case, the cut-off is partial, the resolution can be very high, 6DoF are provided and stereoscopic projection is possible (again using special glasses). The second type includes systems that project the virtual environment with 3DoF. In this case, the degree of cut-off is clearly higher, but the degrees of freedom are limited. It is understood that in HMDs the stereoscopic projection exists, but the refresh rate and the field of view are, usually, limited. In both types of systems, interaction is often done with controllers that simulate physical movements.
- Fully immersive. In this category, only 6DoF HMDs were chosen to be included. It was considered that, with today's technological standards, these offer the greatest separation from the external environment (as do 3DoF HMDs), high resolution, stereoscopic projection, high refresh rate, and large field of view (in the very advanced systems), 6DoF, and the possibility of manipulating objects in a completely natural way (even in the absence of special controllers). Consequently, only by using 6DoF HMDs, it is possible to achieve fully immersive VR. Also, a space has been created in this category where all the technologies that have not yet appeared can be integrated.

Figure 31 shows the immersion continuum of the VR systems, i.e. how the different degrees of immersion are derived based on the four criteria mentioned above. Obviously, the ideal fully immersive system is one where the indices of the four factors are placed at the right end of the continuum.

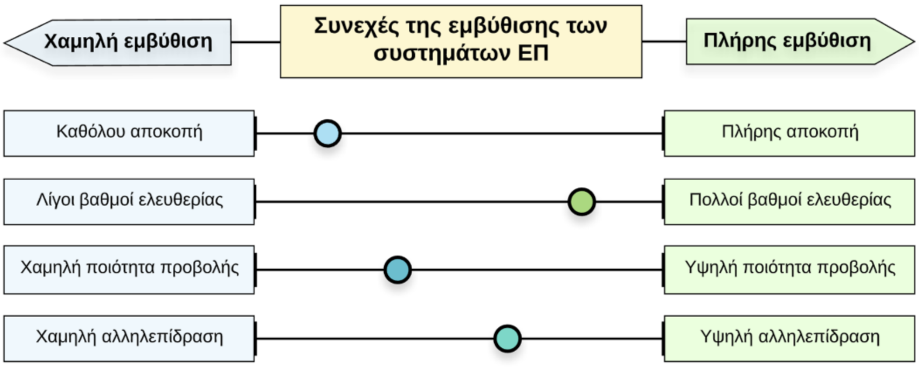


**Figure 31.** The continuum of immersion of VR systems

# Chapter 5. Areas of applications of Virtual Reality

At this point, it is appropriate to mention (without, however, constituting a systematic and detailed literature review) the applications of VR in selected areas, which are either considered important for the improvement of people's everyday lives or concern research fields of particular interest. It should be stressed that, in order to simplify the presentation, it has been considered appropriate not to analyze methods or any other technical element, unless this is necessary to clarify a specific application or outcome. It should also be noted that no reference will be made to the applications of VR in entertainment and games, since these areas have been researched in depth and there is a rich literature, making it difficult to refer to them in a comprehensive manner.

### 5.1. Sport and physical activities

There are various sporting activities where VR could be useful, either for recreational and leisure purposes or for training and practice. However, there are several obstacles to be overcome. For example, Miles et al. (2012) pointed out that practice in field games, such as football, the playing area is vast compared to the space in which someone in a VR system can usually move.

VR has been used to understand perception and action in sports. As an example, Ruffaldi et al. (2011) examined the conditions for successful practice in rowing and described a haptic VR system that included a large screen. Rauter et al. (2013) described a CAVE system enhanced with auditory and haptic capabilities, again for rowing, which was even compared to conventional training. The researchers in both cases concluded that the simulator could be used as a complementary training tool, as there was sufficient skill transfer from the virtual to the real environment. Again, in the rowing training context, Wellner et al. (2010) noted the relatively high degree of presence felt by the participants. Several other applications of VR in sports involved simulated baseball and handball (Vignais et al., 2009), skiing (Solina et al., 2008), detecting deceptive movements in rugby (Bideau et al., 2010; Brault et al., 2009), and shooting (Argelaguet Sanz et al., 2015).

Another example of the use of VR is watching sports matches with a non-physical presence. Kalivarapu et al. (2015) used a CAVE-type system, HMDs and simple video. They concluded that with CAVE and HMDs, participants experienced a greater degree of realism and that there were similar effects regarding presence.

The use of VR for physical exercise is an extension of "exergaming." This includes, for example, connecting an exercise bike to a screen so that the rider's actions affect what is being projected (for example, faster pedaling leads to an increase in the speed of the projected environment) (Anderson-Hanley et al., 2011). In addition, incentive factors can be introduced, such as virtual competitors. Other researchers have used "cybercycling" as above, this time on older people (Anderson-Hanley et al., 2012). They found that their cognitive functions improved and that there was likely a delay in cognitive decline, compared to traditional exercise.

The use of HMDs for physical exercise is a special case due to the reduced field of view compared to conventional displays, but also due to other limitations. One study examined the significant design challenges in this area by comparing a classic exercise bike without feedback, an exercise bike with an external display, and a bike with an HMD (Shaw, Wünsche, Lutteroth, Marks, & Callies, 2015). The two feedback systems outperformed the classic bike but did not differ from each other. They were also rated as more pleasant than the classic bicycle.

A different approach is to use VR to implicitly motivate people to exercise more. As an example, Fox and Bailenson (2009) conducted a study where participants used HMDs to see their virtual character. Participants at various points could choose to either perform physical exercises or not. When they did not perform exercises, their virtual body became thicker while when they did the virtual body became thinner. It was found that the group that had this positive and negative reinforcement exercised more.

## 5.2. Data visualization

Visualization and interaction with data is important for scientific evaluation. Data can be static or relate to dynamic processes. 3D representations of real or modeled data are important for understanding the data and for making decisions based on that understanding.

Norrby et al. (2015) built an application in which immersive 3D imaging of protein molecules was combined with interaction with them through gesture recognition. Users found the system potentially useful for protein design and enjoyed using it. The aim of the study by Leinen et al. (2015) was to manipulate nanometer-sized molecular compounds via HMD. The manipulation accuracy was improved by the optical feedback provided by HMD imaging compared to non-immersive systems. In the study by Cali et al. (2015), a CAVE-type system was used to evaluate the spatial distribution of glycogen granules in astrocytes (a type of brain cell). The authors found that the immersive projection of the 3D structure is crucial for identifying this distribution. Prabhat et al. (2008) compared user performance in manipulating Drosophila (vinegar fly, Drosophila Melanogaster) data, such as the egg chamber, brain, and gut, using three different media (monocular display, stereoscopic display, and CAVE-type system). The more immersive system allowed users to better quantify specific features mainly related to spatial distribution, co-location, and geometric relationships.

## 5.3. Authoritarianism, violence, dilemmas, racial, and other prejudices

Milgram, in the 1960s, conducted a series of experiments to find explanations for how ordinary people can be persuaded to perform horrible acts. The most typical of these was the administration of escalating intensity of electric shocks to a stranger by the subjects of the experiment (who did not know that they were the subjects of the experiment and that they were not administering any shocks), at the command of someone in authority (Milgram, 1974). About 60% of the subjects submitted to the commands and even went so far as to administer lethally intense electric shocks. The results raised awareness as they demonstrated that people are capable of inflicting severe pain on others on command.

In 2006, a virtual repetition of these experiments was performed, but this time a virtual subject was subjected to electroshock (Slater et al., 2006). This experiment, although conducted in VR, produced the same results as the original (however, lower levels of anxiety were observed). In some ways, it appeared that despite the gap between reality and VR, presence leads participants to respond to virtual stimuli as if they were real.

In the late 1960s, 38 people witnessed the murder of a woman and did nothing to help her. Latane and Darley (1968) introduced the term "bystander effect" which, in essence, argues that the more people present at an emergency event, the less likely it is that any of them will intervene, due to diffusion of responsibility. However, for ethical and practical reasons it is not possible to conduct experiments that recreate such incidents to elicit the factors that influence the behavior of individuals in violent situations (Rovira et al., 2009). Instead, in VR it is possible to create simulated situations, where it is known from research that people are likely to react realistically to the events depicted. For example, King et al. (2008) used Second Life (a 3D multi-user virtual environment) to examine how bystanders react to an emergency/violent incident and whether they would help. They concluded that one reason people do not intervene is because they believe this should be the responsibility of the controlling bodies, not ordinary citizens. In another experiment, Kozlov and Johansen (2010) found that participants were less prone to helping behavior when larger groups of virtual characters were present. Slater et al. (2013) used a CAVE-type system to study the social identity hypothesis, i.e., that participants who share the same social identity as the victim (in this experiment, they were fans of the same football team) are more likely to intervene to help. Their experiment demonstrated the validity of this assumption.

Sometimes, in their professional and personal lives, individuals are confronted with ethical problems/questions that cannot be easily answered by any kind of sound scientific reasoning. A famous example is the "trolley car problem," where one has to decide whether to allow it to continue on its course and kill five people or to divert it from its course to kill only one (Thomson, 1976). According to evidence from a related study (Hauser et al., 2007), most people will choose to save the greatest number of people.

There are similar examples of applications and experiments where the possibilities of presence in VR were used to pose such dilemmas to the participants. Navarrete et al. (2012) implemented a variant of the "trolley problem" using a VR application and found that just over 90% of the subjects chose the utilitarian solution (to kill only one person). However, the utilitarian path led to more internal conflict among participants but also constituted the least stressful option. Pan and Slater (2011) illustrated a dilemma equivalent to the trolley problem. Participants, in a CAVE system, controlled an elevator in a virtual art gallery and had to decide, in a short time, whether to direct a character who suddenly started shooting on a floor where there was only one person or to leave him on a floor where there were five. The fundamental reaction of the participants was confusion and panic. A more sophisticated version was replicated in a study based on HMDs (Friedman et al., 2014) and realistic virtual characters, with results similar to the previous studies. In general, it was found that people become more utilitarian in VR compared to what they would answer in a questionnaire, i.e., they are more likely to adopt a decision with the lowest cost in lives (saving five rather than one person).

Research has demonstrated that VR can help draw conclusions about racial and other discriminations, by simulating experiences from the perspective of another group. Groom et al. (2009) embedded white or black people in a black or white virtual body in the context of a scenario that was an interview for a job. HMDs were used, with participants viewing their virtual bodies in a mirror, and the experiment lasted for just over a minute. The researchers found that there was a greater bias in favor of white people for those who were integrated into the black virtual body. This difference was not observed when participants simply imagined being in a white or black body.

Peck et al. (2013) conducted a study on racial bias, where participants were embedded for 12 minutes in either a black body, a white body, a purple body, or no body at all. HMDs were used, the virtual body moved in sync with the participants' actual body movements, and participants viewed their virtual bodies in a mirror. It was found that implicit racial bias was significantly reduced only for those who had the black incarnation.

Ahn et al. (2013) used HMDs to have people with normal vision experience certain types of color blindness. In three experiments they compared results where participants either simply imagined having colorblindness or the app actually made them have colorblindness in the virtual environment. They found that the VR experience had an impact on changing participants' attitudes towards people with colorblindness, both within the experiment and afterward. This shows how VR could be used to provide people with experiential situations and how this may affect their behavior compared to other techniques.

## 5.4. Industrial applications and product design

In a review of the use of VR in automotive manufacturing, Lawson et al. (2016) pointed out that it can be used for design, avoiding the complex and costly process of building physical mock-ups. Other researchers found that VR can be used for learning tasks related to industrial assembly, maintenance training, and remote maintenance (for example, Gavish et al., 2011, 2015; Seth et al., 2011).

In another context, Tiainen et al. (2014) found that by using HMDs potential car buyers were able to make meaningful suggestions for improving the design of car interiors. In a similar way, VR has been used in the clothing industry, allowing customers to try on clothes on virtual representations of their own bodies (Hauswiesner et al., 2011; Magnenat-Thalmann et al., 2011; Sun et al., 2015). Ruppert (2011) described how VR can be used to study shoppers' behavior when they have to choose between different types of packaging and layout in supermarkets. He suggested different types of product presentations so that they can be more easily identified by the target audience. Therefore, as argued by Lawson et al. (2016), VR can improve product design, standardization, production, and evaluation processes.

## 5.5. Journalism and news

VR opens up a whole new field which is immersive news presentation, usually referred to as "immersive journalism." However, it is important to stress that it is not journalism that is immersive, but the presentation of the outcome of journalism (i.e., the news) through immersive media that leads to the creation of a new type of media. In other words, immersive journalism is the production of news in a format in which people can gain first-person experiences of the events or situations described in the news (De la Peña et al., 2010). On the other hand, it should be emphasized that the goal of immersive journalism is not so much to present "what happened," but to give people an experiential, non-analytical view of events so that they have the illusion of being present at them. This presence can lead to a different understanding of the events, perhaps an understanding that cannot be expressed well verbally, in writing, or in pictures.

The first production of immersive journalism depicted a virtual prison in Guantanamo. It was created by the journalist Nonny De la Peña with the help of the artist Peggy Weil. Using the transcript of the interrogation of detainee 063, Mohammed Al Qahtani, at the Guantanamo Bay prison in 2002-2003 as a basis, an app was developed in which users, using HMDs, took on the role of the detainee (wearing the distinctive orange uniform) watching a harsh interrogation (De la Peña et al, 2010). All participants reported that although they sat comfortably, they felt uncomfortable. In fact, they had the feeling that they would be the next to be interrogated. De la Peña made other productions such as, "Hunger in Los Angeles" which was based on the real-life incident of a diabetic passing out in a line of people waiting to pick up food, and "Project Syria" which depicted the bomb blast in a Syrian city.

Alternatively, instead of using graphics to reconstruct events, 360° videos can be used, which can then be viewed on HMDs. Arora (senior advisor and film producer at the United Nations) and Milk (Vrse.works) in "Waves of Grace" used this technique to recreate the true story of an Ebola survivor in Liberia. They also created "Clouds over Sidra," a documentary about a child refugee in the Syrian war. Jebb and Miller (Immersiv.ly) used 360° video to cover the unrest in Hong Kong and a self-guided 360° interactive experience of VR paintings. Finally, the New York Times and BBC are showing news stories with 360° videos.

## 5.6. Health sciences

The area of VR for surgical education has been thoroughly investigated (Alaraj et al., 2011). Indeed, there is a huge increase in research on the effectiveness of VR in terms of training for surgical procedures (Al-Kadi et al., 2012; Lorello et al., 2014; Zendejas et al., 2013), the transfer of this training to real-world settings (Buckley et al., 2014; Connolly et al., 2014), and other specialized applications (Arora et al., 2014; Jensen et al., 2014; Singh et al., 2014). Imaging the human body through an immersive perspective can provide an unprecedented understanding of its anatomy, and body processes in physiological and pathological states, and allows exploration of organs at micro- and macro-scale.

Although there are studies that attempt to assess how useful VR can be for improving anatomy learning (e.g., Codd & Choudhury, 2011; Seixas-Mikelus et al., 2010), including studies suggesting that VR could replace the use of cadavers. Most systems so far use desktop VR. However, even non-immersive 3D body models for studying anatomy seem to achieve good results. The most common uses of VR, so far, for surgical training are those for laparoscopic procedures (Seymour et al., 2002), ophthalmology (Jonas et al., 2003), and stent placement (Dawson, 2006).

VR can provide training in many different scenarios involving the management of patient behavior (Cendan & Lok, 2012; Cook et al., 2010). For example, Kleinsmith et al. (2015) investigated empathy training with virtual patients, although only ethical problems were considered. Also, Pan et al. (2016) conducted an experiment with experienced and practicing physicians using HMDs, through which each physician had a dialogue with a virtual mother and her daughter, the former requesting antibiotics, even though the latter's illness was viral. Participants initially resisted this, but when the dummy mother became angry and threatening, most participants eventually prescribed the antibiotics. Also, the results demonstrated that the more experienced the doctors were, and, at the same time, the stronger the sense of presence, the less likely they were to prescribe drugs that were not necessary.

## 5.7. Social behavior, Proxemics

Proxemics is the study of how people use the so-called "personal space" and what effects the concentration of individuals in space has on behavior, communication, and interpersonal relationships (Hall, 1969). Thus, an interesting question that arises is the extent to which similar findings can be made in VR, which would be an indication that VR could be useful in the study of social interaction.

The truth is that there is no extensive literature on how VR can contribute in this area. In research using an application of immersive VR, it was found that people kept greater distances when encountering virtual representations of people compared to the distances they kept when encountering cylinders representing virtual people (Bailenson et al., 2001). It also appeared that participants kept greater distances from virtual people when the approach was frontal compared to when the approach was from behind, and greater distances when they were gazing at each other (Bailenson et al., 2003). Other studies have also indicated similar behaviors in virtual environments (e.g., Friedman et al., 2007; Wilcox et al., 2006). It should be emphasized that these findings are consistent with the findings of real-world studies, even though they involved virtual characters and no actual social interaction took place.

Research has demonstrated that the distances people keep from virtual characters can be used as a predictor of aggression (McCall et al., 2009). In this study, the distance participants (who self-identified as white Caucasians) kept from two white or two black virtual characters was measured. Participants then engaged in a shooting game with these virtual characters as targets. It was found that there was a positive correlation between the distance maintained from the virtual black characters and the degree of aggression shown towards them.

## 5.8. Body transformation

VR may prove useful in neuroscience research (Blascovich et al., 2002). This is because studies that are impossible in reality for practical or ethical reasons are possible in VR (cf. Chapter "5.3. Authoritarianism, violence, dilemmas, racial and other biases"). Also, VR allows for exact repetition of experimental conditions; virtual characters performing certain actions in a scenario can repeat them as many times as desired. Thus, VR allows for control of both the internal and generalized power of experiments (Rovira et al., 2009). The ability to generalize results from the laboratory to real-world situations is important. This is because, as already mentioned, in many areas of the application of VR, presence leads to behavior that is quite similar to the behavior one would have in reality under approximately the same conditions.

An interesting area in which VR allows experimentation is the transformation of the body. For example, how does the brain distinguish that a hand is part of a person's body and an object holding the hand is not? Based on common sense, one would think that the internal representation of the body is fixed, or at least something that changes slowly over time. However, experiments have demonstrated that it is quite easy to shift the sense of ownership of the body to objects that are not part of the body, or to a radically transformed body so that the body's representation is something malleable.

A classic experiment that demonstrates the validity of this view is called the "rubber hand illusion" (Botvinick & Cohen, 1998). In this experiment, the subject sits at a table on which a rubber hand is placed in parallel to their real hand, which is hidden behind a partition. The researcher lightly taps or strokes both the rubber hand and the hidden real hand of the subject at the same time. After about two minutes, two-thirds of the subjects, when asked to indicate which hand is touched, point to the rubber hand. This is because the brain tends to consolidate into one, two separate but simultaneous sensory inputs (in the above experiment, vision, the subject sees the rubber hand being touched feels that something is touching their real hand). Several other researchers have addressed these illusions to examine how the brain perceives the body (e.g., Blanke, 2012; Blanke et al., 2015; Ehrsson, 2012).

The use of VR to transform the way the brain perceives the body was first carried out by Lanier in the late 1980s (Lanier, 2006, 2010). Lanier used the term "homuncular flexibility" to refer to the finding that the brain can adapt to different body configurations and learns how to manipulate an alien body by changing the relationship between localized and provided motion. Using VR, Slater et al. (2008), demonstrated that a virtual arm could be considered to belong to participants in a manner similar to the rubber arm illusion experiment. Ehrsson (2009) and Guterstam et al. (2011), using similar multisensory techniques, concluded that it is possible to give participants the illusion that virtual arms were embedded in their hands.

In terms of body shape, Kilteni et al. (2012) argued that it is possible to create the illusion of ownership of an asymmetrical human body, where one arm is three times longer than the other (which participants tended to withdraw when threatened). Steptoe et al. (2013) demonstrated how people could adapt to having a tail using a CAVE system in which participants viewed their virtual bodies from behind. In fact, they learned to use their tail to avoid damage to their body.

One of the most important advantages of VR compared to the use of plastic hands is that the virtual limbs or even the entire virtual body can be moved. Sanchez-Vives et al. (2010) exploited this to show that the illusion of ownership of a virtual arm can be induced by synchronizing real and virtual hand movements (visuomotor synchrony). The same can be done for the body as a whole. The term "virtual embodiment" (or simply embodiment) refers to the process of -representationally- replacing a person's body with a virtual one (even though it may not resemble the real body). Additional multisensory associations such as visual-haptic and visual-motor synchronization can be included to intensify the effect (Spanlang et al., 2014). Kokkinara and Slater (2014) concluded that when subjects view their virtual body from a first-person perspective (i.e., through the "eyes" of the virtual body), visual-motor synchrony is a more powerful motivator of the illusion of body ownership than visual-haptic synchrony. Several others have addressed the technology required for virtual embodiment (e.g., Spanlang et al., 2013, 2014), studying the conditions that can lead to such body ownership illusions (e.g., Blom et al, 2014; Borland et al., 2013; González-Franco et al., 2013; Maselli & Slater, 2014; Pomes & Slater, 2013; Slater et al., 2009, 2010) and exploring the effects of distortions beyond the normal form of an individual's actual body (e.g., Kilteni et al., 2012; Slater et al., 2010; Steptoe et al., 2013).

Also, the method of virtual embodiment has been used to give adults the experience of being children (Banakou et al., 2013). This has been found to affect the way individuals move (Kilteni et al., 2013) and leads to size overestimation. Indeed, Van der Hoort et al. (2011) demonstrated that, when average-sized adults had the illusion of body ownership with smaller or larger virtual bodies than their own, this led to changes in their perception of object sizes (in a small body, objects appeared larger to them, but also smaller in a large body). Banakou et al. (2013) replicated the same effect in an immersive VR application, showing that when the form of the virtual body represented that of a (four-year-old) child, the size overestimation was about twice as large as when the form of the virtual body was that of an adult.

Yee and Bailenson (2007) introduced the term "Proteus effect" to describe how a person's digital self-representation affects their attitude and behavior in virtual environments, but also their actual behavior outside of them. They concluded that embedding individuals in an avatar that had a face more attractive than their real one led them to move closer to someone in a collaborative virtual environment, compared to those participants whose avatar was judged to be less attractive. Similarly, embedding in taller avatars led to more aggressive behaviors than if embedded in shorter ones. The theoretical basis of the Proteus effect is the Self-perception Theory (Bem, 1972), which suggests that people form their attitudes by observing their own behaviors and the context in which they occur.

### 5.9. Cultural heritage

The ideal way to preserve cultural heritage is through physical protection, conservation, and restoration of sites. For years there has been research dealing with the digital capture and visualization of these sites, which can be implemented with VR applications (Rua & Alvito, 2011). The first and obvious use of VR in this area is to allow people to interactively explore such sites. This is no different from virtual travel/tourism, except for the nature of the attraction. Another type of application is to represent these sites as if they were fully restored, or as they were in the past, or under different conditions (such as different lighting). In a similar way, there could be applications that depict heritage sites in the future under different conditions, such as under different global warming scenarios.

An example of a cultural heritage VR application is the tour of the ancient city of Miletus through a CAVE system (Gaitatzes et al., 2001). Other examples are the virtual tour of the monastery of Santa Maria de Ripoll in Catalonia, Spain (Callieri et al., 2011) and the digitization and rendering of Michelangelo's statue of David and various other statues and artifacts of ancient Rome (Levoy et al., 2000). Carrozzino and Bergamasco (2010) stated that the reasons why the use of VR in museums may not have been researched in even greater depth are cost, the need to have a team of people from different disciplines working together, the space required to install VR systems, and the fact that visitors may not want to wear VR equipment. However, many of these problems have been solved in recent years with the advent of low-cost, high-quality HMDs. Yet, it is still true that a multidisciplinary team is required to create the environments (Dunn et al, 2012). In addition, the digitization of heritage sites requires a huge amount of data. For example, the previously mentioned statue of David required two billion polygons to construct.

Sometimes a digital reconstruction is the only way to see a location. The ancient Egyptian temple of Kalabsha was moved from its original location to save it from the rising waters of the Nile. Sundstedt et al. (2004) digitally reconstructed it to depict it in its original location, and how it might have looked two millennia ago.

Webel et al. (2013) pointed out that expensive CAVE systems are not always suitable for busy environments such as museums. On the other hand, HMDs provide a more natural means of interaction and increase immersion considerably. A similar conclusion was reached by Kateros et al. (2015) in their review of the use of HMDs in cultural heritage, and Casu et al. (2015) who compared the display of artworks in the classroom through a non-immersive system and HMDs. There are, however, some issues to be tackled. For example, Loizides et al. (2014) compared powerwall (a system for projecting VR applications on a large screen) and HMDs for virtual visits to heritage sites in Cyprus. They found that participants appreciated both types of display especially the increased presence that HMDs elicited. However, the use of HMDs resulted in some participants experiencing symptoms of nausea (simulator sickness, cf. Chapter "2.2 Principles and operating elements of Head Mounted Displays").

## 5.10. Cooperation, shared environments

As presented in previous chapters, the virtual environment can be used by several people at the same time. In these cases, each participant is represented by a virtual body (also known as an "avatar") and can see the representations of others. Ideally, the avatars move through the virtual environment as the participants do, by tracking their movements. There are many technical issues involved in implementing such systems, such as how to distribute the application and synchronize participants (Steed & Oliveira, 2009). Probably the first published work involving how more than one person could exist in the same virtual environment was presented by Blanchard et al. (1990) and involved just two participants. Nowadays all VR systems now support this possibility (Tecchia et al., 2010). Indeed, there are platforms that support the simultaneous online presence of thousands of people, such as Second Life, although these are not fully immersive.

Early research in this area focused on technical issues and on exploiting the potential of VR to improve remote collaboration (e.g., Koleva et al., 2001). Later work has focused on exploring social dynamics in shared virtual environments (e.g., Slater et al., 2000; Tromp et al., 1998). In general, researchers have found that dynamics are influenced, to a large extent, by the type of immersion. Steed et al. (2003), using a CAVE system, found that avatars play an important role, especially when they represent the participants' entire body. Other researchers have focused on interesting details of this type of communication, such as the shaking of virtual hands (Giannopoulos et al., 2011; Wang et al., 2011), gaze tracking (Steptoe et al, 2008, 2010), and whether participants in such communication react as in physical communication (Dodds et al., 2011; Pizarro et al., 2015). Indeed, touch, which is difficult to transfer (since one cannot "touch" avatars), has been the subject of a number of studies. Bourdin et al. (2013) created an application where participants could feel a vibration from a small vibrator placed on their shoulder when someone "touched" their avatar. Bailenson et al. (2007) conducted experiments using haptic virtual environments and demonstrated that touch helped to communicate emotions. Basdogan et al. (2000) using a haptic environment conducted a series of experiments and found that haptic feedback could convey critical information. Similarly, Kim et al. (2004) concluded that haptic feedback improved the sense of co-presence, i.e. that distant participants felt that they were together.

## 5.11. Travel and tourism

The contribution of travel to the global economy is colossal. According to the World Travel and Tourism Council (World Travel and Tourism Council, 2015), travel and tourism generated $7.6 trillion in 2014. On the other hand, travel comes with significant costs (Reford & Leston, 2011) and has a fairly significant environmental footprint (Kampa & Castanas, 2008). Another problem is particularly related to business travel. These trips can disrupt both the business and the personal life of the traveler, causing physical and mental burnout (Jensen, 2014), but also bringing family conflicts (Gustafson, 2012). Nevertheless, for businesses, face-to-face contact is considered essential. Even if they can be replaced by one of the various forms of video conferencing systems available, it has been suggested that these types of virtual meetings may even create more physical travel (Gustafson, 2012). Indeed, the interesting fact is that those who travel the most are the ones who participate in most video conferencing. Therefore, it is reasonable to ask the question of whether VR can be beneficial in this area, and whether it can replace leisure travel.

Using VR it is possible that one may not need to physically go to a place to say that one has visited it. Indeed, with $360^o$ videos, someone sitting at home can navigate the streets of Hong Kong, visit the Taj Mahal, explore the Forbidden City in Beijing, or even see a landscape on Mars. Individuals can attend ceremonies from exotic places. These are obvious and much-discussed potential applications. The possibilities are limited only by the imagination and what technology can offer at a given moment.

These are not all new ideas, as already for two decades people in the travel industry have been examining what has been called the "virtual threat to travel and tourism" (Cheong, 1995), arguing that the threat of VR becoming a substitute for travel is not unfounded and should not be ignored. VR offers particular advantages over actually visiting a site that could lead to the replacement of travel and tourism by VR. Among other things, (a) technology could eventually support the perfect "virtual experience" where the sun never stops shining or the snow is perfect, there are no annoying people around, (b) there is no stress and cost of travel, (c) the places that could be visited include those that are not easily accessible (Mars is an extreme example), (d) one could travel to the past or imaginary worlds, (e) people who cannot travel due to illness or disability will find it easy to do so, (f) there are no risks of tropical diseases and accidents, and (g) there is no environmental impact to the places visited. However, Cheong (1995) stated that VR is not a substantial threat, as presence and immersion are not a substitute for actually being in a place. For example, it is difficult in VR for one to interact with the locals and reproduce the complexity and randomness of the real world.

## 5.12. Spatial representation and navigation

VR can be useful in the study of spatial representation and spatial navigation. This is because VR can transport subjects to another space, which can be explored with or without movement. Spatial navigation is useful in various fields such as the restoration of spatial abilities after a neurological disorder or brain damage that affected this function, and even for the planning of a city. Since navigation in virtual space can activate the same brain mechanisms as navigation in the real world, spatial presence can be successfully reproduced (Brotons-Mas et al., 2006; Wirth et al., 2007).

Thus, navigation through VR has been found to provide a reasonably good method for studying the function of the hippocampus, which is the main brain structure that supports spatial representation (Gould et al., 2007). Navigation in virtual cities has been used to identify which parts of the brain are activated during the mental creation of a route (Hartley et al., 2003), as well as to identify problems in spatial cognitive functions in disorders such as depression (Gould et al., 2007), Alzheimer's disease (Cushman et al., 2008), after brain injury, and other neurological disorders (Bertella et al, 2001; Kober et al., 2013; Koenig et al., 2009). For example, using a virtual model of a city, active navigation helped stroke survivors regain some pathfinding ability (Claessen et al., 2015). In addition, practicing spatial ability in VR protects against age-related decline in hippocampal functions (Lovden et al., 2012).

The study of the strategies people use for spatial navigation is another area where VR has been exploited (Rothman & Warren, 2006; Schnapp & Warren, 2007). However, there is concern about whether the techniques learned to navigate effectively in a virtual environment transfer to the real world. Darken and Goerger (1999) pointed out that while the use of VR seems to produce better results in terms of spatial knowledge acquisition, the knowledge and skills acquired often do not transfer to the real world. However, those who use VR simply to rehearse what they would later do in a real space, without relying on detailed cues, seemed to ultimately perform better (spatially). Ruddle et al. (1999) compared navigation between a desktop VR system and one based on HMDs with head motion tracking. They found that although there were no differences in performance between the two systems in terms of estimating distance traveled, users with HMDs stopped more often to look at the scene around them and were better able to estimate paths between two points. This difference between the two systems suggests that in immersive VR, body-centered perception improves the likelihood of transferring knowledge to a real-world situation. Ruddle et al. (2011, 2013) compared desktop VR, HMDs that did not allow participants to walk but only to look around, and HMDs that allowed participants to walk, and found that participants in the third group produced better mental maps. The conclusion from these studies was that simply placing someone in a virtual world to learn a particular environment can be effective, provided that the navigation involves active control by the participant.

## 5.13. Psychology and treatment of diseases

VR has been used extensively for psychological, or occupational therapy, and for the rehabilitation of various conditions. The first applications of VR in psychology appeared very early (e.g., North et al., 1996; Lamson, 1997). In general, patients are navigated through virtual environments and perform specially designed tasks. For example, VR is widely used as an alternative form of exposure therapy, in which patients interact with harmless virtual representations of traumatic stimuli in order to reduce fear responses such as heights, public speaking (Parsons & Rizzo, 2008), flying, and confined spaces (Anderson et al., 2013). It has been found to be particularly effective in treating post-traumatic stress disorder (PTSD) (Rizzo et al., 2010), in helping people who have had a stroke or brain injury to regain muscle control (Reger et al, 2009), in treating disorders such as body dysmorphia, and in improving the social skills of people with autism (Kandalaft et al., 2012). In fact, to achieve better results, in many cases, immersive VR is used so that patients are isolated from external stimuli and become immersed in the virtual environment.

Unlike traditional cognitive behavioral therapy, VR-based therapy allows for the adaptation of the virtual environment, such as adding intensity-controlled odors, or adding and adjusting vibrations, and allowing experts the therapist to determine each patient's response levels. Therapists using VR-exposure therapy, like those using in-vivo exposure therapy, can apply two approaches The first, named flooding, presents first those stimuli that cause the most distress. For soldiers who have developed PTSD, this might mean first exposing them to a scene where fellow soldiers are shot or wounded, followed by less stressful stimuli such as just the sounds of war. On the other hand, graded exposure, takes a more relaxed approach in which less distressing stimuli are introduced first.

In any case, within the virtual environment, patients can safely interact with a representation of their phobia. However, a challenge for the effectiveness of exposure therapy is recreating the level of trauma that exists in real environments within a virtual environment. One way to overcome this is to create a realistic virtual environment and provide patients with a variety of sensory stimuli (Bush, 2008). A typical example of such an application, widely used in the treatment of soldiers with PTSD, is Virtual Iraq, in which patients are navigated in a Humvee through the virtual representations of Iraq, Afghanistan, and the US. By safely exposing themselves to traumatic environments, patients reduce their anxiety. Its effectiveness is particularly high, as it is thought to treat approximately 75% of patients (Rizzo et al., 2014). VR exposure therapy is also used to treat specific phobias, especially phobias of animals such as spiders, which can be easily produced in a virtual environment (Parsons & Rizzo, 2008). Indeed, applications have been developed that can be used by patients (Haworth et al., 2012).

The term "virtual rehabilitation" refers to both physiotherapy and cognitive interventions (for example, for patients suffering from amnesia or attention deficit disorder). In this case, the patient's treatment is based largely or entirely on VR environments rather than on physical means. It has a number of advantages such as it is fun and therefore motivates the patient, it provides realistic environments, it provides ways of objectively measuring outcomes, it can be implemented remotely (for example, in the patient's home), the patients can "forget" that they are undergoing treatment and thus expresses themselves more "freely", and has reduced costs (Burdea, 2002). On the other hand, patients should be able to successfully project and experience their anxiety in a virtual environment. Unfortunately, this projection is highly subjective, individualized, and outside the therapists' control. This limitation can negatively impact treatment (Bush, 2008). Additionally, there is no guarantee that if patients successfully combat their phobia in a virtual environment, this means that the same will be true in real life. Furthermore, when treating more complex conditions such as schizophrenia, it is not certain that a patient's delusions can be fully transferred to the virtual world (Park et al., 2019).

Applications of VR have also been developed to combat depression, especially in patients with mild/moderate symptoms. For example, in the game Sparx, users assume the role of a character who travels through a fictional world, "fighting" negative thoughts and, at the same time, they are taught techniques to manage their depression (Merry et al., 2012).

VR has also been used to treat eating disorders and physical deformities. In one study, participants performed various tasks in virtual environments that included showing the effects of achieving the desired weight, comparing their actual body shape to an avatar created using their perceived body size, and changing a virtual reflection to match their actual body size (Marco et al., 2013). Similarly, there are examples, albeit very few, of the therapeutic benefits of VR for transgender individuals experiencing gender dysphoria. Through the use of VR video games and chat rooms, those suffering from gender dysphoria can create avatars of themselves, interact anonymously, and work towards therapeutic goals (Brown, 2019).

VR improves the social skills of young adults with autism. In one study, participants controlled an avatar in different virtual environments and performed various social tasks, such as interviewing, meeting new people, and addressing arguments. Researchers found that participants improved in the areas of emotional recognition and in examining other people's thoughts. Participants were surveyed months after the study about how effective they felt the treatment they followed was and the responses were overwhelmingly positive (Kandalaft et al., 2012). Similar results were achieved in school-aged children suffering from attention deficit hyperactivity disorder (ADHD). These children, subjected to a series of classroom cognitive therapy sessions, achieved the same management of their impulsivity and distraction symptoms as children receiving medication (Bioulac et al., 2018). Similar results were obtained in research that aimed to "teach" students with ADHD basic behaviors in the school environment (Fokides et al., 2019).

Research has demonstrated that stroke patients have found beneficial VR-based rehabilitation techniques as part of their physiotherapy (De Rooij et al., 2016). A rehabilitation program includes high-intensity, repetitive and specific exercises, but can be physically demanding and require several days of training per week. Moreover, most cases produce only moderate and/or delayed results. In contrast, a physiotherapy regimen using VR provides the opportunity for individualization and adds a level of intrigue and engagement for the patient (De Rooij et al., 2016). In a related study, it was found that patients who used a VR application, in combination with a physiotherapy program, had greater improvement in walking speed than others who followed a conventional physiotherapy program (Kim et al., 2009).

Similar effects have been observed in people with Parkinson's disease, improving their sense of balance, gait, daily activities, and cognitive functions (Corbetta et al., 2015). In terms of trauma and pain treatment, it has been observed that the more immersive the experiences are in a VR environment, the less time patients spend thinking about pain, anxiety, and symptoms of depression (Scapin et al., 2018). Unfortunately, there are not many studies that have examined the effect of VR on chronic pain.

# Chapter 6. Virtual Reality and learning

From the previous chapter, it became evident that VR is applicable to a wide range of sciences and activities. It is reasonable to assume that VR is an interesting educational tool. Furthermore, in Chapter "3. The main features of VR", it was demonstrated that immersion, presence, and interaction affect the user experience in virtual environments. Probably, these very same factors are the ones that give VR educational/learning value. It is these issues that are addressed below.

## 6.1. Virtual Reality as a cognitive tool

Learning tools enable learners to increase, extend, and enhance their cognitive abilities (Derry, 1990; Jonassen & Carr, 2000). For technology to be considered a learning tool, learning must occur with it, not from it (Jonassen, 1995). Indeed, it can be argued that VR does not cause learning in itself, but provides the capabilities and becomes the means by which learning will be induced (Dalgarno & Lee, 2010; Dickey, 2005; Rueda et al, 2018).

VR has found application in most learning domains and levels of education (Bellotti et al., 2010; Falloon, 2010), and has been successfully used in scientific fields such as mathematics and health sciences (Rizzo et al, 1997; Vaughan et al., 2016). Many studies on the educational applications of VR cite positive findings, such as increased engagement with the learning material (Bonde et al., 2014; Cheung et al., 2013; Huang et al., 2010; Thisgaard & Makransky, 2017), enjoyment (Ferracani et al., 2014), increased motivation to learn, and knowledge retention (Huang et al., 2010). Furthermore, according to Hew and Cheung (2010), virtual environments influence users' moods and social interactions. Also, it has been found that VR is, in many cases, more effective, in terms of learning outcomes, compared to conventional teaching (Merchant et al., 2014). In addition, there are examples from universities and schools that have used VR applications alongside conventional teaching, demonstrating positive learning outcomes (e.g., Dalgarno et al., 2011; Petrakou, 2010).

However, leaving aside the acquisition of knowledge through VR, a number of essential questions arise, such as what it is that leads to better outcomes using VR, or what characteristics/factors play a role in learning with VR. For example, many interpret outcomes in terms of direct and indirect learning experiences, for which the terms "first-person experiences" and "third-person experiences" are used respectively (Fokides & Atsikpasi, 2018). Although more on this topic will be discussed in Chapter "9.2. The fourth generation of educational computer use", at this point it should be mentioned that first-person experiences come from the direct contact of the individual with the learning material, while third-person experiences are mediated by another medium, such as the teacher or a book.

First-person experiences, due to their immediacy, lead to better learning outcomes (Fokides, 2017a). When first-person experiences cannot be acquired in the real world because the environments are not readily accessible and/or unsafe, then VR offers this possibility (Quinn & Lyons, 2013). It is speculated that the 3D objects present in a VR environment give the user a sense of the "real" (as opposed to their 2D analogs), promoting the creation of diverse cognitive representations of the same object and facilitating the development of integrated mental models (Dede et al, 1999). How powerful first-person experiences are in VR environments is a parameter that has not been studied in depth.

## 6.2. The educational potential of Virtual Reality

The educational uses of VR are a broad field (see reviews by Abulrub et al., 2011; Freina & Ott, 2015; Merchant et al., 2014; Mikropoulos & Natsis, 2011). According to Mikropoulos and Natsis (2011), VR, with its specific characteristics and in combination with its potential, seems that it contributes to the creation of positive learning outcomes.

As regards the concept of "potential," some further clarification should be provided. Among the first to speak of this term were Gibson (1979) and Salomon (1993), referring to those functional properties that determine the potential usefulness of an object or environment. In addition, educational capabilities, refer to those characteristics that an educational resource has that would potentially allow a particular learning behavior to be put into practice (Kirschner et al., 2004). Educational potential, from a technological perspective, means that technology influences instructional design in terms of use, compatibility, preparation, and continuous "upgrades" of the knowledge provided, which is controlled, adapted, and constructed, usually by teachers. Thus, it can be argued that the learning process is promoted through VR as it provides educational opportunities such as:

- Investigation of situations that cannot be done in any other way, for example, simulation of complex systems, macroscopic and microscopic imaging, and simulation of dynamic events (Kalawsky, 1993). Furthermore, virtual environments often represent concepts that may be intangible in the real world and relate to activities beyond those that a student would experience in a classroom (Trindade et al., 2002). VR provides opportunities to solve problems faced by traditional teaching that are related to science (Mikropoulos & Natsis, 2011). Furthermore, thanks to the 3D visualization it provides, it helps teaching in cases where the actual representation of the content of a lesson is not possible. For example, when teaching electromagnetism, it is very difficult to describe abstract concepts such as the electric force as it is an invisible force acting at a distance or electromagnetic radiation penetrating physical space (Ilie et al., 2019). Another example concerns mathematics. Hwang and Hu (2013) suggested that the use of a collaborative virtual environment has advantages over traditional teaching in learning geometric concepts. Similarly, Roussou (2009) and Roussou et al. (2006) examined the results regarding the comparison of fractions using a "virtual playground" in a CAVE system.
- Breaking the boundaries of reality. For example, applications can be built where gravity or the speed of light is varied (Dede et al., 1997).
- Provide high-quality and compelling learning experiences (Sundar et al., 2013), to a wide population of learners who are not physically present in the same environment, due to either space or geographical constraints, extraordinary situations (Hutchins, 2003), costly or dangerous situations (Dalgarno & Lee, 2010). An example is virtual visits (Lin et al., 2013) and virtual tours (Çaliskan, 2011).
- Developing users' creativity, while at the same time, it can help in research and material production (such as artistic expression, sharing projects, and instructor-student collaboration), i.e. pedagogical benefits that go beyond conventional tools (So & Lu, 2019).
- Testing prior perceptions in virtual models (Pan et al., 2006).
- Active participation in learning (Mikropoulos & Natsis, 2011). An example of this is surgical training. A related review highlights how VR is increasingly being used in neurosurgery training (Alaraj et al., 2011) and ideally in combination with a haptic interface (Müns et al., 2014).
- Tailoring the material to the needs of the students (Lee & Wong, 2008).

- Elimination of student anxiety (Ilie et al., 2019), i.e. VR acts as a stress reliever for those who, when involved in an activity, are concerned about their performance and the opinion of others about their performance.
- Encouraging teachers to use alternative ways of teaching (Pan et al., 2006). Bailenson et al. (2008) were concerned with the transmission of instruction rather than the content. They concluded that in a virtual classroom, it is possible to organize a collaborative virtual environment in which the learner is the center of attention. Moreover, virtual classmates could take on the role of the model student, with positive learning outcomes. Bailenson and Beall (2006) referred to this type of technique as "transformative social interaction."

## 6.3. Factors in VR that influence learning

Several characteristics (factors) are considered important for the experience one has in VR environments, however, three seem to play an important role, immersion, presence, and interaction, as presented in the previous chapter (see Chapter "3. The main characteristics of Virtual Reality"). These characteristics seem to play an important role in knowledge acquisition either in formal learning conditions (Dalgarno et al, 2011; Fokides & Zampouli, 2017; Skulmowski & Rey, 2018) or informal (Fokides & Atsikpasi, 2018; Petrakou, 2010).

Other characteristics that influence a virtual experience have also emerged, as presented below. Indeed, almost - if not all - are included in many studies that utilize the Technology Acceptance Model (Davis et al., 1989), which attempts to explain people's intentions to use technological tools, as well as in models related to VR (Lee et al., 2010).

*Immersion and learning*

In a previous chapter (see Chapter "3.2. Immersion") it was demonstrated that the users' sense of immersion in a virtual environment depends on whether it is sensorilly complete, i.e. whether the information it provides to the participants simulates that of the real one. Indeed, when this is the case, users feel immersed in the experience of the virtual environment and as a consequence, there is a positive impact on learning (Mikropoulos, 2006; Mikropoulos & Bellou 2006), better learning outcomes are achieved, and higher performance compared to conventional teaching (Cheng et al., 2015; De Lucia et al., 2009).

Furthermore, immersion in a virtual environment can enhance learning in three ways as (a) it provides multiple perspectives, (b) it contextualizes an environment and (c) it supports the transferability of the knowledge acquired (Dede, 2009). For example, haptic immersion supports user learning in a virtual environment, and, in particular, is more related to skill learning (Adams, 2004), such as during nursing training where familiarity with how to administer medication in an injectable form is essential (Worrall & Hutchinson, 2014). To achieve this, special VR gloves or controllers are used. Similarly, strategic immersion in a virtual world, which is intellectual in nature, helps to develop trainees' skills such as teamwork, communication, and decision-making (Adams, 2004; Ermi & Mayra, 2005), for example, in successfully managing a risk (Worrall & Hutchinson, 2014). Emotional immersion makes users become emotionally involved with the content of the virtual experience (Bjork & Holopainen, 2004), which can result in learning. In particular, within the virtual world, empathy can be cultivated in users, which improves their skills. For example, firefighters, when involved in a scenario where a person is trapped somewhere, in addition to learning how to manage emergency situations, are also emotionally involved, and, as a result, there is a high probability that they will transfer this experience to real life (Engelbrecht et al, 2019). Another type of immersion that enhances learning in a virtual environment is narrative, as it has the property of "enveloping" learners in the story plot (Adams, 2004). An example is when users experience the virtual experience very vividly, thanks to the narrative and engagement with the characters, with a positive impact on cognitive outcomes (Worrall & Hutchinson, 2014).

*Presence and learning*

In a previous chapter (see Chapter "3.3. Presence"), the concept of presence was clarified as the users' subjective sense of being in a virtual environment, having the illusion of non-mediation (Bulu, 2012). That is, the sense of presence in a VR experience makes users have the illusion that there is nothing interfering between them and the experience (especially when HMDs, controllers, and input/output devices are used), that they are experiencing something real. As a result, virtual environments create experiential experiences for users, (due to the sense of presence), resulting in learning (e.g., Bulu, 2012; Lee et al., 2010). The stronger the sense of presence in users, the better the learning outcomes achieved (Rupp et al., 2019).

One of the types of presence that seems to affect learning outcomes is social presence. It involves the interaction of participants with (artificial) social characters that look like real people or with representations of other people (avatars) that have been connected to the same virtual environment (Lee, 2004). Indeed, these characters can also be created through artificial intelligence for training professionals on skills such as decision-making and action in emergency situations (Sharma et al, 2017). Furthermore, Greenwald et al. (2017) also concluded that co-existing and sharing the same space with other individuals can benefit their training and education. It is worth noting that the social presence one feels in VR is also related to the dual concept of synchronicity (Dennis & Valacich, 1999). On the one hand, it concerns the learners, who all participate together in the same activity, with the same content, and, on the other hand, synchronicity concerns the media itself, i.e. creating the impression that they are all working on a topic together, with common goals (Carlson & George, 2004).

Furthermore, it has been found that spatial experiences in virtual environments can have a positive effect on the knowledge that is transferred and applied in the real world (Choi & Hannafin, 1995). In VR this is because participants feel that they exist in an environment that feels real (Schubert et al., 2001). Similarly, Schultze (2010) considered that the higher the spatial presence users feel, the more they are absorbed and emotionally engaged with the virtual environment. For example, to raise awareness of deforestation among students, reading a brochure with information may not "convince" them the same, compared to the experience where tree cutting is simulated (Ahn et al., 2014). Similarly, when individuals see a traffic accident or near miss in a virtual world, they are sensitized, and emotional reactions are triggered, resulting in a positive effect on their learning about road behavior (Sheridan, 2016). Thus, strong emotions (Diemer et al, 2015) and corresponding emotional experiences can lead to the formation of more detailed memories (Adelman & Estes, 2013), where the experience is converted into knowledge and transferred to long-term memory. At the same time, spatial presence encourages students to actively interact with the (virtual) environment and reduces the cognitive effort of processing information in the environment. It could be argued that the above makes learners reach the point of acting intuitively, without thinking before acting (in a natural way).

However, when participants feel self-present (being alone) in a virtual environment, lower learning outcomes were achieved compared to those achieved by social presence (Selverian & Hwang, 2003). However, some caution is needed, as an increased sense of presence has been found to result in high cognitive load and impaired learning (Makransky et al, 2017). Therefore, there needs to be some balance between knowledge and sense of presence to ultimately result in benefit to learners.

*Interaction and learning*

Interaction in a virtual environment, as highlighted in a previous chapter (see Chapter "3.4. Interaction"), is the -as natural as possible- communication and connection between users and the virtual environment (Burdea & Coiffet, 2003). When users engage in interactive learning systems with 3D virtual objects, they move from being passive observers to active thinkers (Trindade et al, 2002). It seems that this feature of VR plays a role in users' learning, as it creates interactive and experiential learning experiences, which contrast with the -usually- passive learning of traditional teaching (Cheung et al., 2013; Ferracani et al., 2014; Zhou et al., 2018).

Two main types of interaction are implemented in VR. The first type is the active interaction induced by users towards the system with controllers that allow them to select an object or trigger a sequence of events (Ferguson et al., 2020). The second type is embodied interaction, which enables one's (physical) body to interact with the virtual environment, for example, with gestures (Hartson & Pyla, 2012). The latter type of interaction will be discussed in a later chapter, as it is more relevant to fully immersive VR (cf. Chapter "7. Fully Immersive Virtual Reality and learning"). Regarding active interaction, it is worth noting that users who freely and actively navigate a virtual space are positively affected, as their cognitive interest increases, coupled with the sense of presence they feel (Ferguson et al, 2020).

However, beyond free browsing in a virtual environment, it has been found that guiding learners during an intervention can also yield good learning outcomes (Topu & Goktas, 2019). In particular, passive interaction, for example, a guided tour, was found to increase the effectiveness of learning more in terms of recall and retention of knowledge (Ferguson et al., 2020), compared to active interaction. The question arises as to whether the teacher wishes to produce material that implements free browsing or whether to opt for a more guided approach. In this dilemma, selective (where appropriate) learner support would probably provide the solution (Shute et al., 2017).

*Other factors affecting learning in the VR*

In addition to the above factors, the following factors can be mentioned for which there has been increased research interest regarding learning in virtual environments (Sekhar et al., 2018):

- Engagement. Engagement, as a term, has been associated with the direct user-material connection, which can also be described as a dependency relationship (McMahan, 2003), as well as emotional engagement with a particular object or product (Mollen & Wilson, 2010). It could be said that engagement is associated with active, purposeful, flexible, and constructive interactions with social and physical environments (Furrer & Skinner, 2003). Engagement in virtual environments refers to the state in which individuals actively engage with the material in ways that are new to them (Trindade et al., 2002). There appears to be a direct relationship between interaction and engagement, as there is increased engagement of participants in kinesthetic learning environments (Lindgren et al, 2016). Furthermore, according to Antonacci and Modaress

(2005), a virtual environment can increase user engagement and as a consequence, they can develop higher-level cognitive skills such as analysis, evaluation, and problem-solving.

- Realism. From a technical point of view, the realism of an application varies depending on how detailed the virtual objects are and, in general, how much their behavior resembles the real ones. It is also considered a subjective characteristic, as individuals perceive it differently. Furthermore, it plays an important role in users' experience and learning when engaging with virtual environments (Dalgarno & Lee, 2010; Lee et al., 2010); essentially, 3D representations facilitate users' learning (Harrington, 2012).
- Ease of use. Ease of use is also an important factor that influences whether individuals accept the use of a technological tool (Davis et al., 1989). Key elements that a virtual environment should have in order to be classified as easy to use are easy identification of the topic, clear instructions, and easy handling by users (Fokides, 2017b). Furthermore, ease of use and immersion -in combination- can positively influence learners perceived cognitive functions in virtual worlds (Chen, 2016).
- Usefulness. Usefulness, in this case, is the perception users have that the technological tool they use facilitates their learning. Similarly, in the case of VR, it is the extent to which individuals believe that virtual environments facilitate the learning process and enhance their productivity and performance, compared to other teaching methods (Fokides & Atsikpasi, 2018). It is worth mentioning that, for a virtual world to be considered useful by users, it should provide them with features such as ease of use, but also the feeling of enjoyment (Tokel & İsler, 2015). In terms of the effect of usefulness on learning, it has been found to influence cognitive outcomes when ICT tools are used (Hong & Tam, 2006), including VR (Fokides, 2017b), being primarily related to skill learning (Lee et al., 2010).
- Enjoyment. Studies have demonstrated that positive emotions contribute significantly to knowledge acquisition (Gulikers et al., 2005; Park et al., 2015). The negative or positive mood of users hinders or, respectively, promotes learning (Brand et al., 2007). In fact, having a negative mood, users put more effort into performing a task that requires cognitive processing. In line with other technological tools, the fun, and, more generally, the pleasure felt by users in a virtual environment can be determined by the extent to which they consider their experience a pleasant one (Ducoffe, 1996). For example, playful features in a virtual environment can lead to increased levels of fun and enjoyment, and, in turn, increased motivation to learn or acquire knowledge (Fokides & Zampouli, 2017; McLellan, 2004).
- Motivation for learning. Modern cognitive theories view motivation for learning as a non-static feature, but as an intrinsically unstable element that is sensitive to the way the content is presented (Linnenbrink & Pintrich, 2002). Researchers believe that the 3D representation of objects in VR, the interaction of participants with the objects, and the increased control users have over what they choose to see, can influence motivation and, therefore, learning (Fokides, 2017a; Fokides & Zampouli, 2017; McLellan, 2004). It has also been found that 3D learning environments can increase learners' motivation and engagement, much more so than 2D environments (Limniou et al, 2008). For example, research has indicated that VR promotes learners' motivation and interest in learning 3D Animation (Ho et al., 2019).

# Chapter 7. Fully Immersive Virtual Reality and learning

The key features/factors of VR were found to influence learning outcomes (see Chapter "6. Virtual Reality and learning"). These factors are present in fully immersive VR as well, but in this case, they are more intense and have a greater influence on users. The reason lies in the nature of the medium used, since, based on the taxonomy adopted, fully immersive VR results from the use of 6DoF HMDs.

In general, studies have looked at whether fully immersive VR can bring about positive learning outcomes in a variety of subjects and at all levels of education, but also whether it can be used to develop specialized skills, for example in robotic surgery (Bric et al, 2016). It could be argued that there is a growing research interest in the educational use of fully immersive VR, as in recent years, the following, among others, have been considered (Muhanna, 2015; Papadakis et al., 2011; Shaw, Wünsche, Lutteroth, Marks, Buckley, & Corballis, 2015; Slater et al., 2007):

- The creation or not of positive experiences.
- The effectiveness of learning.
- The degree of the sense of immersion.
- The degree of the sense of presence.
- The degree of sense of embodiment.
- The degree of enjoyment and motivation.
- Minimizing latency.
- Intuitive interaction with the virtual environment.
- The degree to which the individual's perceptual awareness of the virtual environment is affected.

With 6DoF HMDs, users are free from external distractions and fully immersed in the virtual environment (Falah et al., 2014). Indeed, a number of studies have confirmed that with HMDs the immersion (and presence) experienced by users is increased (McKenzie et al., 2019; Passig et al., 2016; Rupp et al., 2016). Immersion, along with rich audiovisual stimuli, ultimately provides users with unique experiences that are superior to other types of VR, and to conventional instruction (Fowler, 2015; Freina & Ott, 2015; Olmos et al, 2018). For example, research on teaching engineering subjects compared traditional teaching with two immersive learning environments (Alhalabi, 2016). The results indicated that participants learned more about astronomy, transportation, and networks with immersive VR compared to traditional teaching. Similar results were obtained by Webster's (2016) research comparing lecturing with fully immersive VR in terms of acquiring knowledge about Environmental Education and soil erosion. It seemed participants learned more about the theory, principles, and erosion prevention with fully immersive VR compared to just lecturing.

In fully immersive VR, in addition to immersion, there is also a sense of presence (Falah et al., 2014). As a result, there is more engagement with the learning material, better recall of information, and increased awareness of the virtual space (Papadakis et al., 2011). In addition, for users who feel that they are in a virtual space that involves skill acquisition, there is a likelihood that they will transfer what they have learned to the real world (Ahn et al., 2014).

The truth is, however, that there is no clear link between presence and learning outcomes in fully immersive VR environments. For example, Moreno and Mayer (2002) compared the effects of using fully immersive VR environments with desktop VR to teach about botany. The researchers found that fully immersive VR did not increase learning, but increased the sense of presence. Similarly, another study of medical students found that no better learning outcomes were achieved in the neuroanatomy course when using HMDs, 3D videos, and when interacting with a 3D model of the human brain, compared to reading books on the Internet for the same amount of time (Stepan et al., 2017).

Makransky et al. (2017) concluded that although fully immersive VR led to a greater sense of presence, the cognitive effects were not particularly good, due to the increased cognitive load it caused in users. It seemed that their research was in agreement with others that measured cognitive overload due to fully immersive VR (Gerjets et al., 2014; Mills et al., 2017).

Furthermore, Makransky and Lilleholt (2018), examined whether there are differences between fully immersive VR and desktop VR and whether different levels of immersion in a virtual world affect learning outcomes. The sample consisted of students and two questionnaires were administered (the first explored prior knowledge and the second explored factors that influence learning). It appeared that the users preferred to use fully immersive VR more than the desktop VR and the factors found to play a greater role in learning were presence and motivation. Again, however, there were no different results at the cognitive level.

North and North (2016) investigated the factors that contribute to increasing the sense of presence in traditional and fully immersive VR environments. They conducted two experiments involving flight simulation. The analysis indicated a statistically significant difference regarding participants' sense of presence between the two environments. Specifically, they had a higher sense of presence with fully immersive VR compared to the traditional method, which led to a richer learning experience through fully immersive VR. However, learning outcomes were not different between the two environments.

Apart from the fact that most types of interaction that affect learning in VR also affect learning in fully immersive VR, one type of interaction that has a particular impact on learning outcomes in the latter case is embodied interaction.

The theory of embodied knowledge argues that knowledge (meaning high-level mental structures such as concepts, but also performance in various cognitive tasks such as conceptual understanding or critical thinking) is acquired/formed through body actions (involving the motor and perceptual system, but also bodily interactions with the environment) (Wilson & Foglia, 2011). This is because when activities and processes are carried out with the body, the conceptual basis on which new knowledge is constructed is provided (Lindgren et al., 2016). According to this theory, when individuals engage with tangible-physical objects, the way they think about them is affected (Lakoff & Johnson, 1999; Lakoff & Núñez, 2000). Embodied interaction relates to the haptic interaction created between users and objects (e.g., controllers or electronic pens) in which haptic feedback has been included (Ishii & Ullmer, 1997).

Thus, it can be assumed that good learning outcomes are achieved in a fully immersive VR system, thanks to the embodied interaction of users with the virtual environment. Indeed, it was found that physical activity improves learning outcomes (Skulmowski & Rey, 2018), i.e. the interaction of the virtual system with one's whole body and the multimodality provided by a virtual environment can increase learning (Dalgarno & Lee, 2010; Fowler, 2015). Embodied interaction appears to simultaneously enhance engagement and learning in virtual environments (Lindgren et al., 2016), highlighting the direct relationship between action and learning (Wilson & Foglia, 2011). Physical interaction with virtual objects improves reading and writing, memorization (Kiefer & Trumpp, 2012), comprehension of abstract concepts (Atmatzidou & Demetriadis, 2016), as well as concepts belonging to "difficult" cognitive domains, such as mathematics and science (Manches et al., 2010). Thus, embodied interaction in a fully immersive VR environment transforms learning activities into action and immersive learning experiences for users (Lindgren & Johnson-Glenberg, 2013; Johnson-Glenberg, 2017, 2019; Johnson-Glenberg et al., 2014; Skulmowski & Rey, 2018).

On the other hand, it has been argued that high embodied interaction in an immersive virtual environment does not necessarily guarantee higher learning outcomes, compared to an approach that provides a lower level of physical engagement (Skulmowski et al, 2016; Tran et al., 2017). It appears that during an activity with increased embodied interaction, a high cognitive load is created for users, which may hinder embodied learning (Ruiter et al., 2015; Skulmowski et al., 2016). Perhaps embodied interaction is successful in activities that are not particularly complex (Song et al., 2014), for example, simple movement patterns for learning to dance (Warburton et al., 2013).

Research indicated that poor app development or poor-quality HMDs (e.g., poor focus), that negative effects (e.g., visual distractions and simulator sickness) are caused (Duchowski et al., 2014). For example, in a study that examined the gaming experience with and without HMDs, it appeared that most participants felt higher levels of simulator sickness during the process of playing with HMDs (Tan et al, 2015). Similar conclusions were reached by another study (Carnegie & Rhee, 2015). It should be noted that the annoyances of using HMDs can be minimized, as they depend on manufacturing characteristics, such as the type of HMDs used and the quality of the respective application (Porcino et al., 2017).

It has also been found that when HMDs are perceived as difficult to use, then the learning objectives (either in terms of knowledge or skills) are not achieved. For example, in a study on engineering (Ritter et al., 2018), users did not learn much with HMDs because the devices' cables combined with the low sound made them difficult to use. In contrast, they seemed to learn more with desktop VR because they found it easy enough to use. Moreover, usability seems to play an important role, as a difficult interface forces the user to put more effort into navigating and understanding the system, interrupting the flow of their experience (Glaser & Schmidt, 2018).

Furthermore, the role of immersion and presence may be negative either because of the lack of user concentration (Karageorgakis & Nisiforou, 2018; McKenzie et al., 2019) or because users themselves placed more importance on the novelty of the experience, without being so interested in the content (Rupp et al., 2016). This means that ways need to be found for users to engage with both the environment and content. Contradictory results were also found in studies that examined the levels of collaboration between participants. Although increased levels of teamwork were reported (Sun et al., 2018), several problems were also reported (Karageorgakis & Nisiforou, 2018).

In addition, it is worth noting that fully immersive VR applications take many hours to build. This, perhaps, may deter teachers from using these technologies in the future (Fokides, 2017b; Fokides & Zampouli, 2017). Furthermore, the high cost of purchasing HMDs is a consideration, although in recent years, these have become much more affordable to the average user. As the technology gradually becomes more accessible to the general public and the software responds more accurately to human interaction, the experience in fully immersive VR applications will become increasingly satisfying. Consequently, reduced costs and technological innovation will remove barriers to its adoption.

# Chapter 8. Fully Immersive Digital Learning Experience

This chapter attempts to link and synthesize what has been analyzed in the previous chapters. The purpose is to highlight a new term, that of the fully immersive digital learning experience (FIDLE).

## 8.1. Summary of the previous chapters

When examining a subject, whether at a theoretical or practical level, it is important to take into account, if not all, at least the most important elements that shape it. This has been attempted for VR. The conclusion is that it is a technology that can offer rich user experiences. It was found that these experiences are significantly influenced by immersion, presence, and interaction, with the latter being instrumental to the other two factors. Immersion was considered more of a technical characteristic and is about how complete is the sensory information provided to the user by the virtual environment; the greater its similarity to the real world, the more immersed users feel. Presence is more of a subjective phenomenon, as it is about how much users feel that "they are" in a virtual environment and have the illusion of non-mediation. Interaction is about the natural communication and connection between users and the virtual environment.

Regarding the educational uses of VR, it was found that it offers possibilities that go beyond those of other digital tools, such as exploring situations that are not possible in any other way, breaking the boundaries of reality, providing high-quality and convincing learning experiences, developing creativity, testing preconceptions, active participation in learning, adapting the material to the needs of students, eliminating their anxiety, and encouraging teachers for alternative ways of teaching. It was also found that learning in virtual environments, in addition to immersion, presence, and interaction, is influenced by the engagement, realism, ease of use, usefulness, enjoyment, and motivation offered by VR.

Out of all the technologies that fall under the umbrella of VR, HMDs are of interest, as they can offer fully immersive experiences (and thus, implement what is called fully immersive VR). Apart from the fact that HMDs cut off users from the external environment, so that the audiovisual stimuli they receive come only from them, the degree of immersion they achieve depends on a fairly significant number of technical features, such as motion tracking, degrees of freedom, type of controls, field of view, screen resolution, refresh rate, visual calibration, and low response time.

Fully immersive VR, resulting from the use of HMDs, seems to have a lot to offer in learning. This is mainly due to immersion, presence, enjoyment, and engagement.

## 8.2. Defining Fully Immersive Digital Learning Experience

Often, in the text, reference was made to the fact that VR offers rich user experiences. These are digital experiences since the tools used by VR are technological/digital. But how exactly is a digital experience defined?

It could be argued that the term "digital experience" is synonymous with the term "user experience," since any experience that takes place on the Internet, through software, or a digital device is, at its core, a digital experience (Lee et al., 2018). Indeed, what experiences individuals have when using digital media and what constitutes a "good" experience have been of concern to researchers from early on (e.g., Forlizzi & Battarbee, 2004; Hassenzahl & Tractinsky, 2006; Wright et al., 2004). Unfortunately, there is no commonly accepted definition of this concept. This is because the concepts with which it is associated, such as fun, pleasure, surprise, and intimacy, are subjective. Moreover, researchers tend to constantly add other attributes, resulting in an ever-increasing complexity of the relationships between them (Cockton, 2006). In general, it refers to what the user experiences from a (digital) product or (digital) service used to achieve a specific goal (Agiledrop, 2020) and what emotions are generated (Biondi et al., 2015; Kamstrupp, 2016; McIntosh & Wright, 2019).

However, it is possible that there is no "use" (in the absolute sense of the word) of a digital artifact (tangible or intangible). For example, one can simply watch a movie or video on YouTube or listen to music on one's computer. In other words, users may be passive receivers. It goes without saying that a person would have to start a program to implement the above. So, there is some use of software or hardware, but it is brief; for the most part, the passive dimension prevails, but it is still digital since it comes from a digital medium. It would therefore be better to adopt the view that the digital experience is a superset of the (digital) user experience.

In terms of what would qualify as a positive digital experience, it could be argued that it is:
*The very positive impressions and emotions that people get when dealing with intangible or tangible digital artifacts.*

A positive digital experience includes three very basic characteristics (Seasia Infotech, n. d.):
- Excellent design. Users should be convinced of what is provided/presented to them. For example, a VR application should provide fidelity, verisimilitude, and very good graphics.
- Excellent functionality. Any construction/functional problems are bound to ruin the user experience.
- Custom content. It is important that content is adapted to the needs and requirements of users. For example, if it is a digital game, it could be possible to configure the "player" (profile and avatar creation), or the difficulty level of the track, or to enable/disable various features.

By analogy with the digital experience, can it be said that the learning experience also exists, and if so, on what factors does it depend?

The truth is that the term "learning experience" is not new and refers to any course, program, or other activity through which someone learns something (The Glossary of Education Reform, 2013). Indeed, because the above definition implies that individuals learn through a variety of situations and ways, the use of the term "learning experience" is preferred to the term "course," since it has a relatively limited meaning and/or conventional connotation. In addition, the increasing use of the term "learning experience" by the educational and scientific community reflects the changes that have occurred in the way individuals are educated, due to significant pedagogical changes, but more importantly, due to technological developments. Essentially, it shows the need for a renewal of perceptions of how, when, and where learning takes place (Entwistle & Ramsden, 2015).

On the other hand, the above definition of the learning experience, while it informs about the ways (...any lesson, program or other activity) and about the end result (...someone learns something), it does not inform about what is involved and what happens on the side of the recipient, i.e., the one who learns (beyond the fact that they learned something). Thus, drawing from Experiential Learning

Theory, it could be argued that learning is a process in which experience acquisition, thinking, and action are involved (Kolb, 1984; Kolb & Kolb, 2009).

However, even if the above is included in the definition of learning experience, it still does not take into account what the learner feels (in contrast to the definition of digital experience given above). Indeed, others have also stressed the importance of emotions during learning. For example, Moon (2013), considered that emotions are related to learning since (a) they influence the construction of knowledge, (b) they influence the learning process, and (c) they can further promote the learning process. Not only that, but positive emotions lead students to engage more actively in learning activities, increase their motivation to learn (Artino, 2012; Weissberg et al., 2015), their efficiency and enjoyment (Briscoe, 2012; Kohn, 2004), their engagement with the subject matter (Rowe et al., 2015), and their degree of satisfaction (Vacharkulksemsuk & Fredrickson, 2013).

Considering the above, the learning experience is:
*The mental state that results from the interaction of the learner with any form of learning material. It is the combined result of the actions, experiences, and emotions caused by this interaction. The (desired) end result is the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

Similarly, a positive learning experience is considered to be:
*The mental state in which the learner actively interacts with the cognitive material, having experiences that could be considered "unique", while at the same time feeling positive emotions. The above results in the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

It was mentioned above that technology has had a significant impact on users' learning experiences, as it has multiplied and diversified the ways they can learn and interact with learning materials. Indeed, students have at their disposal multimedia applications, digital educational games, and realistic virtual experiences, they can exchange emails, and chat with teachers or peers. Moreover, thanks to technology, they can learn at their own pace, with or without instruction or supervision. All these are technology-enhanced learning experiences and are created by technology alone.

Considering the ever-increasing digital character of learning experiences, the terms "learning experience" and "digital experience" could -potentially- be unified into a new term, something that could be called "digital learning experience" (DLE). In other words, the two strands that constitute DLE create a new kind of experience, combining everything that the user wants and expects from a digital environment that aims to teach something. That is, to learn in an active way, create positive emotions, and live a unique experience, in a digital environment with an excellent design, without glitches, in which they can adapt the content according to their needs.

Thus, the DLE could be defined as:
*The mental state that results from the learner's interaction with any form of digital learning material. It is the combined result of the actions undertaken by the individuals, the experiences they have, and the emotions evoked by this interaction, and is directly dependent on the design, functionality, and adaptability of the digital learning material. The (desired) end result is the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

The positive DLE could be defined as follows:
*A positive digital learning experience is the fusion of the learning and digital experience characterized by the excellent design, excellent functionality, and adaptability of the digital learning material, the active participation of the learner, and the positive emotions and experiences that the learner feels or experiences. The above, results in the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

Moving DLE into the context of VR, the elements of immersion, presence, and interaction should be included since these were considered to be its key characteristics. In fact, the same factors are present to a greater extent and intensity in fully immersive VR. Therefore, in fully immersive VR, DLE can be transformed into a "fully immersive digital learning experience" (FIDE) (Figure 32).

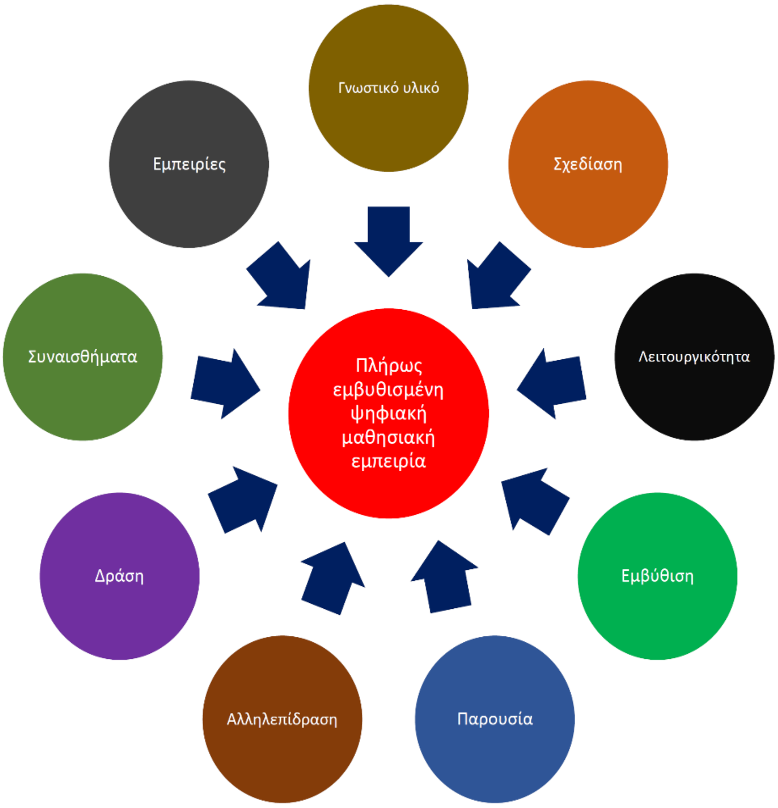


**Figure 32.** The fully immersive digital learning experience

Thus, the FIDE could be defined as:
*The mental state that results from the interaction of the learner with any form of learning material offered by media belonging to fully immersive Virtual Reality. It is the combined result of the actions undertaken by the individuals, the experiences they have, and the emotions evoked. It depends directly on the design, functionality, and adaptability of the digital learning material, as well as on the degree of immersion, presence, and interaction it offers. The (desired) end result is the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

Corresponding to the previous definitions:
*The positive fully immersive digital learning experience is the fusion of the learning and digital experience offered by media belonging to fully immersive Virtual Reality. It is characterized by the*

*excellent design, excellent functionality, and adaptability of the digital learning material, the active action/participation of the learner, the positive emotions and experiences that the learner feels or experiences under the influence of the high degree of immersion in the content/application, the strong sense of presence felt, and the high degree of interaction with the digital medium. The above, results in the acquisition of knowledge, and/or experience, and/or skills, and/or attitudes.*

## 8.3. Factors affecting FIDLE

In the previous section, an attempt was made to define FIDLE. What arises, as a legitimate question, is how it can be examined. To this end, research related to this topic, i.e., research on VR or fully immersive VR in relation to learning, was searched in repositories of scientific publications. A key requirement was that these studies utilized questionnaires and scales that examined some or all of the dimensions of fully immersive VR as summarized in Figure 32. All possible combinations of the following keywords were used: virtual reality, HMD(s), scale(s), questionnaire(s), learning, education, and student(s).

After a sufficient number of such studies (over 150) were retrieved, the questionnaires/scales they used (in case they were not included in the article) were searched. Where the researchers used adapted questionnaires, i.e., questionnaires that were about another technology, but the researchers adapted them to address issues related to VR or immersive VR, the originals were searched.

It was found that the surveys utilized 61 unique questionnaires (several surveys used the same original questionnaires), examining 22 constructs (Table 4), with a total of 164 factors (Table 5). The concept with the most factors used was Experience (*n* = 73), followed by Presence (*n* = 38), Immersion (*n* = 18), Flow (n = 18, which several researchers included as part of Presence or Immersion), and Satisfaction (*n* = 14 each). Tables 6 to 11 detail the factors by concept. The most frequently occurring factor was Presence (*n* = 17, including its various variants), followed by Control (*n* = 10), Immersion (*n* = 7), Attention, Satisfaction, Goals, Feedback, Involvement, and Affect (positive or negative) (*n* = 5 all).

**Table 4.** Concepts addressed by the questionnaires

| Concept/Construct | | |
|---|---|---|
| **Experience** | **Self-efficacy** | **Hedonic and pragmatic quality** |
| Presence | Usability | Emotions |
| Immersion | reality judgment | Absorption |
| Motivation | Affect | Beliefs |
| Flow | Anxiety | Empathy |
| Engagement | Interest | Learning impact |
| Satisfaction | cognitive load | Enjoyment |
| | | Simulator sickness |

**Table 5.** Frequency of occurrence of factors in the questionnaires

| Agent | *n* | | Agent | *n* | Agent | *n* | Agent | *n* |
|---|---|---|---|---|---|---|---|---|
| Presence | 2 | 17 | Confidence | 2 | Understandability | 1 | Communication place | 1 |
| Spatial presence | 8 | | Self-efficacy | 2 | System naturalness | 1 | Narratives | 1 |
| social presence | 3 | | Trait anxiety | 2 | Autotelic focus | 1 | Non-mediation | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Natural presence | 1 | | Relevance | 2 | Audiovisual appeal | 1 | state anxiety | 1 |
| Core self-presence | 1 | | Autotelic experience | 1 | External correspondence | 1 | Comprehension | 1 |
| Extended self-presence | 1 | | Internal/external correspondence | 1 | personal gratification | 1 | Transformation of time | 1 |
| Proto self-presence | 1 | | Gameplay | 1 | Ease of control | 1 | Anger | 1 |
| Control | | 10 | Long learning phase | 1 | Nausea | 1 | Dissociation | 1 |
| Immersion | | 7 | Help | 1 | Action awareness | 1 | Pride | 1 |
| Attention | | 5 | Increase status | 1 | Emotional reaction | 1 | Intention to use | 1 |
| Satisfaction | | 5 | Likelihood to recommend | 1 | Temporal dissociation | 1 | Perspective-taking | 1 |
| Goals | | 5 | Happy | 1 | Fun | 1 | Play engrossment | 1 |
| Feedback | | 5 | Navigation | 1 | Behavioural engagement | 1 | Consistency | 1 |
| Involvement | | 5 | No bugs/errors | 1 | social interaction | 1 | Dependability | 1 |
| Affect (positive/ negative) | | 5 | No extrinsic | 1 | system responsiveness | 1 | Frustration | 1 |
| Usability | | 4 | Ownership | 1 | Competition | 1 | Hopelessness | 1 |
| Enjoyment | | 4 | Perspicuity | 1 | Spatial awareness | 1 | Focused attention | 1 |
| Sensory | | 4 | Guidance | 1 | Learn friends | 1 | Hope | 1 |
| Flow | | 4 | loss of self | 1 | Core self | 1 | Frequent use | 1 |
| Challenge | | 4 | reality judgment | 1 | Mastery | 1 | Relief | 1 |
| Anxiety | | 4 | Personal innovativeness | 1 | Narrative understanding | 1 | Distress | 1 |
| visual aesthetics | | 4 | Focused immersion | 1 | Empathic concerns | 1 | Pleasure | 1 |
| Curiosity | | 3 | Social experience | 1 | Gaming | 1 | Playability | 1 |
| Skills (advanced, mainframe, beginning) | | 3 | knowledge improvement | 1 | Emotional attachment | 1 | Hedonic quality-stimulation | 1 |
| Distraction | | 3 | Fictional | 1 | Freedom | 1 | Discovery | 1 |
| Realism | | 3 | Pragmatic quality | 1 | Facilitators | 1 | Accomplishment | 1 |
| Autonomy | | 3 | Extended self | 1 | Creative freedom | 1 | Shame | 1 |
| Concentration | | 3 | natural mapping | 1 | Menus | 1 | Delightfulness | 1 |
| Ease of use | | 2 | Possible actions | 1 | Unusual action | 1 | Disorientation | 1 |
| cognitive load | | 2 | Efficiency | 1 | Hedonic quality | 1 | Camera | 1 |
| Absorption | | 3 | Emotional reaction towards system | 1 | Emotional engagement | 1 | Paradox of control | 1 |
| Playfulness | | 2 | Play-direct | 1 | Mission | 1 | Commitment | 1 |
| Audio aesthetics | | 2 | Settings | 1 | Reuse | 1 | Oculomotor | 1 |
| Attractiveness | | 2 | Tension | 1 | Simplicity | 1 | Aesthetics | 1 |
| Boredom | | 2 | Trust | 1 | Tiredness | 1 | Operator | 1 |
| Empathy | | 2 | Anticipation | 1 | Variety | 1 | skill balance | 1 |
| Usefulness | | 2 | Environment | 1 | Creativity | 1 | Relatedness | 1 |
| Stimulation | | 2 | Expectations | 1 | Emotions personal | 1 | Fantasy | 1 |
| Competence | | 2 | Multimodality | 1 | Excitement | 1 | Engagement | 1 |
| Efficiency | | 2 | Varied drawing | 1 | Captivation | 1 | Unusual actions | 1 |
| Novelty | | 2 | loss of self-consciousness | 1 | Action awareness merging | 1 | Controls | 1 |
| | | | | | | | Focus | 1 |

**Table 6.** Factors by concept (a)

| **Experience** | | |
|---|---|---|
| Absorption | Emotional reaction towards system | Likelihood to recommend |
| Accomplishment | Emotions personal | mobile site |
| Affect | Enjoyment | Navigation |
| Affect (Negative) | Environment | No bugs/errors |
| Affect (Positive) | Excitement | No extrinsic |
| Attractiveness | Expectations | Novelty |
| Audiovisual appeal | Facilitators | Ownership |
| Autonomy | Feedback | Perspicuity |
| Autotelic focus | Fictional | Play-direct |

|  |  |  |
|---|---|---|
| Boredom | Flow | Playfulness |
| Camera | Freedom | Reuse |
| Challenge | Frequent use | Sensory |
| Commitment | Frustration | Settings |
| Competence | Fun | Simplicity |
| Competition | Gameplay | Social experience |
| Consistency | Goals | Stimulation |
| Control | Guidance | Tension |
| Curiosity | Happy | Tiredness |
| Delightfulness | Help | Trust |
| Dependability | Immersion | Usability |
| Discovery | Increase status | Usefulness |
| Ease of control | Learn friends | Variety |
| Ease of use | Mission | visual aesthetics |
| Efficiency | Mastery |  |
| Emotional attachment | Menus |  |

**Table 7.** Factors by concept (b)

| **Presence** |  | **Immersion** |
|---|---|---|
| Anticipation | Realism | Attention |
| Attention | Satisfaction | Captivation |
| Attention/absorption | Sensory | Challenge |
| cognitive load | social presence | Comprehension |
| Control | Social presence-Behavioral engagement | Concentration |
| Core self-presence | Social presence-Involvement/Empathy | Control |
| Creativity | spatial presence | Curiosity |
| Distraction | Spatial Presence-Believability | Dissociation |
| Extended self-presence | Spatial Presence-Imagination | Distraction |
| Involvement | Spatial Presence-Interest | Emotional engagement |
| Involvement/Control | Spatial Presence-Involvement | Empathy |
| Internal/external correspondence | Spatial Presence-Possible actions | Focus |
| Long learning phase | Spatial Presence-Self-location | Gaming |
| Multimodality | Spatial Presence-Spatial awareness | Immersion |
| natural mapping | System naturalness | Involvement |
| Non-mediation | system responsiveness | Narrative understanding |
| Natural presence | Understandability | Realism |
| Presence | Unusual actions | Sensory |
| Proto self-presence | Varied drawing |  |

**Table 8.** Factors by concept (c)

| **Motivation** | **Flow** | **Engagement** | **Satisfaction** |
|---|---|---|---|
| Attention | Action awareness merging | Absorption | Audio aesthetics |
| Autonomy | Autotelic Experience | Aesthetics | Communication place |
| Competence | Challenge/Skill balance | Control | Creative freedom |

| | | | |
|---|---|---|---|
| Confidence | Concentration | Distraction | Enjoyment |
| Controls | Control | Engagement | Feedback |
| Immersion | Feedback | Flow | Flow |
| Relatedness | Flow | Focused attention | Goals |
| Relevance | Goals | Immersion | Narratives |
| Satisfaction | Goals and feedback | Novelty | Operator |
| | Immersion | Presence | personal gratification |
| | loss of self-consciousness | Realism | Play engrossment |
| | Paradox of control | Sensory | Satisfaction |
| | Skills | Usability | Usability/Playability |
| | Transformation of time | | visual aesthetics |

**Table 9.** Factors by concept (d)

| Self-efficacy | Usability | reality judgment | Affect | Anxiety |
|---|---|---|---|---|
| Advanced level skills | Usability | reality judgment | Negative affect | Anxiety |
| Beginning level skills | | | Positive affect | state anxiety |
| Mainframe level skills | | | | Trait anxiety |
| Self-efficacy | | | | |

**Table 10.** Factors by concept (e)

| Interest | Cognitive load | Hedonic and pragmatic quality | Emotions | Beliefs |
|---|---|---|---|---|
| Attention | cognitive load | Attractiveness | Anger | Ease of use |
| Confidence | | Hedonic quality-stimulation | Anxiety | Intention to use |
| Relevance | | Pragmatic quality | Boredom | Self-efficacy |
| Satisfaction | | | Enjoyment | Usefulness |
| | | | Hope | |
| | | | Hopelessness | |
| | | | Pride | |
| | | | Relief | |
| | | | Shame | |

**Table 11.** Factors by concept (f)

| Absorption | Empathy | Learning impact | Enjoyment | Simulator sickness |
|---|---|---|---|---|
| Focused immersion | Perspective-taking | knowledge improvement | Autonomy | Disorientation |
| Curiosity | Empathic concern | | Challenge | Nausea |
| Enjoyment | Fantasy | | Concentration | Oculomotor |
| Control | Distress | | Feedback | |
| Personal innovativeness | | | Goals | |
| Playfulness | | | Immersion | |
| Temporal dissociation | | | Pleasure | |
| | | | Satisfaction | |
| | | | social interaction | |

Figure 33 visualizes the most frequently occurring factors, while Figure 34 attempts to illustrate the complexity of the relationships between concepts and factors, as it arose from the fact that in many cases identical or similar factors were used to examine different concepts.

The image illustrates most vividly the difficulty of defining concepts such as the experience and emotions caused to users by the use of digital media, even though, on the surface, this seems relatively simple. It is also evident that it is not feasible to consider all of the above factors at the same time.

Thus, the research that had been identified and the questionnaires used were re-read in order to see if any factors were identical or if some of them could be included under the same umbrella. Indeed, this led to the significant narrowing down of the factors that were likely to be considered. It was also found that the concepts of Flow, Immersion, and Presence were extremely difficult to separate, as a significant number of studies either considered them synonymous-similar concepts or used similar questionnaires to examine them. Therefore, it was decided to unify them

**Figure 33.** Visualization of the frequency of occurrence of factors

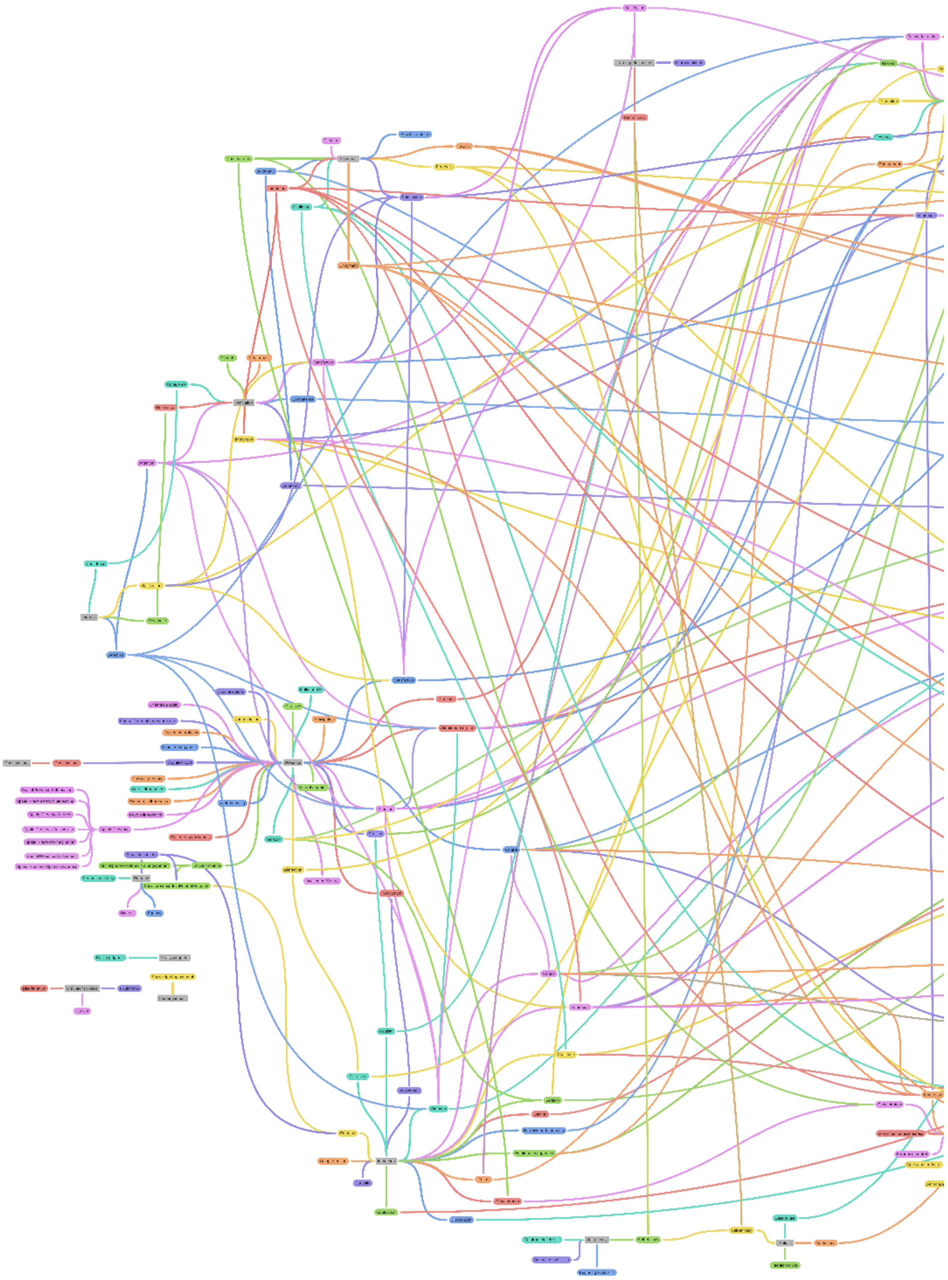


**Figure 34.** The relationships between concepts and their factors

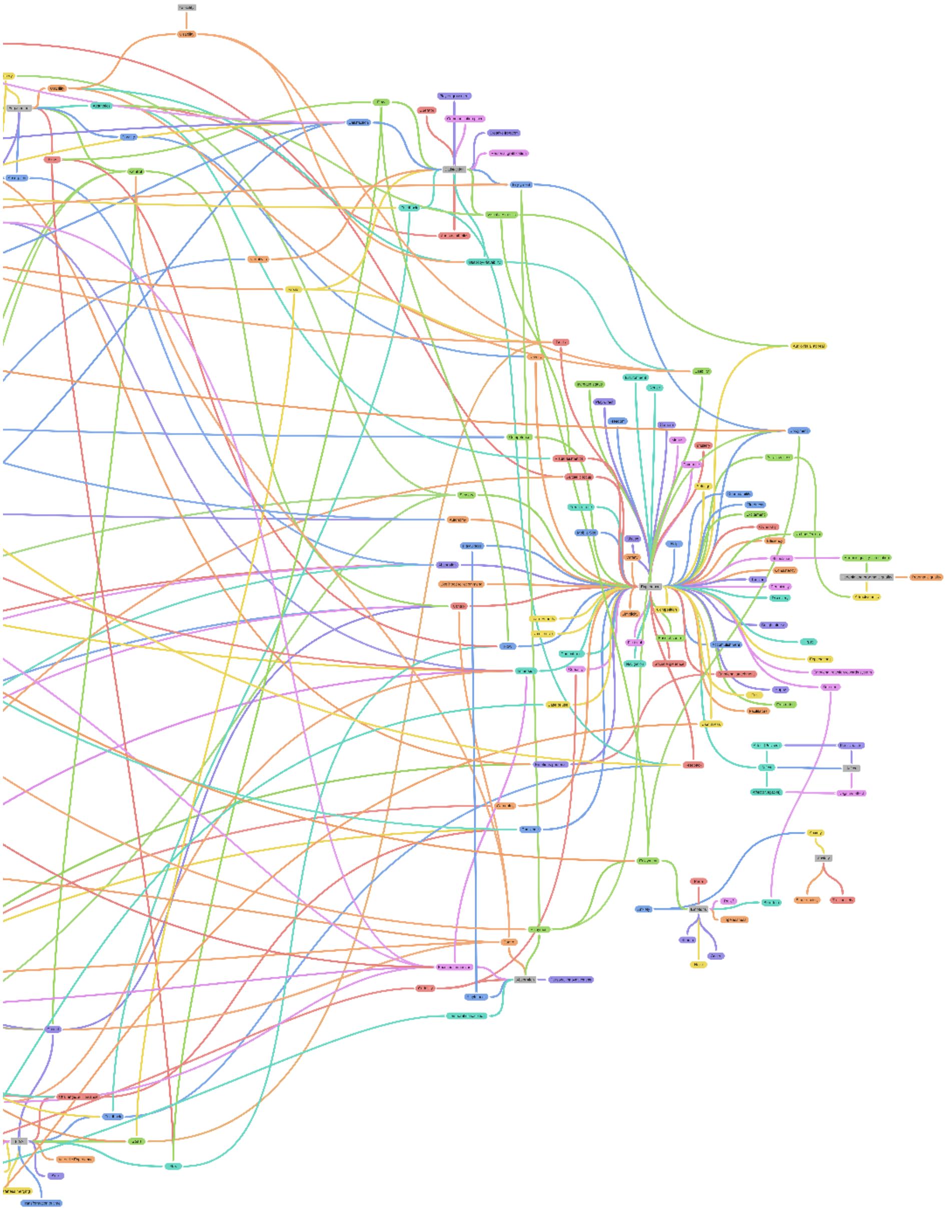


Table 12 presents the initial factors and their consolidation into broader factors.

**Table 12.** Consolidation of factors

| Original factor | New factor | Original factor | New factor |
|---|---|---|---|
| Aesthetics | Aesthetics/ appeal | Absorption | Flow/Immersion/Presence |
| Attractiveness | | Action awareness | |
| Audio aesthetics | | Action awareness merging | |
| Audiovisual appeal | | Attention | |
| Environment | | Autotelic experience | |
| Realism | | Autotelic focus | |
| Variety | | Behavioral engagement | |
| visual aesthetics | | Concentration | |
| cognitive load | cognitive load | Core self | |
| No extrinsic | | Core self-presence | |
| Autonomy | Control | Dissociation | |
| Control | | Distraction | |
| Mastery | | Emotional attachment | |
| Mission | | Empathic concerns | |
| Ownership | | Engagement | |
| Play-direct | | Extended self | |
| Expectations | Relevance to personal interests | Extended self-presence | |
| Relevance | | External correspondence | |
| Camera | Ease of use/Usability | Fantasy | |
| Consistency | | Flow | |
| Controls | | Focus | |
| Dependability | | Focused attention | |
| Ease of control | | Focused immersion | |
| Ease of use | | Immersion | |
| Gameplay | | Internal/external correspondence | |
| Gaming | | Involvement | |
| Long learning phase | | loss of self | |
| Narrative understanding | | loss of self-consciousness | |
| Navigation | | Non-mediation | |
| No bugs/errors | | Perspicuity | |
| Operator | | Natural presence | |
| Play engrossment | | Presence | |
| Playability | | Proto self-presence | |
| Pragmatic quality | | reality judgment | |
| Simplicity | | Relatedness | |
| System naturalness | | Sensory | |
| system responsiveness | | skill balance | |
| Understandability | | social presence | |
| Usability | | Spatial awareness | |
| Enjoyment | Enjoyment | Spatial presence | |
| Fun | | Temporal dissociation | |
| Hedonic quality | | Transformation of time | |
| Hedonic quality-stimulation | | Commitment | Motivation |
| Novelty | | Frequent use | |

| | |
|---|---|
| Playfulness | |
| Pleasure | |
| Stimulation | |
| Facilitators | Guidance/ feedback |
| Feedback | |
| Goals | |
| Guidance | |
| Help | |
| Menus | |
| Narratives | |
| natural mapping | |
| Settings | |
| Creative freedom | Interaction |
| Freedom | |
| Paradox of control | |
| Possible action | |
| Competence | Self-efficacy |
| Efficiency | |
| Efficiency | |
| Self-efficacy | |
| Skills (advanced, mainframe, beginning) | |
| Disorientation | Simulator sickness |
| Nausea | |
| Oculomotor | |
| Comprehension | Subjective knowledge gains |
| Creativity | |
| Discovery | |
| knowledge improvement | |
| Usefulness | |
| Communication place* | Excluded (could not be classified) |
| Competition* | |
| Fictional | |
| Learn friends* | |
| Multimodality | |
| Perspective-taking | |
| Social experience* | |
| Social interaction* | |
| Unusual actions | |
| Varied drawing | |
| Intention to use | |
| Likelihood to recommend | |
| Personal innovativeness | |
| Reuse | |
| Accomplishment | Positive-negative affect/feelings |
| Affect (positive/negative) | |
| Anger | |
| Anticipation | |
| Anxiety | |
| Boredom | |
| Captivation | |
| Challenge | |
| Confidence | |
| Curiosity | |
| Delightfulness | |
| Distress | |
| Emotional engagement | |
| Emotional reaction | |
| Emotional reaction toward a system | |
| Emotions personal | |
| Empathy | |
| Excitement | |
| Frustration | |
| Happy | |
| Hope | |
| Hopelessness | |
| Increase status | |
| personal gratification | |
| Pride | |
| Relief | |
| Satisfaction | |
| Shame | |
| state anxiety | |
| Tension | |
| Tiredness | |
| Traits anxiety | |
| Trust | |

*Notes.* Factors marked with an asterisk (*) are for collaborative environments, which is not true for all applications.

The above analysis resulted in 14 factors that can be grouped into three broad categories:

- Factors related to emotions: flow/immersion/presence, enjoyment, and positive/negative affect/feelings.
- Factors related to the learning experience: subjective knowledge gains, domain-specific interest, cognitive load, and motivation to learn.
- Factors related to technical issues: self-efficacy, guidance/feedback, control, aesthetics/appeal, interaction, ease of use/usability, and simulator sickness.

Thus, a model describing the FIDLE can be formulated (Figure 35).

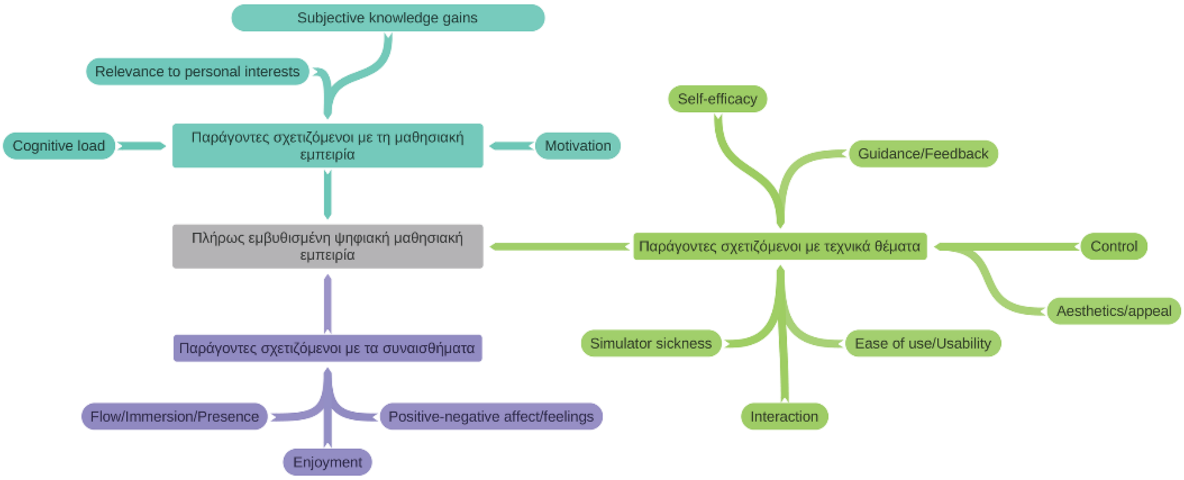


**Figure 35.** The proposed factor model of FIDLE

In the previous section, the positive fully immersive digital learning experience was considered to be one that is characterized by excellent design, excellent functionality, and adaptability of the content, which allows the active action/participation of learners, who gain knowledge, skills, attitudes, and behaviors, but also positive emotions and experiences, due to their immersion in the content/application, sense of presence and interaction with the content. In the above model, it can be observed that all these elements are present. Therefore, this model can describe FIDLE and can be used to construct research tools to examine it.

# Chapter 9. Virtual Reality and constructivism

This chapter analyses why the VR and, by extension, the CPD, can more effectively implement the principles of constructivism, thereby helping to bring about a meaningful transformation of the educational process.

## 9.1. The generations of educational use of computers

From the early stages of their development, computers were considered an ideal teaching tool. The features that have enabled this belief have kept pace with technological developments, notably their increasing computing power, speed, graphical environments, the possibility of integrating images, sound and video, and the Internet.

Thus, the first educational applications of computers implemented behavioristic concepts and placed great emphasis on content. They analyzed the knowledge and skills to be acquired by students into individual components, where their mastery, cumulatively, led to the expected learning outcome. A typical example of this view was Computer Assisted Instruction, which took the form of drill and practice applications, with the learner having little control over what they learn. Everything was predetermined by the application developer, although in some cases the learner was given the option to skip certain topics (Saettler, 2004). Despite the serious criticism of this type of application, there is still, even today, a significant number of applications that fall into this traditional approach to instructional design.

In the second generation of educational computer applications, there was a shift in focus; the emphasis shifted from content to the way in which the content was presented to students. This arose from the realization that the process by which students process information may be more important than the information itself. In this area, behaviorism proved inadequate, while cognitive theories provided a suitable basis for the developers of educational applications. However because behaviorism and cognitive theories treat learning in an objectivistic way (Jonassen, 1991), the transition from one generation to the next was not difficult. The goal remained the transfer of knowledge to the learner in the best possible way (Bednar et al., 1992). In both cases, the designers broke the material into small chunks. In the behavioristic view, they were looking for the best method to achieve the intended behavior, and in the cognitive view, they were looking for ways and systems of transition from the simple to the complex. A typical example of this generation of educational computer applications is the attempt to program them in such a way that they respond "intelligently" to data input from the student, using, for example, a database.

The third generation of educational use of computers was based on the principles of constructivism. The shift in application design was important because of the fact that constructivism does not treat learning objectively. Although efforts have been made to develop computer applications that combine elements of both cognitive information processing theories and constructivism (e.g. Dede, 1992; Spiro et al., 1991; Tolhurst, 1992), the differences are significant. The objectivist approach to learning seeks for instruction to have predetermined outcomes and to interfere with the learning process in such a way that it captures reality in the mind of the learner. In contrast, the constructivist approach, precisely because it argues that there are no predetermined and predictable outcomes, considers that teaching should encourage rather than guide learning. As Jonassen (1994) points out, the problem that constructivism poses to educational program designers is that, since each individual is responsible for structuring knowledge, it is not possible to identify and ensure a set of learning outcomes common to all.

In the same article, he lists the characteristics that instructional design should have according to the constructivist perspective, such as:

- Provide multiple representations of reality and avoid simplifications by presenting the natural complexity of the world.
- Provide students with authentic assignments.
- Provide teaching environments that are based on real-life case studies, rather than being a predetermined teaching sequence.
- Knowledge has to be structured in relation to the context and content applied.
- Encourage reasoning-based practices.
- Support the collaborative construction of knowledge rather than competition between students.

Multimedia and hypermedia largely satisfy the above conditions and allow a non-linear course of instruction, leaving the choice to the learner. They are, thus, used predominantly to implement constructivism's concepts. However, for fear of the learner eventually becoming disoriented, of being "lost" in the maze of hyperlinks and choices, many suggested a combination of old and new teaching methods and a gradual increase in the learner's control over the teaching process (e.g., Jonassen et al., 1993).

From the above summary of the first three generations of educational use of computers, it is easy to see their shortcomings. The first generation saw learning as a one-way road, as something that can be easily described, segmented, and acquired. It does not take into account the specific (individual) needs of learners and cuts off learning from its social dimension, seeing it as something independent. The second and third generations took a more holistic view of learning. However, in the second generation, learner-computer interactions were largely pre-designed, which means that they ultimately drove learning through specific channels. The third generation comes very close to giving the learner control of the learning pace and allowing them to structure their learning. However, the objections to completely "open" design lead to a number of limitations being placed on it.

## 9.2. The fourth generation of educational computer use

The fourth generation of educational use of computers, to which VR applications belong, implements the basic principles of constructivism, just like the previous one. However, according to Winn (1993), this generation goes one step further. Winn, while strongly criticizing cognitive theories, noted that in VR applications the use of symbols is not necessary.

This point deserves further analysis. Cognitive theories treat the human brain as a computer whose basic function is the mental manipulation of symbols (Johnson-Laird, 1988; Munakata, 2006). Cognition is nothing more than the efficient manipulation of these symbols. However, this does not fully explain all mental processes, nor does it explain the way situations are handled when symbols are not used. But in which situations symbols are used and in which they are not?

In Chapter "6.1. Virtual Reality as a cognitive tool", it was mentioned that people perceive the world in two ways, from "first person" experiences and from "third person" experiences. The first ones come from everyday contact with the world around the individual, they are direct, personal, subjective, and somehow "silent," because individuals do not perceive that they acquired some form of knowledge. Above all, however, because of their immediacy with the environment, they do not require the existence of symbols. The latter comes from someone else's description, are indirect, and explicit, and individuals always know that they have learned something. However, in order to enable communication between the one who teaches and the one who learns, the existence of symbols, such as spoken language, letters, and numbers, is necessary. For example, "first person" experiences are the feelings one has when watching a movie. "Third-person" experiences are when, for example, the plot and the role of the protagonists in a scene are explained. The experience the person has is not the same as in the first case, since it is "filtered" by a third party (Figure 36).

**Figure 36.** First and third-person experiences

"First-person" experiences do not require special and concerted thought. In fact, most actions in everyday life are done this way. One does not plan in advance how to wash, dress, eat, and sleep. The action comes directly from the person's perception of the world, without the interference of intense and conscious thought. Thought interferes with action when there is a dilemma, or when something goes wrong, or when attention is needed to deal with a situation.

Computers in the first three generations offered "third person" experiences and this is for the following reasons:

- The computer interposes itself between the person and the information it contains.
- This information comes from a third party; someone has entered it into the computer.
- The information is not directly available, but through the interface, the screen, the mouse, and the keyboard, all of which use symbolic systems.
- These symbols require some thought on the part of the user in order to use them effectively.

Therefore, however important the role of the way information is presented (second generation), however important interactions are (third generation), computers do not offer "first-person" experiences, which, as has become clear, occupy a significant part of everyday life. Constructivism, according to Winn (1993), provides several ideas on how "first-person" experiences could be gained through the use of computers. There are two main points of interest [39]:

- The computer-student interface must be absent, in a way the computer must be "invisible." This means that the student/user should not use traditional devices (mouse, keyboard, and monitor) to communicate with the computer, but other devices that do not use symbols.
- In these applications, the interaction between a person and a computer or between persons should not be pre-planned, but any kind of interaction should potentially be possible.

Such environments belong to the field of VR. As mentioned in several parts of this document, the purpose of VR is, through immersion, presence, and interaction, to create unmediated experiences (Schafer, 2016), which, in essence, means that there is no need to use symbols. Thus, it can be argued that VR learning environments allow for interactions in which symbols are not used, resulting in experiences that are more direct at the individual level, and because of the open design and non-prescriptive interactions, the learning process and its outcomes are not predetermined. Therefore, learning in a VR environment is a dynamic user-driven process that sets goals and changes them at will.

## 9.3. More about constructivism

As has already become apparent from the preceding analysis of the generations of educational computer use, VR is very close to the principles of constructivism. The following analysis explains why VR is particularly compatible with the learning process as this learning theory approaches it.

As far as the learning process is concerned, constructivism generally holds that new knowledge acquired by individuals is based on their previous knowledge and experiences. When faced with a new situation, they must either reconcile with previous knowledge and experiences or change them. In any case, however, knowledge and insight about the world are actively constructed by the individual through experiences and reflection on these experiences (Colburn, 2000). Also, learners need environments rich in social interactions to explore various topics with their teachers and peers. Opportunities to collaborate with more experienced mentors are especially critical for the development of higher cognitive functions (Ertmer & Newby, 2013).

In addition, the discovery learning approach, which is directly related to constructivism, is interested in how to make education more tailored to the needs of the learner and considers learning to be an active process in which individuals ask questions and give their tentative answers. Active participation is achieved through discovery learning, which allows individuals to explore alternatives and understand the relationships between different ideas (Bruner, 1961, 1966, 2009). The role of the teacher is to guide students, through dialogue, to assist in building knowledge on pre-existing structures. Several other researchers such as Papert (1980, 1991) have made significant contributions to the development of the theory of constructivism, especially in the field of educational applications of technology. The point of agreement among researchers is that they seek to provide learners with opportunities for cognitive growth through exploration, unstructured learning, active participation, and problem-solving.

In general, as an educational practice, constructivism involves encouraging students to take action, engage in real-world problem-solving, experiments, and then discuss how his or her perception of things has changed. Teachers, on the other hand, ensure that each activity is structured around students' prior knowledge, and generally their role is to facilitate the whole process, not to be the bearers and transmitters of knowledge.

As Brooks and Brooks (1999) emphasized, in a classroom organized by constructivist standards:

- Students' autonomy and initiative is encouraged.
- The questions to students are open-ended and students are given plenty of time to answer them.
- Critical thinking is encouraged.
- Students talk to each other or to the teacher.
- Classroom activities favor hypothesis formulation and discussion. Primary sources of information, raw data, and interactive materials are used as teaching materials.

To the above, Roblyer and Doering (2012) add:

- Activities emphasize exploration and practical problem-solving in technology-rich environments.
- Collaboration is used.
- Assessment is based on the presentation of assignments and projects.

However, constructivism has been criticized on some issues. One such issue concerns students' prior knowledge. In a constructivist teaching environment, the teacher should first determine what the student knows and what his or her interests are and from that point begin the gradual construction of knowledge. Often, however, constructivist strategies base learning on solving problems involving complex situations without taking into account the skills needed to deal with them. Undoubtedly some students can cope with these situations. But what about those who cannot? How much and what kind of prior knowledge is required for all students to deal with these issues (Dick, 1991)? In this case, the teacher or technology should be able to offer help to students who need it, even if it has to be done on a large scale.

Several people argue that constructivism better addresses some cognitive issues than others (Ertmer & Newby, 2013; Jonassen et al., 1993). In general, constructivist strategies seek to teach problem-solving in ill-structured cognitive domains. Also, instead of covering one topic in depth, it is preferred to cover a wide range of topics at the same time. However, there are cases where it is more desirable to acquire knowledge in a single subject area.

Much criticism has been leveled at constructivism for rejecting evaluation through objective methods and criteria. Although assessment is carried out through other methods (group work, projects, etc.), these do not provide evidence of individual performance. In other words, they do not show whether a student has learned something or acquired certain skills.

## 9.4. The relationship between constructivism and technology

Today's children live in a very different environment from that of yesterday's children. The conditions were such that a wooden sword, a piece of cardboard, a broom, and a lot of imagination were enough to turn children into knights, to fight in magical worlds. Communication was either face-to-face or by mail. Today's children are born into a world of technology. They play computer games and are very comfortable with any kind of electronic device.

Technology in a constructivist educational environment has an important role in everyday activities, but it does not become a subject of teaching itself. A technological environment functions as a laboratory in which students can observe, practice, ask questions, and evaluate knowledge (Boethel & Dimock, 1999). There are two important advantages to implementing constructivist methods through technology. First, technology-based learning environments can and do provide situations that require problem-solving and decision-making (Tam, 2000). Second, because digital media are used for this purpose, they are perfectly compatible with children's daily lives, both inside and outside the classroom.

Technology provides tools that were previously unavailable. Learners are able to draw information in different forms (text, images, and sound) and consider different perspectives as they construct knowledge on a topic. Technology enables them to spend more time on the above tasks and to collaborate with their peers and teachers (Boethel & Dimock, 1999). In earlier years, the space from which information could be drawn was limited. Social interaction and collaboration, encouraged by the constructivist model, are enhanced by technologies such as the Internet, which allows for communication with literally every region of the world (Tam, 2000). Similarly, multimedia and hypermedia encourage creativity. Multimedia applications that provide problem-solving situations help individuals identify and improve problem-solving strategies and transfer knowledge into higher-order intellectual skills (Roblyer & Doering, 2012).

However, it should be noted that the success or failure of technology-rich constructivist environments ultimately depends on the teachers. They have to deal with the task of teaching lessons on a daily basis. Implementing technology and constructivism in the classroom requires good planning and plenty of time. Unfortunately, neither the means are often available nor the time. In fact, when there is time pressure, teachers will eventually return to the old ways of teaching, the ways they were taught. For changes to occur in the way students are taught, there must be a change in the training of teachers. They, too, must experience, as students, the new learning environments (Fokides et al., 2019).

## 9.5. The relationship between Virtual Reality and constructivism

VR brings together the above advantages of multimedia and hypermedia, but because it uses a different technology, it adds additional features. As mentioned in Chapter "6.2. The educational potential of Virtual Reality", VR applications allow users to:

- Manipulate and interact with objects as they would in the physical world, but also be able to change their relative sizes, and apply or overturn the laws of physics.
- Control time. They can study in a few minutes the evolution of a phenomenon that actually takes hundreds, thousands, or even millions of years to complete, and vice versa, that is, to study a phenomenon that actually happens in an infinitesimal amount of time.
- Receive information that under other circumstances would not be available to the human senses.
- Represent and manipulate objects and events that do not have a physical form, such as mathematical equations.
- Interact with other users present in the virtual world.

The immersion of the user in the virtual environment, presence, interaction, the absence of an interface, and, especially, the non-symbolic communication and first-person experiences are the keys to the compatibility of VR with the theory of constructivism. Therefore, with VR it is possible to teach rules and abstract concepts without the use of language and other symbols. The experience (real or virtual) with which an idea or concept is associated is important both for understanding the concept and for its subsequent use (Jonassen, 1991). In other words, the experience is the "vehicle" for the construction and use of knowledge. As noted, because VR uses non-symbolic interaction, it can enable learners to intuitively understand even abstract concepts without the use of the symbolic representations of the relevant cognitive domain, thus providing experiences at a primary level.

VR gives experiences through the "real" use of objects. It requires interaction and encourages active participation. Thus, those who learn are able to control the learning process (Pantelidis, 1993). By reflecting on the real world, they are given the opportunity to learn from their own mistakes without consequences and without risks. Indeed, this can be done in the form of a game, the role of which is crucial (Bruner, 1961, 1966, 2009). VR provides the possibility of adapting the teaching material to the needs and cognitive style of each individual. As a result, they can experience something at their own pace, without being limited by the time constraints of the conventional timetable (Salzman et al., 1999). This solves the problem of how much prior knowledge one needs to cope with the demands of a constructivist teaching environment.

Regarding the possibility of teamwork, there is a general feeling that when people work in groups, they achieve better cognitive outcomes because there are more cognitive resources (Slavin, 1980). However, in most applications, the problem is the development of skills that are conducive to collaboration, such as a sense of individual responsibility within the group, team spirit, and taking initiative and responsibility. Moreover, equal effort and performance among team members is not guaranteed. Therefore, a lot of attention needs to be paid to the design and implementation of collaborative learning practices, especially in VR environments. However, it is a fact that a VR learning environment supports teamwork in a more complete way compared to hypermedia and multimedia. This is because in a collaborative VR environment, many users can coexist in the same virtual space, share the same audiovisual stimuli, share control over the flow of things, and, at the same time, communicate and discuss with each other. Virtual shared environments, virtual classrooms, and the use of avatars are some of the ways in which VR implements the concepts of collaborative learning.

Motivation to learn plays an important role in the educational process and should be taken into account in the design of an educational environment. In motivation to learn, the focus is no longer on whether someone can learn, but on what makes them want to learn (Fokides, 2020). The environment must be designed to provide elements that stimulate interest, over a long period of time, which is not always guaranteed. Motivation to learn is highly dependent on interest and most people find VR a highly interesting experience (e.g., Bertrand et al., 2017; Fabola & Miller, 2016; Ritter et al., 2018; Rupp et al., 2019). But it is not only interest that provides motivation for learning in VR. It is the broader combination of interaction, and realism, sparking the imagination, challenge, and play (Psotka, 1996). Indeed, as Psotka (1996) noted, it is not only the new and unknown that excites users; VR is a technology that opens up many new paths and empowers learning.

Finally, regarding the issue of evaluation, VR has the potential to be a very powerful tool for evaluating and monitoring the performance of trainees, because it allows the recording of each session in a virtual environment (Fokides & Atsikpasi, 2018). Thus, in addition to the formal assessment, which may include checking the knowledge acquired, trainers and trainees can study in detail the actions taken in the virtual world and draw useful conclusions.

# Chapter 10. Virtual Reality and distance education

This chapter gives an example of how VR can reshape education. For this reason, distance education (DL) was chosen as an area where VR can play an important role. Given that technological developments are constant and that there is a need for DL to adapt to them and to increase both its effectiveness and its impact, it would be interesting to consider the role that VR can play in this adaptation.

## 10.1. Problems in distance learning

ICT plays an important role in education. In fact, the importance of their role has been further emphasized by the major upheavals, globally, caused by the Covid-19 pandemic that started at the end of 2019. This, resulted in DL being the only viable solution for teaching during this period.

A short definition of DL would describe it as the education of people who are not physically present in an educational institution (Kaplan & Haenlein, 2016). In general, DL aims at connected and collaborative learning through enriched programs characterized by massiveness and free -usually-access by learners (Siemens, 2005). There are different types of it, such as synchronous, asynchronous, and hybrid. MOOCs are a relatively recent form of DL that offers interactive courses on a large scale, often with free access. The delivery of educational material (inherently multimedia, since it includes text, audio files, images, and video) can be delivered synchronously (e.g., by videoconferencing), asynchronously (e.g., through a Learning Management System), or combined. Finally, all of the above can take the form of a virtual community, the equivalent of a physical classroom.

However, DL is not without its problems. Some of these are limitations in the number of people who can enter a system at the same time and the lack of interaction between learners (El Kabtane et al, 2020). Perhaps the most important problem is the dropout of courses by many learners due to lack of interest, poor communication with the instructor, or the volume of material that learners have to cover by themselves (Yousef et al., 2014). Other issues that DL has to overcome are the need for frequent communication between instructor and learner and the need for frequent guidance of the former by the latter. When these do not occur, the learning outcomes are unsatisfactory and the whole scheme can lead to failure (Garrison, 2011). Other barriers, on the part of the learner, are distraction from external factors, technical problems, and the need for some relevant experience in using ICT tools. Overall, studies indicated that participants in DL drop out much more often than in face-to-face programs due to problems with language, time management, skills required in handling ICT tools, and the lack of physical interaction between trainer and learner (Xu & Jaggars, 2011).

## 10.2. Brief field review on the relationship between VR and DL

Seeking to (briefly) identify the scope and issues of concern to researchers on the relationship between VR and DL, a literature review was conducted. Reviews are a popular approach for synthesizing research evidence (Daudt et al., 2013) and are suitable for determining the extent of the literature on a topic, giving a clear idea of the volume of available studies and their evidence, especially in the case of emerging research areas (Munn et al., 2018).

The search was conducted in ERIC, LearnTechLib, and Scopus and covered the years 2010-2020. The search terms used were "virtual reality" and "distance education," or "distance learning," or "remote learning," or "e-learning"). A total of 513 articles were identified, of which 131 were finally analyzed. To better visualize the whole process, a flowchart of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) type was used (Moher et al, 2009) (Figure 18). This presents the numerical data from identifying original studies and removing duplicates, screening titles/abstracts and excluding those that were not relevant to the topic, and full articles that were read and either justifiably excluded or deemed appropriate and included in the analysis. It should be noted that only the main findings are presented below, as the purpose of the chapter is not to provide an in-depth analysis of the relationship between VR and DL.

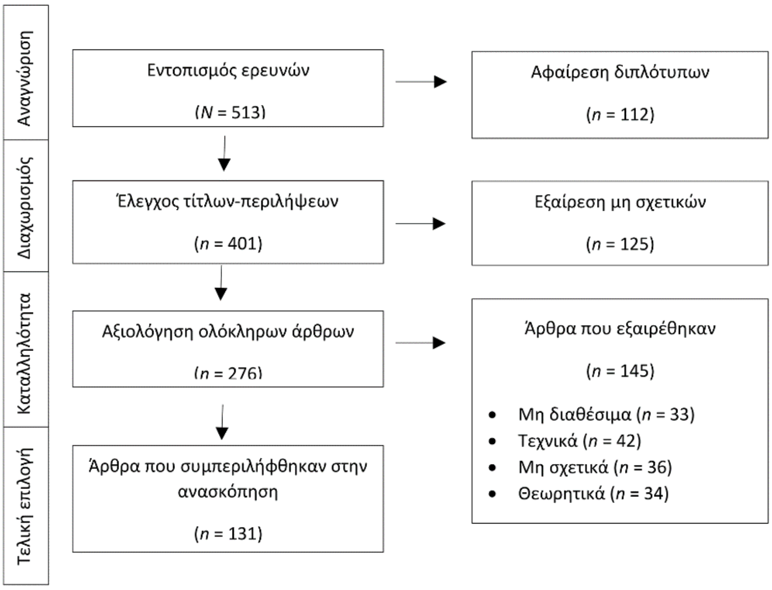


**Figure 18.** PRISMA diagram for the relationship between VR and ERA (Moher et al., 2009)

The first interesting finding was the relatively small number of articles that met the search criteria, which indicates that this area is not yet fully developed. Their distribution per year is relatively stable (10-12 articles) with a relative peak in 2018 (20 articles). About half of the articles were published in conference proceedings (*n* = 60, 46%); 30% were published in peer-reviewed journals, while the rest were chapters in edited volumes, books, or reports of ongoing projects. Of particular interest is the fact that the majority of articles were about interventions/applications in higher education (*n* = 76, 58%). Secondary education and the education of a variety of professional groups were addressed in 24 and 23 articles respectively (about 18% in both cases), leaving, in the end, a very small number of articles dealing with primary education.

The broad themes addressed in the articles were the design of VR environments (*n* = 91), design of LEARNING material/content (*n* = 45), usability issues (*n* = 40), user interaction (*n* = 32), immersion (*n* = 30), sense of presence (*n* = 25), motivation for learning (*n* = 23), time management (*n* = 18), and cognitive load (*n* = 12). Note that some studies examined more than one of the above themes. Regarding the VR technology used, most applications were run on simple computers (which was either the only medium used or a comparison was made with other VR technologies, *n* = 88). The use of HMDs was considered in fewer cases (*n* = 34), perhaps because they have not yet become widespread or for technical/organizational reasons.

Three themes were distinct and almost evenly distributed in terms of the use of VR in relation to DL: (a) lectures (regardless of subject matter, *n* = 36), (b) virtual laboratories (*n* = 40), and (c) simulations of the operation of machines/devices/body organs (*n* = 38). In just over half of the articles (*n* = 70, 53%) there was some form of evaluation for whether knowledge and/or skills were acquired. Focusing on these articles, it was found that the majority of them reported positive outcomes (*n* = 49, 70%). It should be noted that this figure is reported with caution, as in most the number of interventions was small. In fact, in several cases either the evaluation was conducted exclusively using pre- and post-tests or qualitative data were collected without a control group or comparison with another instrument. Focusing on cases in which there was a comparison with another instrument or media (*n* = 51), it was found that, again, the majority of results were positive, but the proportion was considerably reduced (*n* = 28, 55%).

Finally, it was found that, in most cases, the researchers reported that immersion, presence, and interaction, had a positive impact on the acquisition of knowledge and/or skills.

## 10.3. Findings

VR provides solutions to situations that face-to-face teaching cannot support, either because it is impossible to actually exist, or because there are high costs or health risks (Buttussi & Chittaro, 2017). Indeed, as the literature review of the field demonstrated, VR systems and applications are already being used to provide educational experiences, although not yet in a systematic way. Nevertheless, it can be said that VR covers people whose profile is similar to that of people participating in DL programs, i.e., who are not present in the same physical space and who are interested in learning in a systematic way. Furthermore, it was found that the use of VR systems in DL has positive effects in terms of knowledge and/or skill acquisition (e.g., Chang et al., 2016; Penland et al., 2019).

This raises the question of what exactly is the added value that VR can bring to DL. The answer lies in the quality of the learning experiences provided by the VR due to immersion, presence, and interaction, which are among the key features of the VR, as discussed in a previous chapter (see Chapter "3. The key features of Virtual Reality"). Indeed, the literature review indicated that these factors play an important role in achieving satisfactory learning outcomes (e.g., Krassmann et al, 2020; Liu et al., 2019; Zikky et al., 2018). On the other hand, these factors are not highly emphasized in DL (Chen, 2018; El Kabtane et al., 2020). Thus, it can be argued that VR offers users learning experiences whose richness exceeds those offered by the current form of DL.

While in conventional DL users are exposed to rich audiovisual material (such as videos), with VR they can navigate in a 3D virtual space, having the freedom of movement and more direct contact with the material. This immerses them in the learning experience (Rupp et al., 2019; Wu et al., 2020) and makes them feel that they are truly "living" in what is being presented to them (Slater & Sanchez-Vives, 2014).

In other words, with VR, THE learning material is presented in a "richer" way; users receive much more complex sensory information and this, most likely, positively impacts learning (Wu et al., 2020).

Besides, VR can have an impact in other areas, beyond the simple acquisition of knowledge. For example, it can provide users with innovative opportunities to develop their creativity. For example, VR gave participants new opportunities for artistic expression, sharing their works, and instructor-trainee collaboration; in other words, pedagogical benefits that go far beyond a simple painting program (So & Lu, 2019).

In terms of communication, cooperation, and interaction with others, in conventional DL this is limited to text exchange or videoconferencing. In contrast, with VR, users can converse in a virtual space (which may simulate an office or classroom), with other characters who look very real or with representations of other people connected in the same environment (Gugenheimer et al., 2017; Liang et al., 2019). Moreover, VR gives users a wide variety of collaborative tools. For example, learners can draw 3D objects (using apps like Tilt VR and Spatial), make virtual presentations (e.g., with MeetinVR), and handwrite on a virtual whiteboard (with apps like Glue). In short, users can interact with virtual objects in the space or insert one of their own "there," which they and those "around them" can edit. This, besides emphasizing the sense of social presence, has a positive effect on both collaboration between participants and learning outcomes (Barker et al., 2018; Yassien, 2020). Therefore, the concept of collaborative learning environments takes on a new dimension.

From the above brief comparative presentation of the tools/means of DL and VR, it can be concluded that perhaps the current form of DL should be redefined to be implemented through tools that fall under VR or fully immersive VR. This would increase the immersion, presence, and interaction of users. Thus, DL v2.0 could contribute to better communication between learners and their peers or instructors, improved interaction with the learning materials, increased creativity, and, ultimately, rich learning experiences.

# Conclusion

For some time, computers and other similar technological tools have been described by the term "New Technologies." This term was intended to demonstrate their innovative and pioneering nature. Nowadays, the use of computers is commonplace. In this respect, the term is now rather inappropriate. The term "emerging technologies" may be more apt, since it describes technologies that are now emerging or technologies that, while they have been around for some years, are now beginning to realize their potential.

VR and, by extension, fully immersive VR, discussed in the previous chapters, can be characterized as an emerging technology. From the historical review presented, it appeared that the first steps of VR were taken around the 1950s and for HMDs around the 1960s. However, despite the enthusiasm that existed until the early 1990s, VR did not succeed in becoming a mainstream technology accessible to the general public. Thus, its use was limited to research centers and specific professional groups. However, since the second decade of the 21st century, the situation seems to be changing dramatically. The driving force behind this development is the powerful entertainment industry, which is constantly looking for new ways to attract consumer interest. Thus, a range of HMDs has emerged which both have satisfactory technical specifications and are priced at affordable, for the general public, levels. As a result, it can be argued that from this point onwards, technological developments are beginning to allow the (mass) exploitation of the potential of VR.

Regarding how VR is defined, it is worth noting that the term can be approached both in purely technological and psychological-cognitive terms. On the one hand, it can be seen as a set of hardware and software with which individuals are able to visualize and interact with highly complex data in three dimensions. On the other hand, VR can be seen as a situation that is created in the mind and that can, with varying degrees of success, engage a person's attention in a manner similar to that in the real environment.

As presented, the VR places the user in a synthetic environment, identical or completely different from the real one. In this environment, users can choose the path they want, explore everything, whenever and in any way they want, and, finally, interact with the objects that exist in this world. This gives rise to the three basic characteristics of VR, which are immersion, presence, and interaction. Immersion is more of an objective/technical phenomenon and concerns how complete/rich is the sensory information provided to the user by the virtual environment. On the other hand, presence refers to the extent to which users feel that they are in a virtual environment, that they "live" in it and have the illusion of non-mediation. It is therefore more of a subjective phenomenon. Finally, interaction refers to the communication and connection between the user and the virtual environment (or between users). This should be as close as possible to the way individuals interact with the real world.

Based on the above characteristics and, most importantly, using immersion as a starting point, the different variants of VR were redefined, classifying the different systems into three categories (low-immersion, semi-immersion, and full-immersion). In the last category, with the existing data, only those systems using 6DoF HMDs were included, as with them the highest degree of immersion, presence, and interaction is achieved. Focusing on HMDs, a detailed presentation of their operating principles and technical characteristics was made in order to better understand both the advantages and the technical obstacles that remain to be overcome. In general, it appeared that the pace of their development is satisfactory and in line with the fall in their acquisition costs. These two elements allow for greater optimism regarding the diffusion of RDI in the near future.

The wide range of applications of VR is evident in the significant number of studies carried out in various scientific fields. Focusing on the use of VR as a learning tool, it was found that it has application in most subjects and levels of education. Relevant studies report positive findings such as increased engagement with the subject matter, fun, increased motivation to learn, and retention of knowledge.

Some attribute these results to the fact that VR offers users "first person" experiences. As discussed, first-person experiences are direct, do not require the use of symbols (letters, numbers, and language), and are purely subjective. On the other hand, third-person experiences are indirect, require the use of symbols, and project the opinion and beliefs of the person communicating the knowledge. The problem is that teaching, and, more broadly, education, offers "third-person" experiences to learners. This has been realized for some time. Many scholars working on learning theories have proposed practices whereby learners can have vicarious experiences (i.e. first-person experiences) in as many subjects as possible. Yet, there are some limitations. It is not reasonable to expose students to risks just to have first-person experiences of, for example, volcanic eruptions. They cannot travel back in time to see the life of dinosaurs. Nor can they use the Hubble telescope to see the stars, nor microscopes to see microbes. Not only trainees, but all humans are "trapped" in the third-person experiences provided by technology-based and traditional education.

On the contrary, VR seems to provide a solution to the above problems. It is assumed that the 3D objects present in a VR environment give the user a sense of the "real," promoting the creation of diverse cognitive representations of the same object and facilitating the development of integrated mental models. The result is that the user acquires first-person experiences about the subject of the application and creates purely personal representations of the synthetic world in which they find themselves. Learning in such an environment is certainly a dynamic process, fully determined by the user, who alone sets the goals and changes them at will. In addition, the VR can also provide third-person experiences if, for example, the developer places restrictions on what the user can do.

Further analyzing the reasons why VR offers "first person" experiences and why it can be an effective learning tool, it was found that this can be attributed to its three main characteristics mentioned above. Specifically, immersion can enhance learning as it provides multiple perspectives, thematically frames an environment, and supports the transferability of acquired knowledge. Presence enables users to have experiential experiences and become emotionally involved. Finally, interaction also creates interactive and experiential learning experiences, transforming users from passive observers to active thinkers. Indeed, one of the important features of VR is the possibility of more than one user co-existing in the application. Thus, they interact not only with the objects in the synthetic environment but also with each other, being able to converse, exchange views, and guide each other.

VR and, especially, fully immersive VR are significantly differentiated from other digital media in terms of the type of learning experiences they offer to users. Thus, an attempt was made to introduce a new term to describe this very element. The term "fully immersive digital learning experience" has been introduced, defined as the mental state resulting from the interaction of the learner with any form of cognitive material offered by the media (tangible or intangible) belonging to the fully immersive VR. It is the combined result of the actions undertaken by the individual, the experiences they have, and the emotions they experience as a result of this interaction. It depends directly on the design, functionality, and adaptability of the digital medium, as well as on the degree of immersion, presence, and interaction it offers. The desired end result is the acquisition of knowledge and/or experience (including skills and attitudes).

Going a step further, a model that includes the factors that shape the fully immersive digital learning experience was proposed, by abstracting questionnaires and scales used in studies that examined learning using VR and fully immersive VR. Thus, the proposed model includes three groups of factors: (a) factors related to emotions (flow/affection/presence, enjoyment, and positive/negative emotions), (b) factors related to learning experience (subjective perception of learning benefits, relationship to personal interests, cognitive load, and motivation to learn, and (c) factors related to technical issues (self-efficacy, aesthetics, guidance/feedback, control, ease of use, interaction, and simulator sickness).

The last issue examined was whether VR can best implement contemporary concepts of learning, in particular, constructivism. Although from the early stages of their development, computers were considered an ideal teaching tool, the first generation of educational applications implemented behavioristic concepts, and the second generation was based on cognitive theories. Since the third generation, dominated by multimedia and hypermedia applications, there has been a shift to the principles of constructivism. However, for fear that students might eventually become disoriented by the maze of hyperlinks and options, these principles were not implemented to their full extent. Not only that but all the applications of the first three generations offered, more or less, "third-person" experiences.

On the other hand, the immersion of the user in the virtual environment, presence, interaction, the absence of an interface, and, above all, non-symbolic communication and "first-person" experiences are the keys to the compatibility of VR with constructivism, but also to its potential to overcome the above problems. With VR it is possible to even teach abstract concepts without the use of language and other symbols, thus enabling learners to intuitively understand them, providing experiences at a fundamental level. In addition, VR provides experiences through the "real" use of objects. There is interaction and active participation, but mistakes have no consequences. The adaptation of the teaching material to the individual's needs and cognitive style is another feature of VR, which allows users to experience something at their own pace. Regarding the possibility of teamwork, it is a fact that a VR learning environment supports teamwork in a more complete way than hypermedia and multimedia since it allows users to share audiovisual stimuli, share control of the flow of things, and, at the same time, to communicate and discuss with each other. As regards motivation to learn, which depends to a large extent on how interesting a learning experience is, it is worth mentioning that VR seems to offer highly engaging experiences, which work in combination with immersion, presence, interaction, realism of the applications, stimulation of the imagination, challenge, and the "playful" nature of VR applications.

In conclusion, despite the problems that remain to be overcome, the significant developments that have taken place in recent years in the field of VR (spearheaded by the developments in fully immersive VR), leave room to argue that this technology, in the near future, could play an important role in redefining the educational landscape.

# References

## In Greek

Μικρόπουλος, Α. (2016). *Πανεπιστημιακές σημειώσεις*. Πανεπιστήμιο Ιωαννίνων.

Νάτσης, Α., & Ζαχαρής, Γ. (2008). Ιδιότητες εκπαιδευτικών εικονικών περιβαλλόντων 2: Συστήματα εμβύθισης. *Πρακτικά 6ου Πανελλήνιου Συνέδριου με Διεθνή Συμμετοχή "Οι ΤΠΕ στην Εκπαίδευση"*, 145-152.

Φωκίδης, Ε., & Τσολακίδης, Κ. (2011). *Εικονική πραγματικότητα στην εκπαίδευση: Θεωρία και πράξη*. Διάδραση.

## In English

Abulrub, A.-H. G., Attridge, A. N., & Williams, M. (2011). Virtual reality in engineering education: the future of creative learning. *Proceedings of the Global Engineering Education Conference (EDUCON)*, 751-757. IEEE. https://doi.org/10.1109/EDUCON.2011.5773223

Acar, C., & Shkel, A. (2008). *MEMS vibratory gyroscopes: structural approaches to improve robustness.* Springer Science & Business Media. https://doi.org/10.1007/978-0-387-09536-3

Adams, E. (2004). *Postmodernism and the three types of immersion*. http://www.designersnotebook.com/Columns/063_Postmodernism/063_postmodernism.htm

Adelman, J. S., & Estes, Z. (2013). Emotion and memory: A recognition advantage for positive and negative words independent of arousal. *Cognition, 129*(3), 530-535. https://doi.org/10.1016/j.cognition.2013.08.014

Agiledrop (2020). *Customer experience, user experience & digital experience: Basics & useful terms.* https://www.agiledrop.com/blog/customer-experience-user-experience-digital-experience-basics-useful-terms

Ahn, S. J., Le, A. M. T., & Bailenson, J. (2013). The effect of embodied experiences on self-other merging, attitude, and helping behavior. *Media Psychology, 16*, 7-38. https://doi.org/10.1080/15213269.2012.755877

Ahn, S. J. G., Bailenson, J. N., & Park, D. (2014). Short- and long-term effects of embodied experiences in immersive virtual environments on environmental locus of control and behavior. *Computers in Human Behavior, 39,* 235-245. https://doi.org/10.1016/j.chb.2014.07.025

Al-Kadi, A. S., Donnon, T., Paolucci, E. O., Mitchell, P., Debru, E., & Church, N. (2012). The effect of simulation in improving students' performance in laparoscopic surgery: a meta-analysis. *Surgical Endoscopy, 26,* 3215-3224. https://doi.org/10.1007/s00464-012-2327-z

Alaraj, A., Lemole, M. G., Finkle, J. H., Yudkowsky, R., Wallace, A., Luciano, C., Banerjee, P. P., Rizzi, S H., & Charbel, F. T. (2011). Virtual reality training in neurosurgery: review of current status and future applications. *Surgical Neurology International, 2,* 52. https://doi.org/10.4103/2152-7806.80117

Alawadhi, S., AlHabib, N., Murad, D., AlDeei, F., AlHouti, M., Beyrouthy, T., & Al-Kork, S. (2017). Virtual reality application for interactive and informative learning. *Proceedings of the 2nd International Conference on Bio-engineering for Smart Technologies (BioSMART) 2017*, 1-4. IEEE. https://doi.org/10.1109/BIOSMART.2017.8095336

Alhalabi, W. S. (2016). Virtual reality systems enhance students' achievements in engineering education. *Behaviour & Information Technology, 35*(11), 919-925. https://doi.org/10.1080/0144929X.2016.1212931

Alqahtani, A. S., Daghestani, L. F., & Ibrahim, L. F. (2017). Environments and system types of virtual reality technology in STEM: A survey. *International Journal of Advanced Computer Science and Applications (IJACSA), 8*(6), 77-89. https://doi.org/10.14569/IJACSA.2017.080610

Almousa, O., Prates, J., Yeslam, N., Mac Gregor, D., Zhang, J., Phan, V., Nielsen, M., Smith, R., & Qayumi, K. (2019). Virtual reality simulation technology for cardiopulmonary resuscitation training: An innovative hybrid system with haptic feedback. *Simulation and Gaming, 50*(1), 6-22. https://doi.org/10.1177/1046878118820905

Anderson, P. L., Price, M., Edwards, S. M., Obasaju, M. A., Schmertz, S. K., Zimand, E., & Calamaras, M. R. (2013). Virtual reality exposure therapy for social anxiety disorder: A randomized controlled trial. *Journal of Consulting and Clinical Psychology, 81*(5), 751–760. https://doi.org/10.1037/a0033559

Anderson, S., Allen, P., Peckham, S., & Goodwin, N. (2008). Asking the right questions: scoping studies in the commissioning of research on the organisation and delivery of health services. *Health Research Policy and Systems, 6*(1), 7. https://doi.org/10.1186/1478-4505-6-7

Anderson-Hanley, C., Arciero, P. J., Brickman, A. M., Nimon, J. P., Okuma, N., Westen, S. C., Merz, M. E., Pence, B. D., Woods, J. A., Kramer, A. F., & Zimmerman, E. A. (2012). Exergaming and older adult cognition: a cluster randomized clinical trial. *American Journal of Preventive Medicine, 42*(2), 109-119. https://doi.org/10.1016/j.amepre.2011.10.016

Anderson-Hanley, C., Snyder, A. L., Nimon, J. P., & Arciero, P. J. (2011). Social facilitation in virtual reality-enhanced exercise: competitiveness moderates exercise effort of older adults. *Clinical Interventions in Aging, 6*, 275-280. https://doi.org/10.2147/CIA.S25337

Antonacci, D., & Modaress, N. (2005). Second life: The educational possibilities of a massively multiplayer virtual world (MMVW). *Proceedings of the EDUCAUSE Western Regional Conference-Winds of Change: Charting the Course for Technology in Challenging Times* (vol. 28).

Aprile, I., Ferrarin, M., Padua, L., Di Sipio, E., Simbolotti, C., Petroni, S., Tredici, C., & Dickmann, A. (2014). Walking strategies in subjects with congenital or early onset strabismus. *Frontiers in Human Neuroscience, 8*, 484. https://doi.org/10.3389/fnhum.2014.00484

AR VR Journey (2017). *Binaural audio: How 3D audio hacks your brain.* https://arvrjourney.com/binaural-audio-how-3d-audio-hacks-your-brain-a3de0ceb4196

Araullo, J., & Potter, L. E. (2015). The emerging technology consumer: Designing NUI interaction for learning and retention. *Proceedings of the OzCHI 2015: Being Human,* 78-82. https://doi.org/10.1145/2838739.2838830

Argelaguet Sanz, F., Multon, F., & Lécuyer, A. (2015). A methodology for introducing competitive anxiety and pressure in VR sports training. *Frontiers in Robotics and AI, 2,* 10. https://doi.org/10.3389/frobt.2015.00010

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19-32. https://doi.org/10.1080/1364557032000119616

Aromataris, E., & Pearson, A. (2014). The systematic review: an overview. *AJN the American Journal of Nursing, 114*(3), 53-8. https://doi.org/10.1097/01.NAJ.0000444496.24228.2c

Arora, A., Lau, L. Y., Awad, Z., Darzi, A., Singh, A., & Tolley, N. (2014). Virtual reality simulation training in Otolaryngology. *International Journal of Surgery, 12*(2), 87-94. https://doi.org/10.1016/j.ijsu.2013.11.007

Artino, A. R. (2012). Emotions in online learning environments: Introduction to the special issue. *The Internet and Higher Education, 15*(3), 137-140. https://doi.org/10.1016/j.iheduc.2012.04.001

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems, 75,* 661-670. https://doi.org/10.1016/j.robot.2015.10.008

Aukstakalnis, S., & Blatner, D. (1992). *Silicon Mirage: The art and science of VR*. Peach Pit Press.

Bailenson, J. N., Blascovich, J., & Beall, A. C. (2001). Equilibrium theory revisited: mutual gaze and personal space in virtual environments. *Presence: Teleoperators & Virtual Environments, 10(6),* 583-598. https://doi.org/10.1162/105474601753272844

Bailenson, J. N., Blascovich, J., Beall, A. C., & Loomis, J. (2003). Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin, 29*(7), 819-833. https://doi.org/10.1177/0146167203029007002

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: digital transformations of teachers, students, and social context. *The Journal of the Learning Sciences, 17*(1), 102-141. https://doi.org/10.1080/10508400701793141

Bailenson, J. N., Yee, N., Brave, S., Merget, D., & Koslow, D. (2007). Virtual interpersonal touch: expressing and recognizing emotions through haptic devices. *Human-Computer Interaction, 22*(3), 325-353.

Bainbridge, W. S. (2004). *Berkshire encyclopedia of human-computer interaction* (vol. 1). Berkshire Publishing Group LLC.

Balakrishnan, B., & Sundar, S. (2011). Where am I? How can I get there? Impact of navigability and narrative transportation on spatial presence. *Human-Computer Interaction, 26*(3), 161-204.

Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences, 110*(31), 12846-12851. https://doi.org/10.1073/pnas.1306779110

Barfield, W., & Hendrix, C. (1995). The effect of update rate on the sense of presence within virtual environments. *VR, 1*(1), 3-15. https://doi.org/10.1007/BF02009709

Barker, B., Valentine, D., Grandgenett, N., Keshwani, J., & Burnett, A. (2018). Using VR and Telepresence Robotics in Making. *Proceedings of the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2018,* 564-568. Association for the Advancement of Computing in Education (AACE).

Barlow, J., Dyson, E., Leary, T., Bricken, W., Robinett, W., & Lanier, J. (1990). Hip, hype and hope-the three faces of virtual worlds (panel session). *Proceedings* of the *ACM SIGGRAPH 90 Panel,* 1001-1029. ACM. https://doi.org/10.1145/328750.328798

Basdogan, C., Ho, C.-H., Srinivasan, M. A., & Slater, M. (2000). An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer-Human Interaction, 7*(4), 443-460. https://doi.org/10.1145/365058.365082

Bednar, A. K., Cunningham, D., Duffy, T. M., & Perry, J. D. (1992). Theory into practice: How do we link. *Constructivism and the Technology of Instruction: A Conversation*, 8(1), 17-34.

Bellotti, F., Berta, R., & De Gloria, A. (2010). Designing effective serious games: opportunities and challenges for research. *International Journal of Emerging Technologies in Learning, 5*(2010). https://doi.org/10.3991/ijet.v5s3.1500

Bem, D. J. (1972). Self-perception theory. *Advances in Experimental Social Psychology, 6,* 1-62. https://doi.org/10.1016/S0065-2601(08)60024-6

Bertella, L., Marchi, S., & Riva, G. (2001). Virtual environment for topographical orientation (VETO): clinical rationale and technical characteristics. *Presence: Teleoperators & Virtual Environments, 10*(4), 440-449. https://doi.org/10.1162/1054746011470280

Bertrand, J., Bhargava, A., Madathil, K. C., Gramopadhye, A., & Babu, S. V. (2017). The effects of presentation method and simulation fidelity on psychomotor education in a bimanual metrology training simulation*. Proceedings of the 2017 IEEE Symposium on 3D User Interfaces*, 3DUI 2017, 59-68. https://doi.org/10.1109/3DUI.2017.7893318

Beti, R. A., Al-Khatib, F., & Cook, D. M. (2018). The efficacy of using virtual reality for job interviews and its effects on mitigating discrimination. *Proceedings of the International Conference on Computing and Information Technology*, 43-52. Springer. https://doi.org/10.1007/978-3-319-93692-5_5

Bibic, L., Druskis, J., Walpole, S., Angulo, J., & Stokes, L. (2019). Bug off pain: An educational virtual reality game on spider venoms and chronic pain for public engagement. *Journal of Chemical Education, 96,* 1486-1490. https://doi.org/10.1021/acs.jchemed.8b00905

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications, 30(2),* 14-21. https://doi.org/10.1109/MCG.2009.134

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94*(2), 115-147. https://doi.org/10.1037/0033-295X.94.2.115

Bindman, S. W., Castaneda, L. M., Scanlon, M., & Cechony, A. (2018). Am I a bunny? The impact of high and low immersion platforms and viewers' perceptions of role on presence, narrative engagement, and empathy during an animated 360° video. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems,* 1-11. https://doi.org/10.1145/3173574.3174031

Biondi, R., Pagnotta, P., Trentini, G., Cirotti, T., & Parrettini, C. (2015). The wow effect. *Proceedings of the EGU General Assembly 2015*.

Bioulac, S., Micoulaud-Franchi, J.-A., Maire, J., Bouvard, M. P., Rizzo, A. A., Sagaspe, P., & Philip, P. (2018). Virtual Remediation versus methylphenidate to improve distractibility in children with ADHD: A controlled randomized clinical trial study. *Journal of Attention Disorders, 24*(2), 326-335. https://doi.org/10.1177/1087054718759751

Bjork, S., & Holopainen, J. (2004). *Patterns in game design (Game development series)*. Charles River Media Inc.

Blackler, A., Desai, S., McEwan, M., Popovic, V., & Diefenbach, S. (2019). Perspectives on the nature of intuitive interaction. In A. Blackler (Ed.), *Intuitive interaction: Research and application* (pp. 19-39). CRC Press. https://doi.org/10.1201/b22191-2

Blanchard, C., Burgess, S., Harvill, Y., Lanier, J., Lasko, A., & Oberman, M. (1990). Reality built for two: a virtual reality tool. *ACM SIGGRAPH Computer Graphics, 24*, 35-36. https://doi.org/10.1145/91394.91409

Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience, 13*(8), 556-571. https://doi.org/10.1038/nrn3292

Blanke, O., Slater, M., & Serino, A. (2015). Behavioral, neural, and computational principles of bodily self-consciousness. *Neuron, 88*(1), 145-166. https://doi.org/10.1016/j.neuron.2015.09.029

Blascovich, J., Loomis, J., Beall, A., Swinth, K., Hoyt, C., & Bailenson, J.N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry, 13*(2), 103-124. https://doi.org/10.1207/S15327965PLI1302_01

Blom, K. J., Arroyo-Palacios, J., & Slater, M. (2014). The effects of rotating the self out of the body in the full virtual body ownership illusion. *Perception, 43*(4), 275-294. https://doi.org/10.1068/p7618

Blurbusters (2019). *VR guide 2019: Compare popular virtual reality headsets.* https://blurbusters.com/best-vr-guide-2019-compare-popular-virtual-reality-headsets/

Boe, A. & Prasolova-Forland, E. (2015). Teaching and learning aquaculture in virtual reality with Oculus Rift. *Proceedings of the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2015,* 1426-1435. Association for the Advancement of Computing in Education (AACE).

Boethel, M., & Dimock, K. V. (1999). *Constructing knowledge with technology: A review of the literature*. Southwest Educational Development Laboratory.

Bonde, M. T., Makransky, G., Wandall, J., Larsen, M. V., Morsing, M., Jarmer, H., Sommer, M. O. A. (2014). Improving biotech education through gamified laboratory simulations. *Nature Biotechnology, 32*(7), 694-697. https://doi.org/10.1038/nbt.2955

Borland, D., Peck, T., & Slater, M. (2013). An evaluation of self-avatar eye movement for virtual embodiment. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 591-596. https://doi.org/10.1109/TVCG.2013.24

Botvinick, M., & Cohen, J. (1998). Rubber hands "feel' touch that eyes see. *Nature, 391*(6669), 756-756. https://doi.org/10.1038/35784

Bourdin, P., Sanahuja, J. M. T., Moya, C. C., Haggard, P., & Slater, M. (2013). Persuading people in a remote destination to sing by beaming there. *Proceedings of the 19th ACM Symposium on VR Software and Technology*, 123-132. ACM. https://doi.org/10.1145/2503713.2503724

Brooks, J. G., & Brooks, M. G. (1999). *In search of understanding: The case for constructivist classrooms*. AscD.

Brown, E., Hobbs, M., & Gordon, M. (2008). A virtual world environment for group work. *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT), 3*(1), 1-12. https://doi.org/10.4018/jwltt.2008010101

Brown, J. (2019). *How gender questioning and transgender gamers found a safe space in VR*. www.digitaltrends.com

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: how much immersion is enough? *Computer, 40*(7), 36-43. https://doi.org/10.1109/MC.2007.257

Bowman, D. A., McMahan, R. P., & Ragan, E. D. (2012). Questioning naturalism in 3D user interfaces. *Communications of the ACM, 55*(9), 78-88. https://doi.org/10.1145/2330667.2330687

Bradley, R., & Newbutt, N. (2018). Autism and virtual reality head-mounted displays: A state of the art systematic review. *Journal of Enabling Technologies, 12*(3), 101-113. https://doi.org/10.1108/JET-01-2018-0004

Brand, S., Reimer, T., & Opwis, K. (2007). How do we learn in a negative mood? Effects of a negative mood on transfer and learning. *Learning and Instruction, 17*(1), 1-16. https://doi.org/10.1016/j.learninstruc.2006.11.002

Brault, S., Bideau, B., Kulpa, R., & Craig, C. (2009). Detecting deceptive movement in 1 vs. 1 based on global body displacement of a rugby player. *International Journal of VR, 8*(4) 31-36. https://doi.org/10.20870/IJVR.2009.8.4.2746

Bric, J. D., Lumbard, D. C., Frelich, M. J., & Gould, J. C. (2016). Current state of virtual reality simulation in robotic surgery training: a review. *Surgical Endoscopy, 30,* 2169–2178. https://doi.org/10.1007/s00464-015-4517-y

Brien, S., Lorenzetti, D., Lewis, S., Kennedy, J., & Ghali, W. (2010). Overview of a formal scoping review on health system report cards. *Implementation Science, 5*(1), 1-12. https://doi.org/10.1186/1748-5908-5-2

Briscoe, F. M. (2012). Anarchist, neoliberal & democratic decision-making: Deepening the joy in learning and teaching. *Educational Studies, 48*(1), 76-102. https://doi.org/10.1080/00131946.2011.637257

Brotons-Mas, J. R., O'Mara, S., & Sanchez-Vives, M. V. (2006). Neural processing of spatial information: what we know about place cells and what they can tell us about presence. *Presence: Teleoperators and Virtual Environments, 15*(5), 485-499. https://doi.org/10.1162/pres.15.5.485

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical foundations and evidence for its salutary effects. *Psychological Inquiry, 18*(4), 211-237. https://doi.org/10.1080/10478400701598298

Bruner, J. S. (1961). *The act of discovery*. Harvard Educational Review.

Bruner, J. S. (1966). *Toward a theory of instruction*. Belkapp.

Bruner, J. S. (2009). *The process of education*. Harvard University Press. https://doi.org/10.2307/j.ctvk12qst

Buckley, C. E., Kavanagh, D. O., Traynor, O., & Neary, P. C. (2014). Is the skillset obtained in surgical simulation transferable to the operating theatre? *The American Journal of Surgery, 207*(1), 146-157. https://doi.org/10.1016/j.amjsurg.2013.06.017

Bulu, S. T. (2012). Place presence, social presence, co-presence, and satisfaction in virtual worlds. *Computers & Education, 58*(1), 154-161. https://doi.org/10.1016/j.compedu.2011.08.024

Buń, P., Górski, F., Wichniarek, R., Kuczko, W., Hamrol, A., & Zawadzki, P. (2015). Application of professional and low-cost head mounted devices in immersive educational application. *Procedia Computer Science, 75*, 173-181. https://doi.org/10.1016/j.procs.2015.12.235

Burdea, G. (2002). Keynote address: Virtual rehabilitation-benefits and challenges. *Proceedings of the 1st International Workshop on VR Rehabilitation (Mental Health, Neurological, Physical, Vocational) VRMHR (vol. 2002)*, 1-11.

Burdea, G., & Coiffet, P. (2003). *Virtual reality technology* (2nd ed.). John Wiley. https://doi.org/10.1162/105474603322955950

Bush, J. (2008). Viability of virtual reality exposure therapy as a treatment alternative. *Computers in Human Behavior, 24*(3), 1032–1040. https://doi.org/10.1016/j.chb.2007.03.006

Buttussi, F., & Chittaro, L. (2017). Effects of different types of virtual reality display on presence and learning in a safety training scenario. *IEEE Transactions on Visualization and Computer Graphics, 24*(2), 1063-1076. https://doi.org/10.1109/TVCG.2017.2653117

Cali, C., Baghabra, J., Boges, D. J., Holst, G. R., Kreshuk, A., Hamprecht, F. A., Srinivasan, M., Lehväslaiho, H., & Magistretti, P. J. (2015). Three-dimensional immersive virtual reality for studying cellular compartments in 3D models from EM preparations of neural tissues. *Journal of Comparative Neurology, 524*(1), 23-38. https://doi.org/10.1002/cne.23852

Çaliskan, O. (2011). Virtual field trips in education of earth and environmental sciences. *Procedia-Social and Behavioral Sciences, 15,* 3239-3243. https://doi.org/10.1016/j.sbspro.2011.04.278

Callieri, M., Chica, A., Dellepiane, M., Besora, I., Corsini, M., Moyés, J., Ranzuglia, G., Moyés, J., & Brunet, P. (2011). Multiscale acquisition and presentation of very large artifacts: the case of portalada. *Journal on Computing and Cultural Heritage, 3*(4), 1-20. https://doi.org/10.1145/1957825.1957827

Carlson, J. R., & George, J. F. (2004). Media appropriateness in the conduct and discovery of deceptive communication: The relative influence of richness and synchronicity. *Group Decision and Negotiation, 13*(2), 191-210. https://doi.org/10.1023/B:GRUP.0000021841.01346.35

Carnegie, K., & Rhee, T. (2015). Reducing visual discomfort with HMDs using dynamic depth of field. *IEEE Computer Graphics and Applications, 35*(5), 34-41. https://doi.org/10.1109/MCG.2015.98

Carrozzino, M., & Bergamasco, M. (2010). Beyond virtual museums: experiencing immersive virtual reality in real museums. *Journal of Cultural Heritage, 11*(4), 452-458. https://doi.org/10.1016/j.culher.2010.04.001

Castaneda, L. & Pacampara, M. (2016). VR in the classroom-An exploration of hardware, management, content and pedagogy. In G. Chamblee & L. Langub (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2016* (pp. 527-534). Association for the Advancement of Computing in Education (AACE).

Casu, A., Spano, L. D., Sorrentino, F., & Scateni, R. (2015). RiftArt: bringing masterpieces in the classroom through immersive virtual reality. *Proceedings of the Smart Tools and Apps for Graphics-Eurographics Italian Chapter Conference*. Eurographics Association.

Cendan, J., & Lok, B. (2012). The use of virtual patients in medical school curricula. *Advances in Physiology Education, 36*, 48-53. https://doi.org/10.1152/advan.00054.2011

Chang, X. Q., Zhang, D. H., & Jin, X. X. (2016). Application of virtual reality technology in distance learning. *International Journal of Emerging Technologies in Learning, 11*(11). https://doi.org/10.3991/ijet.v11i11.6257

Chen, S. (2018). Research on the application of virtual reality in remote education based on the example of MOOC. *Proceedings of the 2018 15th International Conference on Service Systems and Service Management* (ICSSSM), 1-4. IEEE. https://doi.org/10.1109/ICSSSM.2018.8465027

Chen, X., Chen, Z., Li, Y., He, T., Hou, J., Liu, S., & He, Y. (2019). ImmerTai: Immersive motion learning in VR environments. *Journal of Visual Communication and Image Representation, 58*, 416-427. https://doi.org/10.1016/j.jvcir.2018.11.039

Chen, Y. L. (2016). The effects of virtual reality learning environment on student cognitive and linguistic development. *The Asia-Pacific Education Researcher, 25*(4), 637-646. https://doi.org/10.1007/s40299-016-0293-2

Cheng, A., Yang, L., & Andersen, E. (2017). Teaching language and culture with a virtual reality game. *Proceedings of the Conference on Human Factors in Computing Systems, 2017,* 541-549. https://doi.org/10.1145/3025453.3025857

Cheng, M. T., She, H. C., & Annetta, L. A. (2015). Game immersion experience: its hierarchical structure and impact on game-based science learning. *Journal of Computer Assisted Learning, 31*(3), 232-253. https://doi.org/10.1111/jcal.12066

Cheong, R. (1995). The virtual threat to travel and tourism. *Tourism Management, 16*(6), 417-422. https://doi.org/10.1016/0261-5177(95)00049-T

Chernyak, D., & Stark, L. W. (2001). Top-down guided eye movements. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics), 31*(4), 514-522. https://doi.org/10.1109/3477.938257

Cheung, S. K. S., Fong, J., Fong, W., Wang, F. L., & Kwok, L. F. (Eds.). (2013). *Hybrid learning and continuing education, Proceedings of the 6th International Conference* (vol. 8038). Springer. https://doi.org/10.1007/978-3-642-39750-9

Chittaro, L., & Buttussi, F. (2015). Assessing knowledge retention of an immersive serious game vs. A traditional education method in aviation safety. *IEEE Transactions on Visualization and Computer Graphics, 21*(4), 529-538. https://doi.org/10.1109/TVCG.2015.2391853

Choi, J. I., & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43*(2), 53-69. https://doi.org/10.1007/BF02300472

Christiansen, K. R., & Shalamov, A. (2017). *Motion sensors explainer.* World Wide Web Consortium, Technical Report.

Chu, P. Y., Chen, L. C., Kung, H. W., & Su, S. J. (2017). A study on the differences among M3D, S3D and HMD for students with different degrees of spatial ability in design education. *Proceedings of the International Conference on Human-Computer Interaction*, 293-299. Springer. https://doi.org/10.1007/978-3-319-58750-9_41

Claessen, M. H., van Der Ham, I. J., Jagersma, E., & Visser-Meily, J. M. (2015). Navigation strategy training using virtual reality in six chronic stroke patients: a novel and explorative approach to the rehabilitation of navigation impairment. *Neuropsychological Rehabilitation, 26*(5-6), 822-846. https://doi.org/10.1080/09602011.2015.1045910

Clarke, P. (2016). Smart MEMS microphones market emerges. *EE News Analog*. https://www.eenewsanalog.com/news/smart-mems-microphones-market-emerges

Cockton, G. (2006). Valuing user experience. In E. Law, E. Hvannberg & M. Hassenzahl (Eds.), *Proceedings of the NordiCHI 2006 Workshop: User Experience: Towards a Unified View,* 100-105. COST294-MAUSE.

Codd, A. M., & Choudhury, B. (2011). Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? *Anatomical Sciences Education, 4*(3), 119-125. https://doi.org/10.1002/ase.214

Cohen, J. (2001). Defining identification: A theoretical look at the identification of audiences with media characters. *Mass Communication & Society, 4*(3), 245-264. https://doi.org/10.1207/S15327825MCS0403_01

Colburn, A. (2000). Constructivism: Science education's "grand unifying theory." *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 74*(1), 9-12. https://doi.org/10.1080/00098655.2000.11478630

Computer Discount Warehouse-Government, CDW-G (2010). *21st-century classroom report: Key findings*. http://newsroom.cdw.com/features/feature-06-28-10.html \

Conn, C., Lanier, J., Minsky, M., Fisher, S., & Druin, A. (1989). Virtual environments and interactivity: windows to the future. *Proceedings of the ACM SIGGRAPH 89 Panel*, 7-18. ACM. https://doi.org/10.1145/77276.77278

Connolly, M., Seligman, J., Kastenmeier, A., Goldblatt, M., & Gould, J. C. (2014). Validation of a virtual reality-based robotic surgical skills curriculum. *Surgical Endoscopy, 28*(5), 1691-1694. https://doi.org/10.1007/s00464-013-3373-x

Cook, D. A., Erwin, P. J., & Triola, M. M. (2010). Computerized virtual patients in health professions education: a systematic review and meta-analysis. *Academic Medicine, 85*(10), 1589-1602. https://doi.org/10.1097/ACM.0b013e3181edfe13

Corbetta, D., Imeri, F., & Gatti, R. (2015). Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: a systematic review. *Journal of Physiotherapy, 61*(3), 117-124. https://doi.org/10.1016/j.jphys.2015.05.017 181b33350

Crescentini, C., Chittaro, L., Capurso, V., Sioni, R., & Fabbro, F. (2016). Psychological and physiological responses to stressful situations in immersive virtual reality: Differences between users who practice mindfulness meditation and controls. *Computers in Human Behavior, 59*, 304-316. https://doi.org/10.1016/j.chb.2016.02.031

Crook, C. (1991). Computers in the zone of proximal development: implications for evaluation. *Computers & Education, 17(*1), 81-91. https://doi.org/10.1016/0360-1315(91)90075-3

Crook, C., & Lewthwaite, S. (2010). Technologies for formal and informal learning. *International Handbook of Psychology in Education*, 435-461. Emerald

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM, 35*(6), 64-73. https://doi.org/10.1145/129888.129892

Csikszentmihályi, M. (1990). *Flow: The psychology of optimal experience*. Haper and Row.

Csikszentmihályi, M. (2017). *Finding flow*. Hachette Audio.

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*(12), 888-895. https://doi.org/10.1212/01.wnl.0000326262.67613.fe

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology, 41*(1), 10-32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Dalgarno, B., Lee, M. J., Carlson, L., Gregory, S., & Tynan, B. (2011). An Australian and New Zealand scoping study on the use of 3D immersive virtual worlds in higher education. *Australasian Journal of Educational Technology, 27*(1). https://doi.org/10.14742/ajet.978

Darken, R., & Goerger, S. R. (1999). The transfer of strategies from virtual to real environments: an explanation for performance differences? *Simulation Series, 31,* 159-164.

Daudt, H. M., Van Mossel, C., & Scott, S. J. (2013). Enhancing the scoping study methodology: A large, inter-professional team's experience with Arksey and O'Malley's framework. *BMC Medical Research Methodology, 13*(1), 48. https://doi.org/10.1186/1471-2288-13-48

Davis, A. & Kühnlenz, F. (2017). Optical design using Fresnel lenses: basic principles and some practical examples. *Optik & Photonik, 4*, 52-55. https://doi.org/10.1002/opph.201190287

Davis, D., & Hayes, J. (2012). What are the benefits of mindfulness: A wealth of new research has explored this age-old practice. Here's a look at its benefits for both clients and psychologists. *Monitor on Psychology, 43*, 198-208. https://doi.org/10.1037/e584442012-022

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science, 35*(8), 982-1003. https://doi.org/10.1287/mnsc.35.8.982

Dawson, D. L. (2006). Training in carotid artery stenting: do carotid simulation systems really help? *Vascular, 14*(5), 256-263. https://doi.org/10.2310/6670.2006.00045

De la Peña, N., Weil, P., Llobera, J., Giannopoulos, E., Pomés, A., Spanlang, B., Friedman, D., Sanchez-Vives, M. V., & Slater, M. (2010). Immersive journalism: immersive virtual reality for the first-person experience of news. *Presence: Teleoperators and Virtual Environments, 19*(4), 291-301. https://doi.org/10.1162/PRES_a_00005

De Lucia, A., Francese, R., Passero, I., & Tortora, G. (2009). Development and evaluation of a virtual campus on Second Life: The case of Second DMI. *Computers & Education, 52*(1), 220-233. https://doi.org/10.1016/j.compedu.2008.08.001

De Oliveira, E. C., Bertrand, P., Lesur, M. E. R., Palomo, P., Demarzo, M., Cebolla, A., Baños, R., & Tori, R. (2016). Virtual body swap: A new feasible tool to be explored in health and education. *Proceedings of the 18th Symposium on Virtual and Augmented Reality, SVR 2016*, 81-89. https://doi.org/10.1109/SVR.2016.23

De Rooij, I. J. M., van de Port, I. G. L., & Meijer, J.-W. G. (2016). Effect of virtual reality training on balance and gait ability in patients with stroke: Systematic review and meta-analysis. *Physical Therapy, 96*(12), 1905-1918. https://doi.org/10.2522/ptj.20160054

De Villiers, P. & Blignaut, S. (2016). Readiness of forklift operators to train with serious games. In J. Johnston (Ed.), *Proceedings of the EdMedia + Innovate Learning 2016*, 1696-1704. Association for the Advancement of Computing in Education (AACE).

Dede, C. J. (1992). The future of multimedia: Bridging to virtual worlds. *Educational Technology, 32*(5), 54-60.

Dede, C. J. (2009). Immersive interfaces for engagement and learning. *Science, 323*, 66-69. https://doi.org/10.1126/science.1167311

Dede, C., Salzman, M., Loftin, R. B., & Ash, K. (1997). Using virtual reality technology to convey abstract scientific concepts. In M. J. Jacobson, R. B. Kozma, & L. Erlbaum (Eds.), *Learning the sciences of the 21st century: research, design, and implementing advanced technology learning environments* (pp. 1-44). Lawrence Erlbaum.

Dede, C., Salzman, M. C., Loftin, R. B., & Sprague, D. (1999). Multisensory immersion as a modeling environment for learning complex scientific concepts. In W. Feurzeig & N. Roberts (Eds.), *Computer modeling and simulation in science education* (pp. 282-319). Springer. https://doi.org/10.1007/978-1-4612-1414-4_12

Dennis, A. R., & Valacich, J. S. (1999). Rethinking media richness: Towards a theory of media synchronicity. *Proceedings of the 32nd Hawaii International Conference on Systems Sciences,* 1-10. https://doi.org/10.1109/HICSS.1999.772701

Derry, S. J. (1990). *Flexible cognitive tools for problem solving instruction*. Paper presented at the American Educational Research Association.

Dick, W. (1991). An instructional designer's view of constructivism. *Educational Technology, 31*(5), 41-44.

Dickey, M. D. (2005). Brave new (interactive) worlds: A review of the design affordances and constraints of two 3D virtual worlds as interactive learning environments. *Interactive Learning Environments, 13*(1-2), 121-137. https://doi.org/10.1080/10494820500173714

Diemer, J., Alpers, G. W., Peperkorn, H. M., Shiban, Y., & Mühlberger, A. (2015). The impact of perception and presence on emotional reactions: a review of research in virtual reality. *Frontiers in Psychology, 6*(26), 1-9. https://doi.org/10.3389/fpsyg.2015.00026

Dodds, T. J., Mohler, B. J., & Bülthoff, H. H. (2011). Talk to the virtual hands: self-animated avatars improve communication in head-mounted display virtual environments. *PloS One, 6*(10), e25759. https://doi.org/10.1371/journal.pone.0025759

Doherty, M. E., Jr. (1994). Marshall McLuhan meets William Gibson in "Cyberspace". *CMC Magazine*, 4-5.

Dolgunsöz, E., Yıldırım, G., & Yıldırım, S. (2018). The effect of virtual reality on EFT writing performance. *Journal of Language and Linguistic Studies, 14*, 278-292.

Dourish, P. (2004). *Where the action is: the foundations of embodied interaction*. MIT press.

Duchowski, A. T., House, D. H., Gestring, J., Wang, R. I., Krejtz, K., Krejtz, I., Mantiuk, R., & Bazyluk, B. (2014). Reducing visual discomfort of 3D stereoscopic displays with gaze-contingent depth-of-field. *Proceedings of the ACM Symposium on Applied Perception* (pp. 39-46). ACM. https://doi.org/10.1145/2628257.2628259

Ducoffe, R. H. (1996). Advertising value and advertising on the web-Blog@ management. *Journal of advertising research, 36*(5), 21-32.

Dunn, S., Woolford, K., Norman, S.-J., White, M., & Barker, L. (2012). Motion in place: a case study of archaeological reconstruction using motion capture. *Revive the Past: Proceedings of the 39th Conference in Computer Applications and Quantitative Methods in Archaeology*, 98-106. Amsterdam University Press. https://doi.org/10.2307/j.ctt1zrvhmr.14

Edmund Optics (n. d.). *Advantages of Fresnel lenses.* https://www.edmundoptics.com/knowledge-center/application-notes/optics/advantages-of-fresnel-lenses/

Edwards, S. (2013). *By-passing the debate: Beyond the "technology question" in the early years*. TACTYC Reflections. http://tactyc.org.uk/pdfs/Reflection-Edwards.pdf

Ehrsson, H. H. (2009). How many arms make a pair? Perceptual illusion of having an additional limb. *Perception, 38*(2), 310-312. https://doi.org/10.1068/p6304

Ehrsson, H. H. (2012). The concept of body ownership and its relation to multisensory integration. In B. E. Stein (Ed.), *The new handbook of multisensory processes* (pp. 775-792). MIT Press. https://doi.org/10.1162/pres.1996.5.2.247

Eichenberg, C. (2011). Application of virtual realities in psychotherapy: possibilities, limitations and effectiveness. In J.-J. Kim (Ed.), *Virtual reality* (pp. 469-484). IntechOpen. https://doi.org/10.5772/12914

El Kabtane, H., El Adnani, M., Sadgal, M., & Mourdi, Y. (2020). Virtual reality and augmented reality at the service of increasing interactivity in MOOCs. *Education and Information Technologies,* 1-27. https://doi.org/10.1007/s10639-019-10054-w

El-Mounayri, H. A., Rogers, C., Fernandez, E., & Satterwhite, J. C. (2016). Assessment of STEM e-learning in an immersive virtual reality (VR) environment. *Proceedings of the ASEE Annual Conference and Exposition*. https://doi.org/10.18260/p.26336

Elliman, J., Loizou, M., & Loizides, F. (2016). Virtual reality simulation training for student nurse education. *Proceedings of the 2016 8th International Conference on Games and Virtual Worlds for Serious Applications, VS-Games 2016.* https://doi.org/10.1109/VS-GAMES.2016.7590377

Ellis, S. R. (1996). Presence of mind: a reaction to Thomas Sheridan's "further musings on the psychophysics of presence". *Presence: Teleoperators & Virtual Environments, 5*(2), 247-259. https://doi.org/10.1162/pres.1996.5.2.247

Elmezeny, A., Edenhofer, N., & Wimmer, J. (2018). Immersive storytelling in 360-degree videos: An analysis of interplay between narrative and technical immersion. *Journal for Virtual Worlds Research, 11*(1). https://doi.org/10.4101/jvwr.v11i1.7298

Encyclopaedia Britannica (2020). *Snell's law*. https://www.britannica.com/science/Snells-law

Engadget (2017). *Chinese startup's '8K' VR headset is surprisingly advanced*. https://www.engadget.com/2017-10-12-pimax-8k-vr-headset.html

Engelbrecht, H., Lindeman, R. W., & Hoermann, S. (2019). A SWOT analysis of the field of virtual reality for firefighter training. *Frontiers in Robotics and AI 6*(101), 1-14. https://doi.org/10.3389/frobt.2019.00101

Entwistle, N. & Ramsden, P. (2015). *Understanding student learning*. Routledge. https://doi.org/10.4324/9781315718637

Ermi, L., & Mäyrä, F. (2005). Fundamental components of the gameplay experience: Analysing immersion. *Worlds in Play: International Perspectives on Digital Games Research, 37*(2), 37-53.

Ertmer, P. A., & Newby, T. J. (2013). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly, 26*(2), 43-71. https://doi.org/10.1002/piq.21143

Ezawa, K., Bazinet, J., B., Danely, C., Gursky, J., Homan, D. F., Kim, H. H., May, M., Pritchard, W. H., Rollins, M., Singlehurst, T. A., Wong, K., Yoshida, R., Chan, D., Goyal, S., Harchandani, A. B., Iyer, R. V., Malik, A., Michaeli, I., Raviv, J., … & Yang, W. (2016). *Virtual & Augmented Reality. Are you sure it isn't real*? Citi GPS: Global Perspectives & Solutions. https://www.citibank.com/commercialbank/insights/assets/docs/virtual-and-augmented-reality.pdf

Fabola, A., & Miller, A. (2016). VR for early education: A study. *Proceedings of the International Conference on Immersive Learning*, 59-72. Springer. https://doi.org/10.1007/978-3-319-41769-1_5

Falah, J., Khan, S., Alfalah, T., Alfalah, S. F. M., Chan, W., Harrison, D. K., & Charissis, V. (2014). Virtual reality medical training system for anatomy education. *Proceedings of the 2014 Science and Information Conference,* 752-758. IEEE. https://doi.org/10.1109/SAI.2014.6918271

Falloon, G. (2010). Using avatars and virtual environments in learning: What do they have to offer?. *British Journal of Educational Technology, 41*(1), 108-122. https://doi.org/10.1111/j.1467-8535.2009.00991.x

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191. https://doi.org/10.3758/BF03193146

Ferguson, C., Van den Broek, E. L., & Van Oostendorp, H. (2020). On the role of interaction mode and story structure in virtual reality serious games. *Computers & Education, 143*, 103671. https://doi.org/10.1016/j.compedu.2019.103671

Ferracani, A., Pezzatini, D., & Del Bimbo, A. (2014). A natural and immersive virtual interface for the surgical safety checklist training. *Proceedings of the ACM International Workshop on Serious Games-Serious Games '14*, 27-32. ACM. https://doi.org/10.1145/2656719.2656725

Fokides, E. (2017a). A model for explaining primary school students' learning outcomes when they use multi-user virtual environments. *Journal of Computers in Education, 4*(3), 225-250. https://doi.org/10.1007/s40692-017-0080-y

Fokides, E. (2017b). Pre-service teachers' intention to use MUVEs as practitioners. A structural equation modeling approach. *Journal of Information Technology Education: Research, 16,* 47-68. https://doi.org/10.28945/3645

Fokides, E. (2020). Digital educational games in primary education. Revisiting the results of the research projects of the ETiE initiative. In L. Daniela (Ed.), Epistemological approaches to digital learning in educational contexts (pp. 54-68). Routledge. https://doi.org/10.4324/9780429319501-4

Fokides, E., & Atsikpasi, P. (2018). Development of a model for explaining the learning outcomes when using 3D virtual environments in informal learning settings. *Education and Information Technologies, 25*(3), 2265-2287. https://doi.org/10.1007/s10639-018-9719-1

Fokides, E., Atsikpasi, P., Kaimara, P., & Deliyannis, I. (2019). Factors influencing the subjective learning effectiveness of serious games. *Journal of Information Technology Education: Research, 18*, 437-466. https://doi.org/10.28945/44411

Fokides, E., Chronopoulou, M-. I., & Kaimara, P. (2019). Comparing videos and a 3D virtual environment for teaching school-related functional skills and behaviors to students with ADHD or developmental dyslexia, displaying challenging behaviors: a case study. *Research and Practice in Technology Enhanced Learning, 14*, 22. https://doi.org/10.1186/s41039-019-0117-0

Fokides, E., & Zampouli, C. (2017). Content and Language Integrated Learning in OpenSimulator Project. Results of a pilot implementation in Greece. *Education and Information Technologies, 22*(4), 1479-1496. https://doi.org/10.1007/s10639-016-9503-z

Foley, J. D., & Van Dam, A. (1982). *Fundamentals of interactive computer graphics* (vol. 2). Addison-Wesley

Fominykh, M., Prasolova-Førland, E., Stiles, T.C., Krogh, A.B. & Linde, M. (2018). Conceptual framework for therapeutic training with biofeedback in virtual reality: First evaluation of a relaxation simulator. *Journal of Interactive Learning Research, 29*(1), 51-75.

Forlizzi, J., & Battarbee, K. (2004). Understanding experience in interactive systems. *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques*, 261-268. https://doi.org/10.1145/1013115.1013152

Fowler, C. (2015). Virtual reality and learning: where is the pedagogy? *British Journal of Educational Technology, 46*(2), 412-422. https://doi.org/10.1111/bjet.12135

Fox, J., & Bailenson, J. N. (2009). Virtual self-modeling: the effects of vicarious reinforcement and identification on exercise behaviors. *Media Psychology, 12*(1), 1-25. https://doi.org/10.1080/15213260802669474

Freina, L., Bottino, R. & Tavella, M. (2016). From e-learning to VR-learning: An example of learning in an immersive virtual world. *Journal of e-Learning and Knowledge Society, 12*(2), 101-113.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: state of the art and perspectives. *Proceedings of the International Scientific Conference Elearning and Software for Education,* 1-8.

Friedman, D., Pizarro, R., Or-Berkers, K., Neyret, S., Pan, X., & Slater, M. (2014). A method for generating an illusion of backwards time travel using immersive virtual reality - an exploratory study. *Frontiers in Psychology, 5*, 943. https://doi.org/10.3389/fpsyg.2014.00943

Friedman, D., Steed, A., & Slater, M. (2007). Spatial social behavior in second life. In C. Pelachaud, J.-C. Martin, E. André, G. Chollet, K. Karpouzis, & D. Pelé (Eds.), *Proceedings of the Intelligent Virtual Agents 7th International Conference, IVA 2007,* 252-263. Springer. https://doi.org/10.1007/978-3-540-74997-4_23

Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology, 95*(1), 148. https://doi.org/10.1037/0022-0663.95.1.148

Gabriel, K., Jarvis, J., & Trimmer, W. (1988). *Small machines, large opportunities: A report on the emerging field of microdynamics*. Report of the Workshop on Microelectromechanical Systems Research. AT&T Bell Laboratories.

Gaitatzes, A., Christopoulos, D., & Roussou, M. (2001). Reviving the past: cultural heritage meets virtual reality. *Proceedings of the 2001 Conference on VR, Archeology, and Cultural Heritage*, 103-110. ACM. https://doi.org/10.1145/584993.585011

Garcia, S., Laesker, D., Andujar, M., Kauer, R., & Nguyen, J. (2019). A virtual reality experience for learning languages. *Proceedings of the Conference on Human Factors in Computing Systems, 2019.* ACM. https://doi.org/10.1145/3290607.3313253

Garrison, D. R. (2011). *E-Learning in the 21st century: A framework for research and practice.* Taylor & Francis. https://doi.org/10.4324/9780203838761

Gartner Glossary (n. d.). *Head-mounted Displays (HMDs)*. https://www.gartner.com/en/information-technology/glossary/head-mounted-displays-hmd

Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U. & Tecchia, F. (2015). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments, 23*(6), 778-798. https://doi.org/10.1080/10494820.2013.815221

Gavish, N., Gutierrez, T., Webel, S., Rodriguez, J., & Tecchia, F. (2011). Design guidelines for the development of virtual reality and augmented reality training systems for maintenance and assembly tasks. *Proceedings of the International Conference SKILLS 2011*. BIO Web of Conferences. https://doi.org/10.1051/bioconf/20110100029

Gerjets, P., Walter, W., Rosenstiel, W., Bogdan, M., & Zander, T. O. (2014). Cognitive state monitoring and the design of adaptive instruction in digital environments: Lessons learned from cognitive workload assessment using a passive brain-computer interface approach. *Frontiers in Neuroscience, 8*, 386. https://doi.org/10.3389/fnins.2014.00385

Giannopoulos, E., Wang, Z., Peer, A., Buss, M., & Slater, M. (2011). Comparison of people's responses to real and virtual handshakes within a virtual environment. *Brain Research Bulletin, 85*(5), 276-282. https://doi.org/10.1016/j.brainresbull.2010.11.012

Gibson, J., J. (1979). *The ecological approach to visual perception*. Psychology Press.

Glaser, N. J., & Schmidt, M. (2018). Usage considerations of 3D collaborative virtual learning environments to promote development and transfer of knowledge and skills for individuals with autism. *Technology, Knowledge and Learning*, 1-8. https://doi.org/10.1007/s10758-018-9369-9

González-Franco, M., Peck, T. C., Rodríguez-Fornells, A., & Slater, M. (2013). A threat to a virtual hand elicits motor cortex activation. *Experimental Brain Research, 232*(3), 875-887. https://doi.org/10.1007/s00221-013-3800-1

Górski, F., Buń, P., Wichniarek, R., Zawadzki, P., & Hamrol, A. (2015). Immersive city bus configuration system for marketing and sales education. *Procedia Computer Science, 75,* 137-146. https://doi.org/10.1016/j.procs.2015.12.230

Gould, N. F., Holmes, M. K., Fantie, B. D., Luckenbaugh, D. A., Pine, D. S., Gould, T. D., Burgess, N., Husseini, D., Manji, K., Carlos, D., & Zarate, A. (2007). Performance on a virtual reality spatial memory navigation task in depressed patients. *American Journal of Psychiatry, 164*(3), 516-519. https://doi.org/10.1176/ajp.2007.164.3.516

Grant, M., J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal, 26*(2), 91-108. https://doi.org/10.1111/j.1471-1842.2011.00939.x

Greenwald, S., Kulik, A., Kunert, A., Beck, S., Frohlich, B., Cobb, S., Parsons, S., Newbutt, N., Gouneia, C., Cook, C., Snyder, A., Payne, S., Holland, J., Buessing, S., Fields, G., Corning, W., Lee, V., Xia, L., & Maes, P. (2017). Technology and applications for collaborative learning in virtual reality. *Proceedings of the 12th International Conference on Computer Supported Collaborative Learning (CSCL), Prioritizing Equity and Access in CSCL*.

Groom, V., Bailenson, J. N., & Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence, 4*(3), 231-248. https://doi.org/10.1080/15534510802643750

Gugenheimer, J., Stemasov, E., Frommel, J., & Rukzio, E. (2017). Sharevr: Enabling co-located experiences for virtual reality between HMD and non-HMD users. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 4021-4033. https://doi.org/10.1145/3025453.3025683

Gulikers, J. T., Bastiaens, T. J., & Martens, R. L. (2005). The surplus value of an authentic learning environment. *Computers in Human Behavior, 21*(3), 509-521. https://doi.org/10.1016/j.chb.2004.10.028

Gunawardena, C. N., & Zittle, F. J. (1997). Social presence as a predictor of satisfaction within a computer-mediated conferencing environment. *American Journal of Distance Education, 11*(3), 8-26. https://doi.org/10.1080/08923649709526970

Gustafson, P. (2012). Managing business travel: developments and dilemmas in corporate travel management. *Tourism Management, 33*(2), 276-284. https://doi.org/10.1016/j.tourman.2011.03.006

Guterstam, A., Petkova, V. I., & Ehrsson, H. H. (2011). The illusion of owning a third arm. *PloS One, 6*(2), e17208. https://doi.org/10.1371/journal.pone.0017208

Gutierrez-Maldonado, J., Andres-Pueyo, A., & Talarn-Caparros, A. (2015). Virtual reality to train teachers in ADHD detection. In D. Rutledge & D. Slykhuis (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2015* (pp. 769-772). Association for the Advancement of Computing in Education (AACE).

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis: International version* (7th ed.) Pearson. https://doi.org/10.1016/j.jmva.2009.12.014

Halabi, O., Abou El-Seoud, S., Alja'am, J., Alpona, H., Al-Hemadi, M., & Al-Hassan, D. (2017). Design of immersive virtual reality system to improve communication skills in individuals with autism. *International Journal of Emerging Technologies in Learning (iJET*), *12*(5), 50-64. https://doi.org/10.3991/ijet.v12i05.6766

Hall, E. T. (1969). *The hidden dimension*. Anchor Books.

Hamurcu, A. (2018, October). User insights about using immersive virtual reality in industrial design studio courses. *Proceedings of the 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies, 2018,* 1-8. IEEE. https://doi.org/10.1109/ISMSIT.2018.8567058

Harrington, M. C. (2012). The virtual trillium trail and the empirical effects of freedom and fidelity on discovery-based learning. *VR, 16*(2), 105-120. https://doi.org/10.1007/s10055-011-0189-7

Hartley, T., Maguire, E. A., Spiers, H. J., & Burgess, N. (2003). The well-worn route and the path less traveled: distinct neural bases of route following and wayfinding in humans. *Neuron, 37*(5), 877-888. https://doi.org/10.1016/S0896-6273(03)00095-3

Hartson, R. & Pyla, P. S. (2012*). The UX Book: Process and guidelines for ensuring a quality user experience.* Elsevier.

Hassenzahl, M., Tractinsky, N. (2006). User experience-a research agenda. *Behaviour and Information Technology, 25*(2), 91-97. https://doi.org/10.1080/01449290500330331

Hauser, M., Cushman, F., Young, L., Kang-Xing Jin, R., & Mikhail, J. (2007). A dissociation between moral judgments and justifications. *Mind & Language, 22*(1), 1-21. https://doi.org/10.1111/j.1468-0017.2006.00297.x

Hauswiesner, S., Straka, M., & Reitmayr, G. (2011). Free viewpoint virtual try-on with commodity depth cameras. *Proceedings of the 10th International Conference on VR Continuum and Its Applications in Industry*, 23-30. ACM. https://doi.org/10.1145/2087756.2087759

Havig, P., McIntire, J., & Geiselman, E. (2011). Virtual reality in a cave: limitations and the need for HMDs? In *Head-and helmet-mounted displays XVI: Design and applications* (vol. 3), 8041-8046). International Society for Optics and Photonics. https://doi.org/10.1117/12.883855

Haworth, M. B., Baljko, M., & Faloutsos, P. (2012). PhoVR. *Proceedings of the 11th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry - VRCAI '12*. https://doi.org/10.1145/2407516.2407560

Headphonezone (2020). *Understanding binaural audio.* https://www.headphonezone.in/blogs/audiophile-guide/understanding-binaural-audio

Held, R. M., & Durlach, N. I. (1992). Telepresence. *Presence: Teleoperators & Virtual Environments, 1*(1), 109-112. https://doi.org/10.1162/pres.1992.1.1.109

Heldal, I., Roberts, D., Bråthe, L., & Wolff, R. (2007). Presence, creativity and collaborative work in virtual environments. *Proceedings of the International Conference on Human-Computer Interaction*, 802-811. Springer. https://doi.org/10.1007/978-3-540-73105-4_88

Heeter, C. (1992). Being there: The subjective experience of presence. *Presence: Teleoperators & Virtual Environments, 1*(2), 262-271. https://doi.org/10.1162/pres.1992.1.2.262

Hew, K. F., & Cheung, W. S. (2010). Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research. *British Journal of Educational Technology, 41*(1), 33-55. https://doi.org/10.1111/j.1467-8535.2008.00900.x

Higgins, J. P., & Green, S. (Eds.). (2011). *Cochrane handbook for systematic reviews of interventions* (vol. 4). John Wiley & Sons.

Ho, L. H., Sun, H., & Tsai, T. H. (2019). Research on 3D painting in virtual reality to improve students' motivation of 3D animation learning. *Sustainability, 11*(6), 1605. https://doi.org/10.3390/su11061605

Hong, S., & Tam, K. (2006). Understanding the adoption of multipurpose information appliances: The case of mobile data services. *Information Systems Research, 17*, 162-179. https://doi.org/10.1287/isre.1060.0088

Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education, 55*(3), 1171-1182. https://doi.org/10.1016/j.compedu.2010.05.014

Hutchins, H. M. (2003). Instructional immediacy and the seven principles: Strategies for facilitating online courses. *Online Journal of Distance Learning Administration, 6*(3), 1-11.

Hwang, W. -Y., & Hu, S.-S. (2013). Analysis of peer learning behaviors using multiple representations in virtual reality and their impacts on geometry problem solving. *Computers & Education, 62*, 308-319. https://doi.org/10.1016/j.compedu.2012.10.005

Ihlenfeldt, W. D. (1997). Virtual reality in chemistry. *Molecular Modeling Annual, 3*(9), 386-402. https://doi.org/10.1007/s008940050056

Ilie, R., Shaffer, E., & D'Angelo, C. M. (2019). Learning by immersion: Developing virtual reality labs for electricity and magnetism courses. *In AGU fall meeting 2019*. AGU. https://doi.org/10.5194/egusphere-egu2020-6114

Ishii, H., & Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. *Proceedings of the ACM SIGCHI Conference on Human factors in Computing Systems*, 234-241. https://doi.org/10.1145/258549.258715

Jensen, K., Ringsted, C., Hansen, H. J., Petersen, R. H., & Konge, L. (2014). Simulation-based training for thoracoscopic lobectomy: a randomized controlled trial. *Surgical endoscopy, 28*(6), 1821-1829. https://doi.org/10.1007/s00464-013-3392-7

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies, 23*(4), 1515-1529. https://doi.org/10.1007/s10639-017-9676-0

Jensen, M. T. (2014). Exploring business travel with work - family conflict and the emotional exhaustion component of burnout as outcome variables: the job demands-resources perspective. *European Journal of Work and Organizational Psychology, 23*(4), 497-510. https://doi.org/10.1080/1359432X.2013.787183

Jha, M. (2018). *Spinning up in VR-Part 5: Human-computer interaction in virtual reality*. https://medium.com/@mnrmja007/spinning-up-in-vr-part-5-human-computer-interaction-in-virtual-reality-757242a0751b

Johnson-Glenberg, M. C. (2017). Embodied education in mixed and mediated realties. In *Virtual, augmented, and mixed realities in education*, 193-217. Springer. https://doi.org/10.1007/978-981-10-5490-7_11

Johnson-Glenberg, M. C. (2019). The necessary nine: Design principles for embodied VR and active STEM education. In *Learning in a digital world,* 83-112. Springer. https://doi.org/10.1007/978-981-13-8265-9_5

Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., & Koziupa, T. (2014). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. *Journal of Educational Psychology, 106*(1), 86-104. https://doi.org/10.1037/a0034008

Johnson-Laird, P. N. (1988). *The computer and the mind: An introduction to cognitive science*. Harvard University Press.

Jonas, J. B., Rabethge, S., & Bender, H. J. (2003). Computer-assisted training system for pars plana vitrectomy. *Acta Ophthalmologica Scandinavica, 81*(6), 600-604. https://doi.org/10.1046/j.1395-3907.2003.0078.x

Jonassen, D. H. (1991). Evaluating constructivistic learning. *Educational technology, 31*(9), 28-33.

Jonassen, D. H. (1994). Thinking technology: Toward a constructivist design model. *Educational technology, 34*(4), 34-37.

Jonassen, D. H. (1995). Computers as cognitive tools learning with technology, not from technology. *Journal of Computing in Higher Education, 6*(2), 40-73. https://doi.org/10.1007/BF02941038

Jonassen, D. H., & Carr, C. (2000). Mind tools: Affording multiple knowledge representations in learning. In S. P. Lajoie (Ed.), *Computers as cognitive tools: Volume ii, No more walls* (pp. 165-196). Lawrence Erlbaum Associates Inc. https://doi.org/10.1201/9781315045337-8

Jonassen D. H., Mayes T., McAleese R. (1993) A manifesto for a constructivist approach to uses of technology in higher education. In T. M. Duffy, J. Lowyck, D. H. Jonassen, T. M. Welsh (Eds.), *Designing environments for constructive learning. NATO ASI Series (Series F: Computer and Systems Sciences)* (vol. 105, pp. 231-247). Springer. https://doi.org/10.1007/978-3-642-78069-1_12

Juliano, J. M., Saldana, D., Schmiesing, A., & Liew, S. L. (2019). Experience with head-mounted virtual reality (HMD-VR) predicts transfer of HMD-VR motor skills. *Proceedings of the International*

*Conference on Virtual Rehabilitation* (ICVR), 1-2. IEEE. https://doi.org/10.1109/ICVR46560.2019.8994345

Kalawsky, R. (1993). *The science of virtual reality and virtual environments: A technical, scientific and engineering reference on virtual environments*. Addison Wesley Publishing Company.

Kalivarapu, V., Macallister, A., Hoover, M., Sridhar, S., Schlueter, J., Civitate, A., Thompkins, P., Smith, J., Hoyle, J., Oliver, J., Winer, E., & Chernoff, G. (2015). Game-day football visualization experience on dissimilar virtual reality platforms. *Proceedings of the Engineering Reality of VR 2015*, *SPIE* (vol. 9392), 2-14. International Society for Optics and Photonics https://doi.org/10.1117/12.2083250

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental pollution, 151*(2), 362-367. https://doi.org/10.1016/j.envpol.2007.06.012

Kamstrupp, A. K. (2016). The wow-effect in science teacher education. *Cultural Studies of Science Education, 11*(4), 879-897. https://doi.org/10.1007/s11422-015-9684-6

Kandalaft, M. R., Didehbani, N., Krawczyk, D. C., Allen, T. T., & Chapman, S. B. (2012). *Virtual reality social cognition training for young adults with high-functioning autism. Journal of Autism and Developmental Disorders, 43(1), 34-44.* https://doi.org/10.1007/s10803-012-1544-6

Kaplan, A. M., & Haenlein, M. (2016). Higher education and the digital revolution: About MOOCs, SPOCs, social media, and the cookie monster. *Business Horizons. 59*(4), 441-50. https://doi.org/10.1016/j.bushor.2016.03.008

Karageorgakis, T., & Nisiforou, E. A. (2018). Virtual reality in the EFL classroom. *The Cyprus Review, 30*(1), 381-396.

Karray, F., Alemzadeh, M., Saleh, J. A., & Arab, M. N. (2008). *Human-computer interaction: Overview on state of the art. International Journal on Smart Sensing and Intelligent Systems*, *1*(1), 137-159. https://doi.org/10.21307/ijssis-2017-283

Kasahara, S., Nagai, S., & Rekimoto, J. (2014). LiveSphere: immersive experience sharing with 360 degrees head-mounted cameras. *Proceedings of the Adjunct Publication of the 27th Annual ACM Symposium on User Interface Software and Technology*, 61-62. ACM. https://doi.org/10.1145/2658779.2659114

Kateros, S., Georgiou, S., Papaefthymiou, M., Papagiannakis, G., & Tsioumas, M. (2015). A comparison of gamified, immersive VR curation methods for enhanced presence and human-computer interaction in digital humanities. *International Journal of Heritage in the Digital Era, 4*(2), 221-233. https://doi.org/10.1260/2047-4970.4.2.221

Kaye, N., & Giannachi, G. (2011). Acts of presence: Performance, mediation, virtual reality. *The Drama Review, 55*(4), 88-95. https://www.doi.org/10.1162/dram_a_00124

Kiefer, M., & Trumpp, N. M. (2012). Embodiment theory and education: The foundations of cognition in perception and action. *Trends in Neuroscience and Education, 1*(1), 15-20. https://doi.org/10.1016/j.tine.2012.07.002

Kilteni, K., Bergstrom, I., & Slater, M. (2013). Drumming in immersive virtual reality: the body shapes the way we play. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 597-605. https://doi.org/10.1109/TVCG.2013.29

Kilteni, K., Normand, J.-M., Sanchez-Vives, M. V., & Slater, M. (2012). Extending body space in immersive virtual reality: a very long arm illusion. *PloS One, 7*(7), e40867. https://doi.org/10.1371/journal.pone.0040867

Kim, J. H., Jang, S. H., Kim, C. S., Jung, J. H., & You, J. H. (2009). Use of virtual reality to enhance balance and ambulation in chronic stroke: A double-blind, randomized controlled study. *American Journal of Physical Medicine & Rehabilitation, 88*(9), 693-701. https://doi.org/10.1097/phm.0b013e3

Kim, J., Kim, H., Tay, B. K., Muniyandi, M., Srinivasan, M. A., Jordon, J., Mortensen, J., Oliveira, M., & Slater, M. (2004). Transatlantic touch: a study of haptic collaboration over long distance. *Presence: Teleoperators & Virtual Environments, 13*(3), 328-337. https://doi.org/10.1162/1054746041422370

Kim, J. S. (1999). Physiology of eye movements. *Annals of Clinical Neurophysiology, 1*(2), 173-181.

Kim, T., & Biocca, F. (1997). Telepresence via television: Two dimensions of telepresence may have different connections to memory and persuasion. *Journal of Computer-Mediated Communication, 3*(2), JCMC325. https://doi.org/10.1111/j.1083-6101.1997.tb00073.x

King, T. J., Warren, I., & Palmer, D. (2008). Would Kitty Genovese have been murdered in Second Life? Researching the "bystander effect" using online technologies. Proceedings of the *TASA 2008: Re-Imagining Sociology: The Annual Conference of the Australian Sociological Association*, 1-23. Australian Sociological Association.

Kirschner, P., Strijbos, J. W., Kreijns, K., & Beers, P. J. (2004). Designing electronic collaborative learning environments. *Educational Technology Research and Development, 52*(3), 47. https://doi.org/10.1007/BF02504674

Kleinsmith, A., Rivera-Gutierrez, D., Finney, G., Cendan, J., & Lok, B. (2015). Understanding empathy training with virtual patients. *Computers in Human Behavior, 52*, 151-158. https://doi.org/10.1016/j.chb.2015.05.033

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford Publications.

Klippel, A., Oprean, D., Zhao, J., Wallgrün, J. O., LaFemina, P., Jackson, K., & Gowen, E. (2019). Immersive learning in the wild: a progress report. *Proceedings of the International Conference on Immersive Learning,* 3-15. Springer. https://doi.org/10.1007/978-3-030-23089-0_1

Kober, S. E., Wood, G., Hofer, D., Kreuzig, W., Kiefer, M., & Neuper, C. (2013). Virtual reality in neurologic rehabilitation of spatial disorientation *Journal of Neuroengineering and Rehabilitation, 10*(1), 1-13. https://doi.org/10.1186/1743-0003-10-17

Koenig, S. T., Crucian, G. P., Dalrymple-Alford, J. C., & Dunser, A. (2009). Virtual reality rehabilitation of spatial abilities after brain damage. *Annual Review of CyberTherapy and Telemedicine,* 105-107.

Kohn, A. (2004). The cult of rigor and the loss of joy. *Education Week, 24*(3), 6-8.

Kokkinara, E., & Slater, M. (2014). Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. *Perception, 43*(1), 43-58. https://doi.org/10.1068/p7545

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Kolb, A. Y., & Kolb, D. A. (2009). Experiential learning theory: A dynamic, holistic approach to management learning, education and development. *The SAGE handbook of management learning, education and development*, 42-68. https://doi.org/10.4135/9780857021038.n3

Koleva, B., Taylor, I., Benford, S., Fraser, M., Greenhalgh, C., Schnadelbach, H., Lehn, D. v., Heath, C., Row-Far, J., & Adams, M. (2001). Orchestrating a mixed reality performance. *Proceedings of the*

*SIGCHI Conference on Human Factors in Computing Systems*, 38-45. SIGCHI https://doi.org/10.1145/365024.365033

Kozlov, M. D., & Johansen, M. K. (2010). Real behavior in virtual environments: psychology experiments in a simple virtual-reality paradigm using video games. *Cyberpsychology, behavior, and social networking, 13*(6), 711-714. https://doi.org/10.1089/cyber.2009.0310

Krassmann, A. L., da Rocha Mazzuco, A. E., Melo, M., Bessa, M., & Bercht, M. (2020). Usability and sense of presence in virtual worlds for distance education: A case study with virtual reality experts. *Proceedings of the 12th International Conference on Computer Supported Education (CSEDU*), 155-162). Science and Technology Publications. https://doi.org/10.5220/0009350401550162

Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: Immersion aids recall. *VR, 23*(1), 1-15. https://doi.org/10.1007/s10055-018-0346-3

Krueger, M. W., 1992. An Architecture for artificial realities. *Proceedings of the 37th IEEE Computer Society International Conference (COMPCON'92),* 462-465. IEEE.

Kucirkova, N. (2014). Kindle vs books? Children just don't see it that way. *The Conversation,* 18.

Kwon, C. (2019). Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies. *VR, 23*(1), 101-118. https://doi.org/10.1007/s10055-018-0364-1

Lakoff, G. & Johnson, M. (1999). *Philosophy in the flesh: the embodied mind and its challenge to Western thought.* Basic Books.

Lakoff, G. & Núñez, R. E. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being.* Basic Books.

Lamson, R. J. (1997). *Virtual therapy: prevention and treatment of psychiatric conditions by immersion in virtual reality environments*. Presses Polytechnique de Montréal.

Lanier, J. (2006). Homuncular flexibility. *Edge*, *26*. https://www.edge.org/response-detail/11182

Lanier, J. (2010). *You are not a gadget: A manifesto*. Random House.

Latane, B., & Darley, J. M. (1968). Group inhibition of bystander intervention in emergencies. *Journal of Personality and Social Psychology, 10*(3), 215. https://doi.org/10.1037/h0026570

Lawson, G., Salanitri, D., & Waterfield, B. (2016). Future directions for the development of virtual reality within an automotive manufacturer. *Applied Ergonomics, 53*, 323-330. https://doi.org/10.1016/j.apergo.2015.06.024

Lee, B., & Wong, C. (2008). Transition to comprehensive student guidance service in Hong Kong. *Counselling, Psychotherapy, and Health, Counselling in the Asia Pacific Rim: A Coming Together of Neighbours Special Issue 4*(1), 17-23.

Lee, E. A. L., Wong, K. W., & Fung, C. C. (2010). How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach. *Computers & Education, 55*(4), 1424-1442. https://doi.org/10.1016/j.compedu.2010.06.006

Lee, H. J., Lee, K. H., & Choi, J. (2018). A structural model for Unity of experience: Connecting user experience, customer experience, and brand experience. *Journal of Usability Studies, 14*(1), 8-34.

Lee, K. M. (2004). Presence, explicated. *Communication Theory, 14*(1), 27-50. https://doi.org/10.1111/j.1468-2885.2004.tb00302.x

Leinen, P., Green, M. F., Esat, T., Wagner, C., Tautz, F. S., & Temirov, R. (2015). Virtual reality visual feedback for hand-controlled scanning probe microscopy manipulation of single molecules. *Beilstein Journal of Nanotechnology, 6*(1), 2148-215. https://doi.org/10.3762/bjnano.6.220

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). *Scoping studies:* Advancing the methodology. *Implementation Science, 5*(1), 69. https://doi.org/10.1186/1748-5908-5-69

Levin, M. F. (2011). Can virtual reality offer enriched environments for rehabilitation? *Expert Review of Neurotherapeutics, 11*(2), 153-155. https://doi.org/10.1586/ern.10.201

Levoy, M., Pulli, K., Curless, B., Rusinkiewicz, S., Koller, D., Pereira, L., Ginzton, M., Anderson, S., Davis, J., Ginsberg, J., Shade, J. & Fulk, D. (2000). The digital Michelangelo project: 3D scanning of large statues. *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques,* 131-144. ACM Press/Addison-Wesley Publishing Co. https://doi.org/10.1145/344779.344849

Lewis, P. H., (1994, September). Sound Bytes; He added "Virtual" to "Reality." *The New York Times*, 7. https://www.nytimes.com/1994/09/25/business/sound-bytes-he-added-virtual-to-reality.html

Liang, H. N., Lu, F., Shi, Y., Nanjappan, V., & Papangelis, K. (2019). Evaluating the effects of collaboration and competition in navigation tasks and spatial knowledge acquisition within virtual reality environments. *Future Generation Computer Systems, 95*, 855-866. https://doi.org/10.1016/j.future.2018.02.029

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Medicine, 6*(7), e1000100. https://doi.org/10.1371/journal.pmed.1000100

Limniou, M., Roberts, D., & Papadopoulos, N. (2008). Full immersive virtual environment CAVETM in Chemistry education. *Computer & Education, 51*, 584-593. https://www.doi.org/10.1016/j.compedu.2007.06.014

Lin, H., Chen, M., Lu, G., Zhu, Q., Gong, J., You, X., Wen, Y., Xu, B., & Hu, M. (2013). Virtual Geographic Environments (VGEs): a new generation of geographic analysis tool. *Earth-Science Reviews, 126*, 74-84. https://doi.org/10.1016/j.earscirev.2013.08.001

Lin, S, Lee, T., Wang, H., & Chan, H. (2018). Developing the immersion virtual reality platform based on experiential learning cycle-using fire disaster prevention education as an example. *Proceedings of the 7th International Congress on Advanced Applied Informatics,* IIAI-AAI 2018, 948-949. https://doi.org/10.1109/IIAI-AAI.2018.00195

Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher, 42*(8), 445-452. https://doi.org/10.3102/0013189X13511661

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education, 95*, 174-187. https://doi.org/10.1016/j.compedu.2016.01.001

Linnenbrink, E. A., & Pintrich, P. R. (2002). Motivation as an enabler for academic success. *School Psychology Review, 31*(3), 313-327. https://doi.org/10.1080/02796015.2002.12086158

Liu, D., Jenkins, S. A., Sanderson, P. M., Fabian, P., & Russell, W. J. (2010). Monitoring with head-mounted displays in general anesthesia: A clinical evaluation in the operating room. *Anesthesia & Analgesia, 110*(4), 1032-1038. https://doi.org/10.1213/ANE.0b013e3181d3e647

Liu, Y. (2017). Bringing VR to your class/school: Where to start. In J. Johnston (Ed.), *Proceedings of the EdMedia + Innovate Learning 2017* (pp. 963-967). Association for the Advancement of Computing in Education (AACE).

Liu, Y., Fan, X., Zhou, X., Liu, M., Wang, J., & Liu, T. (2019). Application of virtual reality technology in distance higher education. *Proceedings of the 2019 4th International Conference on Distance Education and Learning,* 35-39. https://doi.org/10.1145/3338147.3338174

Livingstone, S., Wijnen, C. W., Papaioannou, T., Costa, C., & del Mar Grandío, M. (2013). Situating media literacy in the changing media environment: critical insights from European research on audiences. In N. Carpentier, C. Schrøder, & L. Hallett (Eds.), *Audience transformations: shifting audience positions in late modernity, Vol. 1 Routledge studies in European communication research and education* (pp. 210-228). Routledge.

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*(2), https://doi.org/10.1111/j.1083-6101.1997.tb00072.x

Loizides, F., El Kater, A., Terlikas, C., Lanitis, A., & Michael, D. (2014). Presenting Cypriot cultural heritage in virtual reality: a user evaluation. *Proceedings of the Euro-Mediterranean Conference,* 572-579. Springer. https://doi.org/10.1007/978-3-319-13695-0_57

Loomis, J. M. (1992). Distal attribution and presence. *Presence: Teleoperators & Virtual Environments, 1*(1), 113-119. https://doi.org/10.1162/pres.1992.1.1.113

Lorello, G., Cook, D., Johnson, R., & Brydges, R. (2014). Simulation-based training in anaesthesiology: a systematic review and meta-analysis. *British Journal of Anaesthesia, 112*(2), 231-245. https://doi.org/10.1093/bja/aet414

Loup, G., Serna, A., Iksal, S., & George, S. (2016). Immersion and persistence: Improving learners' engagement in authentic learning situations. *Proceedings of the European Conference on Technology Enhanced Learning*, 410-415. Springer. https://doi.org/10.1007/978-3-319-45153-4_35

Lovden, M., Schaefer, S., Noack, H., Bodammer, N. C., Kuhn, S., Heinze, H. J., Düzel, E., Bäckman, L., & Lindenberger, U. (2012). Spatial navigation training protects the hippocampus against age-related changes during early and late adulthood. *Neurobiology of Aging, 33*(3), 620-629. https://doi.org/10.1016/j.neurobiolaging.2011.02.013

Macpherson, C., & Keppell, M. (1998). Virtual reality: What is the state of play in education? *Australasian Journal of Educational Technology, 14*(1), 60-74. https://doi.org/10.14742/ajet.1929

MacLeod, M. A. M. D., & McLeod, D. B. (1996). *Immersed in technology: art and virtual environments.* MIT Press.

Magnenat-Thalmann, N., Kevelham, B., Volino, P., Kasap, M., & Lyard, E. (2011). 3D web-based virtual try on of physically simulated clothes. *Computer-Aided Design and Applications, 8*(2), 163-174. https://doi.org/10.3722/cadaps.2011.163-174

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development, 1*(24). https://doi.org/10.1007/s11423-018-9581-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2017). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction, 60,* 225-236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Manches, A., O'Malley, C., & Benford, S. (2010). The role of physical representations in solving number problems: A comparison of young children's use of physical and virtual materials. *Computers & Education, 54*(3), 622-640. https://doi.org/10.1016/j.compedu.2009.09.023

Marco, J. H., Perpiñá, C., & Botella, C. (2013). Effectiveness of cognitive behavioral therapy supported by virtual reality in the treatment of body image in eating disorders: One year follow-up. *Psychiatry Research, 209*(3), 619-625. https://doi.org/10.1016/j.psychres.2013.02.023

Maselli, A., & Slater, M. (2014). Sliding perspectives: dissociating ownership from self-location during full body illusions in virtual reality. *Frontiers in Human Neuroscience, 8*, 693. https://doi.org/10.3389/fnhum.2014.00693

Mays, N., Roberts, E., & Popay, J. (2001). Synthesizing research evidence. In N. Fulop, P. Allen, A. Clarke, & N. Black (Eds.), *Studying the organisation and delivery of health services: Research methods* (pp. 188-219). Routledge.

McIntire, J. P., Havig, P. R., & Geiselman, E. E. (2014). Stereoscopic 3D displays and human performance: A comprehensive review. *Displays, 35*(1), 18-26. https://doi.org/10.1016/j.displa.2013.10.004

McCall, C., Blascovich, J., Young, A., & Persky, S. (2009). Proxemic behaviors as predictors of aggression towards Black (but not White) males in an immersive virtual environment. *Social and Personality Psychology Compass, 3*(5), 744-758. https://doi.org/10.1111/j.1751-9004.2009.00195.x

McIntosh, I. A. N., & Wright, S. (2019). Exploring what the notion of "lived experience" offers for social policy analysis. *Journal of Social Policy, 48*(3), 449-467. https://doi.org/10.1017/S0047279418000570

McKenzie, S., Rough, J., Spence, A., & Patterson, N. (2019). Virtually there: The potential, process and problems of using 360 video in the classroom. *Issues in Informing Science and Information Technology, 16*, 211-219. https://doi.org/10.28945/4318

McLellan, H. (2004). Virtual realities. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology*. Erlbaum Associates.

McMahan, A. (2003). Immersion, engagement, and presence: A method for analyzing 3-D video games. In *The video game theory reader,* 67-86. Routledge.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A metaanalysis. *Computers & Education, 70*, 29-40. https://doi.org/10.1016/j.compedu.2013.07.033

Merry, S. N., Stasiak, K., Shepherd, M., Frampton, C., Fleming, T., & Lucassen, M. F. G. (2012). The effectiveness of SPARX, a computerised self help intervention for adolescents seeking help for depression: randomised controlled non-inferiority trial. *BMJ, 344*(apr18 3), e2598–e2598. https://doi.org/10.1136/bmj.e2598

Mikropoulos, T. A. (2006). Presence: a unique characteristic in educational virtual environments. *VR, 10*(3), 197-206. https://doi.org/10.1007/s10055-006-0039-1

Mikropoulos, T. A. & Bellou, J. (2006). The unique features of educational virtual environments. In P. Isaias, M. McPherson, & F. Banister (Eds.), *Proceedings of e-society 2006, International Association for Development of the Information Society* (vol. 1), 122-128. IADIS.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999-2009). *Computers & Education, 56*(3), 769-780. https://doi.org/10.1016/j.compedu.2010.10.020

Miles, H. C., Pop, S. R., Watt, S. J., Lawrence, G. P., & John, N. W. (2012). A review of virtual environments for training in ball sports. *Computers & Graphics, 36*(6), 714-726. https://doi.org/10.1016/j.cag.2012.04.007

Milgram, P. & Kishino, A. F. (1994). Taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, 1321-1329.

Milgram, S. (1974). *Obedience to authority*. McGraw Hill.

Mills, C., Fridman, I., Soussou, W., Waghray, D., Olney, A. M., & D'Mello, S. K. (2017). Put your thinking cap on: Detecting cognitive load using EEG during learning. *Proceedings of the 7th International Learning Analytics & Knowledge Conference,* 80-89. ACM. https://doi.org/10.1145/3027385.3027431

Moesgaard, T., Fiss, J., Warming, C., Klubien, J., & Schoenau-Fog, H. (2015). Implicit and explicit information mediation in a virtual reality museum installation and its effects on retention and learning outcomes. *Proceedings of the European Conference on Games Based Learning*, 387-394.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. (2009). *Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement*. *PLoS Med 6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Mollen, A., & Wilson, H. (2010). Engagement, telepresence and interactivity in online consumer experience: Reconciling scholastic and managerial perspectives. *Journal of Business Research, 63*(9-10), 919-925. https://doi.org/10.1016/j.jbusres.2009.05.014

Moon, J. A. (2013). *A handbook of reflective and experiential learning: Theory and practice*. Routledge. https://doi.org/10.4324/9780203416150

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology, 94*(3), 598-610. https://doi.org/10.1037/0022-0663.94.3.598

Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017a). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education, 10*(6), 549-559. https://doi.org/10.1002/ase.1696

Moro, C., Štromberga, Z., & Stirling, A. (2017b). Virtualisation devices for student learning: Comparison between desktop-based (Oculus Rift) and mobile-based (Gear VR) virtual reality in medical and health science education. *Australasian Journal of Educational Technology*, *33*(6). https://doi.org/10.14742/ajet.3840

Muhanna, M. A. (2015). Virtual reality and the CAVE: Taxonomy, interaction challenges and research directions. *Journal of King Saud University-Computer and Information Sciences, 27*(3), 344-361. https://doi.org/10.1016/j.jksuci.2014.03.023

Munakata, Y. (2006). Information processing approaches to development. In D. Kuhn, R. S. Siegler, W. Damon, & R. M. Lerner (Eds.), *Handbook of child psychology: Cognition, perception, and language* (pP. 426-463). John Wiley & Sons Inc.

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology, 18*(1), 1-7. https://doi.org/10.1186/s12874-018-0611-x

Müns, A., Meixensberger, J., & Lindner, D. (2014). Evaluation of a novel phantom-based neurosurgical training system. *Surgical Neurology International, 5.* https://doi.org/10.4103/2152-7806.146346

Murray, J. H. (1997). *Hamlet on the holodeck: The future of narrative in cyberspace*. Free Press.

Nakatsu, R., & Tosam N. (2005). Active immersion: the goal of communications with interactive agents. *Proceedings of the Fourth International Conference on Knowledge-Based Intelligent Engineering Systems and Allied Technologies,* 85-89.

Naumann, A., Hurtienne, J., Israel, J. H., Mohs, C., Kindsmüller, M. C., Meyer, H. A., & Hußlein, S. (2007). Intuitive use of user interfaces: defining a vague concept. *Proceedings of the International Conference on Engineering Psychology and Cognitive Ergonomics*, 128-136. Springer. https://doi.org/10.1007/978-3-540-73331-7_14

Navarrete, C. D., McDonald, M. M., Mott, M. L., & Asher, B. (2012). Virtual morality: emotion and action in a simulated three-dimensional "trolley problem." *Emotion, 12*(2), 364. https://doi.org/10.1037/a0025561

Normand, J. M., Giannopoulos, E., Spanlang, B., & Slater, M. (2011). Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. *PloS One, 6*(1), e16128. https://doi.org/10.1371/journal.pone.0016128

Norrby, M., Grebner, C., Eriksson, J., & Bostrom, J. (2015). Molecular rift: virtual reality for drug designers. *Journal of Chemical Information and Modeling, 2015, 55*(11), 2475-2484. https://doi.org/10.1021/acs.jcim.5b00544

North, M. M., & North, S. M. (2016). A comparative study of sense of presence of traditional virtual reality and immersive environments. *Australasian Journal of Information Systems, 20*. https://doi.org/10.3127/ajis.v20i0.1168

North, M. M., North, S. M., & Coble, J. R. (1996). *Virtual reality therapy: An innovative paradigm*. Ipi Press.

Noton, D., & Stark, L. (1971). Eye movements and visual perception. *Scientific American, 224*(6), 34-43.

Nowak, K. L., & Biocca, F. (2003). The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence: Teleoperators & Virtual Environments, 12*(5), 481-494. https://www.doi.org/10.1162/105474603322761289

Nunez, D. (2004). How is presence in non-immersive, non-realistic virtual environments possible? *Proceedings of the 3rd International Conference on Computer Graphics, VR, Visualisation and Interaction in Africa*, 83-86. ACM. https://doi.org/10.1145/1029949.1029964

Olmos, E., Cavalcanti, J. F., Soler, J. L., Contero, M., & Alcañiz, M. (2018). Mobile virtual reality: A promising technology to change the way we learn and teach. *Mobile and Ubiquitous Learning,* 95-106. Springer. https://doi.org/10.1007/978-981-10-6144-8_6

Olmos, H., Gómez, S., Alcañiz, M., Contero, M., Andrés-Sebastiá, M. P., & Martín-Dorta, N. (2015). Combining virtual reality and relaxation techniques to improve attention levels in students from an initial vocational qualification program. In G. Conole G., T. Klobučar, C. Rensing, J. Konert, & E. Lavoué (Eds.), *Design for teaching and learning in a networked world. EC-TEL 2015* (pp. 613-616). Springer. https://doi.org/10.1007/978-3-319-24258-3_71

Oprean, D. (2014). *Understanding the immersive experience: Examining the influence of visual immersiveness and interactivity on spatial experiences and understanding* [Unpublished doctoral dissertation]. University of Missouri.

Organisation for Economic Co-operation and Development-OECD (2015). *Students, computers and learning: Making the connection*. OECD Publishing.

Pagé, C., Bernier, P. M., & Trempe, M. (2019). Using video simulations and virtual reality to improve decision-making skills in basketball. *Journal of Sports Sciences, 37*(21), 2403-2410. https://doi.org/10.1080/02640414.2019.1638193

Palanque, P. (Ed.) (2001). Interactive systems. Design, specification, and verification. *Proceedings of the 7th International Workshop, DSV-IS 2000*, *Revised Papers*. Springer Science & Business Media. https://doi.org/10.1007/3-540-44675-3

Pan, Z., Cheok, A.D., Yang, H., Zhu, J., Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics, 30*(1), 20-28. https://doi.org/10.1016/j.cag.2005.10.004

Pan, X., & Slater, M. (2011). Confronting a moral dilemma in virtual reality: a pilot study. *Proceedings of the 25th BCS Conference on Human-Computer Interaction*, 46-51. BCS. https://doi.org/10.14236/ewic/HCI2011.26

Pan, X., Slater, M., Beacco, A., Navarro, X., Bllido Rivas, A. I., Swapp, D., Hale, J., Fordes, P. A. G., Denvir, C., Hamilton A. F. de C., & Delacroix, S. (2016). The responses of medical general practitioners to unreasonable patient demand for antibiotics - a study of medical ethics using immersive virtual reality. *PloS One, 11*(2), e0146837. https://doi.org/10.1371/journal.pone.0146837

Pantelidis, V. S. (1993). Virtual reality in the classroom. Educational Technology, 33(4), 23-27.

Papachristos, N. M., Vrellis, I., & Mikropoulos, T. A. (2017). A comparison between oculus rift and a low-cost smartphone VR headset: immersive user experience and learning. *Proceedings of the IEEE 17th International Conference on Advanced Learning Technologies* (*ICALT 2017)*, 477-481. IEEE. https://doi.org/10.1109/ICALT.2017.145

Papadakis, G., Mania, K., & Koutroulis, E. (2011). A system to measure, control and minimize end-to-end head tracking latency in immersive simulations. *Proceedings of the 10th International Conference on VR Continuum and Its Applications in Industry,* 581-584. ACM. https://doi.org/10.1145/2087756.2087869

Papert, S. (1980). *Mindstorm-children, computers, and powerful ideas*. Basic Books.

Papert, S. (1991). Situating constructionism. In S. Papert & I. Harel (Eds.), *Constructionism*. Ablex.

Park, B., Knörzer, L., Plass, J. L., & Brünken, R. (2015). Emotional design and positive emotions in multimedia learning: An eyetracking study on the use of anthropomorphisms. *Computers & Education, 86*, 30-42. https://doi.org/10.1016/j.compedu.2015.02.016

Park, M. J., Kim, D. J., Lee, U., Na, E. J., & Jeon, H. J. (2019). A literature overview of virtual reality (VR) in treatment of psychiatric disorders: Recent advances and limitations. *Frontiers in Psychiatry, 10*. https://doi.org/10.3389/fpsyt.2019.00505

Parmar, D., Bertrand, J., Babu, S. V., Madathil, K., Zelaya, M., Wang, T., Wagner, J., Gramopadhye, A. K., & Frady, K. (2016). A comparative evaluation of viewing metaphors on psychophysical skills education in an interactive virtual environment. *VR*, *20*(3), 141-157. https://doi.org/10.1007/s10055-016-0287-7

Parsons, T. D., & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 39*(3), 250–261. https://doi.org/10.1016/j.jbtep.2007.07.007

Passig, D., Tzuriel, D., & Eshel-Kedmi, G. (2016). Improving children's cognitive modifiability by dynamic assessment in 3D immersive virtual reality environments. *Computers & Education, 95,* 296-308. https://doi.org/10.1016/j.compedu.2016.01.009

Pham, M. T., Rajić, A., Greig, J. D., Sargeant, J. M., Papadopoulos, A., & McEwen, S. A. (2014). A scoping review of scoping reviews: advancing the approach and enhancing the consistency. *Research Synthesis Methods, 5*(4), 371-385. https://doi.org/10.1002/jrsm.1123

Pearson, A. (2004). Balancing the evidence: incorporating the synthesis of qualitative data into systematic reviews. *JBI Reports, 2*, 45-64. https://doi.org/10.1111/j.1479-6988.2004.00008.x

Peck, T. C., Seinfeld, S., Aglioti, S. M., & Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and Cognition, 22*(3), 779-787. https://doi.org/10.1016/j.concog.2013.04.016

Penland, J. L., Laviers, K., Bassham, E., & Nnochiri, V. (2019). Virtual learning: a study of virtual reality for distance education. In *Handbook of research on blended learning pedagogies and professional development in higher education*, 156-176. IGI Global. https://doi.org/10.4018/978-1-5225-5557-5.ch009

Pennestri, E., Cavacece, M., & Vita, L. (2005). On the computation of degrees-of-freedom: a didactic perspective. *Proceedings of the 2005 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC'05)* (vol. 6), 1733-1741. https://doi.org/10.1115/DETC2005-84109

Petrakou, A. (2010). Interacting through avatars: Virtual worlds as a context for online education. *Computers & Education, 54*(4), 1020-1027. https://doi.org/10.1016/j.compedu.2009.10.007

Pimentel, K., & Teixeira, K. (1993). *VR: Through the new looking glass*. Intel Windcrest.

Pirker, J., Lesjak, I., & Guetl, C. (2017). Maroon VR: A room-scale physics laboratory experience. *Proceedings of the IEEE 17th International Conference on Advanced Learning Technologies (ICALT 2017)*, 482-484. IEEE. https://doi.org/10.1109/ICALT.2017.92

Pirker, J., Lesjak, I., Parger, M., & Gütl, C. (2018). An educational physics laboratory in mobile versus room scale virtual reality-A comparative study. In *Online engineering & Internet of things*, 1029-1043. Springer. https://doi.org/10.1007/978-3-319-64352-6_95

Pizarro, R., Hall, M., Bermell-Garcia, P., & González-Franco, M. (2015). Augmenting remote presence for interactive dashboard collaborations. *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, 235-240. ACM. https://doi.org/10.1145/2817721.2823486

Pollard, K. A., Oiknine, A. H., Files, B. T., Sinatra, A. M., Patton, D., Ericson, M., Thomas, J., & Khooshabeh, P. (2020). Level of immersion affects spatial learning in virtual environments: results of a three-condition within-subjects study with long intersession intervals. *VR*, 1-14. https://doi.org/10.1007/s10055-019-00411-y

Pomes, A., & Slater, M. (2013). Drift and ownership towards a distant virtual body. *Frontiers in Human Neuroscience, 7*, 908. https://doi.org/10.3389/fnhum.2013.00908

Porcino, T. M., Clua, E., Trevisan, D., Vasconcelos, C. N., & Valente, L. (2017). Minimizing cyber sickness in head mounted display systems: design guidelines and applications. *Proceedings of the 5th International Conference on Serious Games and Applications for Health* (SeGAH), (pp. 1-6). IEEE. https://doi.org/10.1109/SeGAH.2017.7939283

Prabhat, P., Forsberg, A., Katzourin, M., Wharton, K., & Slater, M. (2008). A comparative study of desktop, Fishtank, and CAVE systems for the exploration of volume rendered confocal data sets. *IEEE Transactions on Visualization and Computer Graphics, 14*(3), 551-563. https://doi.org/10.1109/TVCG.2007.70433

Prensky, M. (2001). *Digital game-based learning*. McGraw Hill

Psotka J. (1996). *Immersive tutoring systems, virtual reality and education and training*. U.S. Army Research Institute, ATTN, PERI-IIC

Pulijala, Y., Ma, M., Pears, M., Peebles, D., & Ayoub, A. (2018). An innovative virtual reality training tool for orthognathic surgery. *International Journal of Oral and Maxillofacial Surgery*, *47*(9), 1199-1205. https://doi.org/10.1016/j.ijom.2018.01.005

Pulijala, Y., Ma, M., Pears, M., Peebles, D., & Ayoub, A. (2018). Effectiveness of immersive virtual reality in surgical training-A randomized control trial. *Journal of Oral and Maxillofacial Surgery, 76*(5), 1065-1072. https://doi.org/10.1016/j.joms.2017.10.002

Qualcomm (n. d.). *Snapdragon XR1 platform.* https://www.qualcomm.com/products/snapdragon-xr1-platform

Queiroz, A. C. M., Nascimento, A. M., Tori, R., & da Silva Leme, M. I. (2018). Using HMD-based immersive virtual environments in primary/K-12 education. *Proceedings of the International Conference on Immersive Learning,* 160-173. Springer. https://doi.org/10.1007/978-3-319-93596-6_11

Quinn, F., & Lyons, T. (2013). Educating for sustainability in virtual worlds: Does the virtual have value? Strand 9 Environmental. *Health and Outdoor Science Education, 118*.

Rauter, G., Sigrist, R., Koch, C., Crivelli, F., van Raai, M., Riener, R., & Wolf, P. (2013). Transfer of complex skill learning from virtual to real rowing. *PloS One, 8*(12), e82145. https://doi.org/10.1371/journal.pone.0082145

Rebelo, F., Noriega, P., Duarte, E., & Soares, M. (2012). Using virtual reality to assess user experience. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*(6), 964-982. https://www.doi.org/10.1177/0018720812465006

Reford, L., & Leston, J. (2011). *WWF UK policy position statement on business travel*. Worldwide Wildlife Foundation. http://assets.wwf.org.uk/downloads/business_travel_ps_0709.pdf

Reger, G. M., Gahm, G. A., Rizzo, A. A., Swanson, R., & Duma, S. (2009). Soldier evaluation of the virtual reality Iraq. *Telemedicine and e-Health, 15*(1), 101-104. https://doi.org/10.1089/tmj.2008.0050

Ritter III, K. A., Borst, C. W., & Chambers, T. L. (2018). Virtual solar energy center case studies. *Computers in Education Journal, 9*(3), 1-7.

Rizzo, A., Hartholt, A., Grimani, M., Leeds, A., & Liewer, M. (2014). Virtual reality exposure therapy for combat-related posttraumatic stress disorder. *Computer, 47*(7), 31-37. https://doi.org/10.1109/MC.2014.199

Rizzo, A. A., Buckwalter, J. G., & Neumann, U. (1997). Virtual reality and cognitive rehabilitation: A brief review of the future. *The Journal of Head Trauma Rehabilitation*. https://doi.org/10.1097/00001199-199712000-00002

Rizzo, A. S., Difede, J., Rothbaum, B. O., Reger, G., Spitalnick, J., Cukor, J., & Mclay, R. (2010). Development and early evaluation of the virtual Iraq/Afghanistan exposure therapy system for combat-related PTSD. *Annals of the New York Academy of Sciences, 1208*(1), 114-125. https://doi.org/10.1111/j.1749-6632.2010.05755.x

Road to VR (2019). *Snapdragon XR2 chip to enable standalone headsets with 3K×3K resolution & 7 cameras*. https://www.roadtovr.com/qualcomm-snapdragon-xr2-5g-announcement/

Roblyer, M. D., & Doering, A. H. (2012). *Integrating educational technology into teaching*. Pearson.

Ropelato, S., Zünd, F., Magnenat, S., Menozzi, M., & Sumner, R. (2018). Adaptive tutoring on a virtual reality driving simulator. *International Series on Information systems and management in creative Emedia (CreMedia), 2017*(2), 12-17.

Rothman, D. B., & Warren, W. H. (2006). Wormholes in virtual reality and the geometry of cognitive maps. *Journal of Vision, 6*(6), 143-143. https://doi.org/10.1167/6.6.143

Roussou, M. (2009). A VR playground for learning abstract mathematics concepts. *IEEE Computer Graphics and Applications, 29*(1), 82-85. https://doi.org/10.1109/MCG.2009.1

Roussou, M., Oliver, M., & Slater, M. (2006). The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. *VR, 10*(3-4), 227-240. https://doi.org/10.1007/s10055-006-0035-5

Rovira, A., Swapp, D., Spanlang, B., & Slater, M. (2009). The use of virtual reality in the study of people's responses to violent incidents. *Frontiers in Behavioral Neuroscience, 3*, 59. https://doi.org/10.3389/neuro.08.059.2009

Rowe, A. D., Fitness, J. & Wood, L. N. (2015). University student and lecturer perceptions of positive emotions in learning. *International Journal of Qualitative Studies in Education, 28*(1), 1-20. https://doi.org/10.1080/09518398.2013.847506

Rua, H., & Alvito, P. (2011). Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage - the case-study of the Roman villa of Casal de Freiria. *Journal of Archaeological Science, 38*(12), 3296-3308. https://doi.org/10.1016/j.jas.2011.07.015

Rueda, C., Godínes, J. & Rudman, P. (2018). Categorizing the educational affordances of 3 dimensional immersive digital environments. *Journal of Information Technology Education: Innovations in Practice, 17*(1), 83-112. https://doi.org/10.28945/4056

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1999). Navigating large-scale virtual environments: what differences occur between helmet-mounted and desktop displays? *Presence: Teleoperators & Virtual Environments, 8*(2), 157-168. https://doi.org/10.1162/105474699566143

Ruddle, R. A., Volkova, E., & Bülthoff, H. H. (2011). Walking improves your cognitive map in environments that are large-scale and large in extent. *ACM Transactions on Computer-Human Interaction, 18*(2), 1-20. https://doi.org/10.1145/1970378.1970384

Ruddle, R. A., Volkova, E., & Bülthoff, H. H. (2013). Learning to walk in virtual reality. *ACM Transactions on Applied Perception, 10*(2), 1-17. https://doi.org/10.1145/2465780.2465785

Ruffaldi, E., Filippeschi, A., Avizzano, C. A., Bardy, B., Gopher, D., & Bergamasco, M. (2011). Feedback, affordances, and accelerators for training sports in virtual environments. *Presence: Teleoperators and Virtual Environments, 20*(1), 33-46. https://doi.org/10.1162/pres_a_00034

Ruiter, M., Loyens, S., & Paas, F. (2015). Watch your step children! Learning two-digit numbers through mirror-based observation of self-initiated body movements. *Educational Psychology Review, 27*, 457-474. https://doi.org/10.1007/s10648-015-9324-4

Rumrill, P., Fitzgerald, S., & Merchant, W. (2010). Using scoping literature reviews as a means of understanding and interpreting existing literature. *Work, 35,* 399-404. https://doi.org/10.3233/WOR-2010-0998

Rupp, M. A., Kozachuk, J., Michaelis, J. R., Odette, K. L., Smither, J. A., & McConnell, D. S. (2016). The effects of immersiveness and future VR expectations on subjective-experiences during an educational 360 video. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (vol. 60, no. 1), 2108-2112. SAGE Publications. https://doi.org/10.1177/1541931213601477

Rupp, M. A., Odette, K. L., Kozachuk, J., Michaelis, J. R., Smither, J. A., & McConnell, D. S. (2019). Investigating learning outcomes and subjective experiences in 360-degree videos. *Computers & Education, 128*, 256-268. https://doi.org/10.1016/j.compedu.2018.09.015

Ruppert, B. (2011). New directions in the use of virtual reality for food shopping: marketing and education perspectives. *Journal of Diabetes Science and Technology, 5,* 315-318. https://doi.org/10.1177/193229681100500217

Ryan, M. L. (2015). *Narrative as virtual reality 2: Revisiting immersion and interactivity in literature and electronic media*. John Hopkins University Press.

Saettler, P. (2004). *The evolution of American educational technology*. IAP.

Salamin, A. D. (2018). *Perception in VR 3D vs VR 360 video: How a key cognitive process in learning operates in virtual environments.* In J. Johnston (Ed.), *Proceedings of the EdMedia + Innovate Learning* (pp. 1565-1571). Association for the Advancement of Computing in Education (AACE).

Salomon, G. (Ed.) (1993). *Distributed cognitions-psychological and educational considerations*. Cambridge University Press.

Salzman, M. C., Dede, C., Loftin, R. B., & Chen, J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators & Virtual Environments, 8*(3), 293-316. https://doi.org/10.1162/105474699566242

Sanchez-Vives, M. V., Spanlang, B., Frisoli, A., Bergamasco, M., & Slater, M. (2010). Virtual hand illusion induced by visuomotor correlations. *PloS One, 5*(4), e10381. https://doi.org/10.1371/journal.pone.0010381

Scapin, S., Echevarría-Guanilo, M. E., Boeira Fuculo Junior, P. R., Gonçalves, N., Rocha, P. K., & Coimbra, R. (2018). VR in the treatment of burn patients: A systematic review. *Burns, 44*(6), 1403-1416. https://doi.org/10.1016/j.burns.2017.11.002

Schafer, S. B. (Ed.) (2016). *Exploring the collective unconscious in the Age of Digital Media*. IGI Global. https://doi.org/10.4018/978-1-4666-9891-8

Schnapp, B., & Warren, W. (2007). Wormholes in virtual reality: what spatial knowledge is learned for navigation? *Journal of Vision, 7*(9), 758-758. https://doi.org/10.1167/7.9.758

Schneps, M. H., Ruel, J., Sonnert, G., Dussault, M., Griffin, M., & Sadler, P. M. (2014). Conceptualizing astronomical scale: Virtual simulations on handheld tablet computers reverse misconceptions. *Computers & Education, 70,* 269-280. https://doi.org/10.1016/j.compedu.2013.09.001

Schönbrunner, O. (2000). *Human-computer interface in the CAVE*. https://old.cescg.org/CESCG-2000/OSchoenbrunner/hci.html

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments, 10*(3), 266-281. https://doi.org/10.1162/105474601300343603

Schultze, U. (2010). Embodiment and presence in virtual worlds: A review. *Journal of Information Technology, 25*(4), 434-449. https://doi.org/10.1057/jit.2010.25

Seasia Infotech, (n. d.) *Building digital experiences*. https://www.seasiainfotech.com/blog/building-digital-experiences/

Seidel, R. J. & Rubin, M. (1977). *Computers and communications: Implications for education*. Academic Press.

Seixas-Mikelus, S. A., Adal, A., Kesavadas, T., Baheti, A., Srimathveeravalli, G., Hussain, A., Chandrasekhar, R., Wilding, G. E., & Guru, K. A. (2010). Can image-based virtual reality help teach anatomy? *Journal of Endourology, 24*(4), 629-634. https://doi.org/10.1089/end.2009.0556

Sekhar, C. C., Ch, S. S., & Rao, G. N. (2018). Future reality is immersive reality. *International Journal of Recent Technology and Engineering, 7*(4), 302-309.

Selverian, M. M., & Hwang, H. S. (2003). In search of presence: A systematic evaluation of evolving VLEs. *Presence: Teleoperators & Virtual Environments, 12*(5), 512-522. https://doi.org/10.1162/105474603322761306

Seth, A., Vance, J. M., & Oliver, J. H. (2011). Virtual reality for assembly methods prototyping: a review. *VR, 15*(1), 5-20. https://doi.org/10.1007/s10055-009-0153-y

Seymour, N. E., Gallagher, A. G., Roman, S. A., O'Brien, M. K., Bansal, V. K., Andersen, D. K., Satava, R. M. (2002). Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Annals of Surgery, 236*(4), 458-463. https://doi.org/10.1097/00000658-200210000-00008

Shackelford, L., Huang, W. D., Craig, A., Merrill, C., Chen, D., & Arjona, J. (2018). A formative evaluation on a virtual reality game-based learning system for teaching introductory archaeology. *Proceedings of the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, 605-611. Association for the Advancement of Computing in Education (AACE).

Sharma, L., Jin, R., Prabhakaran, B., & Gans, M. (2018). LearnDNA: an interactive VR application for learning DNA structure. *Proceedings of the 3rd International Workshop on Interactive and Spatial Computing*, 80-87. ACM. https://doi.org/10.1145/3191801.3191810

Sharma, S., Devreaux, P., Scribner, D., Grynovicki, J., & Grazaitis, P. (2017). Megacity: a collaborative virtual reality environment for emergency response, training, and decision making. Electron. *Imaging 2017*, 70-77. https://www.doi.org/10.2352/ISSN.2470-1173.2017.1.VDA-390

Shaw, L. A., Wünsche, B. C., Lutteroth, C., Marks, S., & Callies, R. (2015). Challenges in virtual reality exergame design. *Proceedings of the 16th Australasian User Interface Conference (AUIC 2015),* 61-68. Australian Computer Society Inc.

Shaw, L. A., Wünsche, B., Lutteroth, C., Marks, S., Buckley, J., & Corballis, P. (2015). Development and evaluation of an exercycle game using immersive technologies. *Proceedings of the 8th Australasian Workshop on Health Informatics and Knowledge Management*, vol. 164.

Sheikh, A., Brown, A., Watson, Z., & Evans, M. (2016). Directing attention in 360-degree video. *Proceedings of the IBC 2016 Conference*. IBC. https://www.doi.org/10.1049/ibc.2016.0029

Sheridan, T. B. (1992). Musings on telepresence and virtual presence. *Presence: Teleoperators & Virtual Environments, 1*(1), 120-126. https://doi.org/10.1162/pres.1992.1.1.120

Sheridan, T. B. (1996). Further musings on the psychophysics of presence. *Presence: Teleoperators & Virtual Environments, 5*(2), 241-246. https://doi.org/10.1162/pres.1996.5.2.241

Sheridan, T. B. (2016). Recollections on presence beginnings, and some challenges for augmented and virtual reality. *Presence: Teleoperators and Virtual Environments, 25*(1), 75-77. https://doi.org/10.1162/PRES_e_00247

Sherman, B., & Judkins, P. (1992). Glimpses of heaven, visions of hell: Virtual reality and its implications. *Hodder & Stoughton*, 42-43.

Sherman, W. R., & Craig, A.B., (2003). *Understanding VR: Interface, application, and design*. Morgan Kaufmann Publishers. https://doi.org/10.1162/105474603322391668

Shibata, T. (2002). Head mounted display. *Displays, 23*(1-2), 57-64. https://doi.org/10.1016/S0141-9382(02)00010-0

Shu, Y., Huang, Y. Z., Chang, S. H., & Chen, M. Y. (2018). Do virtual reality head-mounted displays make a difference? A comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments. *VR*, *23*, 437-446. https://doi.org/10.1007/s10055-018-0376-x

Shute, V., Ke, F., & Wang, L. (2017). Assessment and adaptation in games. In *Instructional techniques to facilitate learning and motivation of serious games*, 59-78. Springer. https://doi.org/10.1007/978-3-319-39298-1_4

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2*(1), 3-10.

Singh, S., Sedlack, R. E., & Cook, D. A. (2014). Effects of simulation-based training in gastrointestinal endoscopy: a systematic review and meta-analysis. *Clinical Gastroenterology and Hepatology, 12*(10), 1611-1623. https://doi.org/10.1016/j.cgh.2014.01.037

Skulmowski, A., Pradel, S., Kühnert, T., Brunnett, G., & Rey, G. D. (2016). Embodied learning using a tangible user interface: The effects of haptic perception and selective pointing on a spatial learning task. *Computers & Education, 92*, 64-75. https://doi.org/10.1016/j.compedu.2015.10.011

Skulmowski, A., & Rey, G. D. (2018). Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cognitive Research: Principles and Implications, 3*, 6. https://doi.org/10.1186/s41235-018-0092-9

Slater, M. (1999). Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence, 8*(5), 560-565. https://doi.org/10.1162/105474699566477

Slater, M. (2002). Presence and the sixth sense. *Presence: Teleoperators and Virtual Environments, 11*(4), 435-439. https://doi.org/10.1162/105474602760204327

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1535), 3549-3557. https://doi.org/10.1098/rstb.2009.0138

Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C., Pistrang, N., & Sanchez-Vives, M. V. (2006). A virtual reprise of the Stanley Milgram obedience experiments. *PloS One, 1*(1), e39. https://doi.org/10.1371/journal.pone.0000039

Slater, M., Frisoli, A., Tecchia, F., Guger, C., Lotto, B., Steed, A., Pfurtscheller, G., Leeb, R., Reiner, M., Sanchez-Vives, M. V., Verschure, P., & Bernardet, U. (2007). Understanding and realizing presence in the Presenccia project. *IEEE Computer Graphics and Applications, 27*(4), 90-93. https://doi.org/10.1109/MCG.2007.93

Slater, M., Perez-Marcos, D., Ehrsson, H. H., & Sanchez-Vives, M. (2008). Towards a digital body: the virtual arm illusion. *Frontiers in Human Neuroscience, 2*, 6. https://doi.org/10.3389/neuro.09.006.2008

Slater, M., Perez-Marcos, D., Ehrsson, H. H., & Sanchez-Vives, M. V. (2009). Inducing illusory ownership of a virtual body. *Frontiers in Neuroscience, 3*, 29. https://doi.org/10.3389/neuro.01.029.2009

Slater, M., Rovira, A., Southern, R., Swapp, D., Zhang, J. J., Campbell, C., Levine, M. (2013). Bystander responses to a violent incident in an immersive virtual environment. *PloS One, 8*(1), e52766. https://doi.org/10.1371/journal.pone.0052766

Slater, M., Sadagic, A., Usoh, M., & Schroeder, R. (2000). Small-group behavior in a virtual and real environment: a comparative study. *Presence: Teleoperators & Virtual Environments, 9*(1), 37-51. https://doi.org/10.1162/105474600566600

Slater, M., & Sanchez-Vives, M. V. (2014). Transcending the self in immersive virtual reality. *Computer, 47*(7), 24-30. https://doi.org/10.1109/MC.2014.198

Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PloS One, 5*(5), e10564. https://doi.org/10.1371/journal.pone.0010564

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments, 6*(6), 603-616. https://doi.org/10.1162/pres.1997.6.6.603

Slavin, R. E. (1980). Cooperative learning. *Review Of Educational Research, 50*(2), 315-342. https://doi.org/10.3102/00346543050002315

Smutny, P., Babiuch, M., & Foltynek, P. (2019). A review of the virtual reality applications in education and training. *Proceedings of the 2019 20th International Carpathian Control Conference, ICCC 2019*. https://doi.org/10.1109/CarpathianCC.2019.8765930

Snelson, C., & Hsu, Y. C. (2019). Educational 360-degree videos in virtual reality: A scoping review of the emerging research. *TechTrends*, 1-9. https://doi.org/10.1007/s11528-019-00474-3

So, S., & Lu, E. (2019). Virtual reality in visual arts education: A study on using Google Tilt Brush. In J. Johnston (Ed.), *Proceedings of EdMedia + Innovate Learning* (pp. 1467-1472). Association for the Advancement of Computing in Education (AACE).

Solina, F., Batagelj, B., & Glamočanin, S. (2008). Virtual skiing as an art installation. *Proceedings of the 50th International Symposium,* vol. 2, 507-510. IEEE.

Song, H. S., Pusic, M., Nick, M. W., Sarpel, U., Plass, J. L., & Kalet, A. L. (2014). The cognitive impact of interactive design features for learning complex materials in medical education. *Computers & Education, 71*, 198-205. https://doi.org/10.1016/j.compedu.2013.09.017

Song, S. H., & Song, E. J. (2019). A study on virtual training system for army thermal equipment maintenance education. *Proceedings of the Korean Institute of Information and Communication Sciences Conference*, 205-207. The Korea Institute of Information and Communication Engineering.

Spiro, R. J., Feltovich, P. J., Feltovich, P. L., Jacobson, M. J., & Coulson, R. L. (1991). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational technology, 31*(5), 24-33.

Sportillo, D., Paljic, A., & Ojeda, L. (2018). Get ready for automated driving using VR. *Accident Analysis & Prevention*, *118*, 102-113. https://doi.org/10.1016/j.aap.2018.06.003

Staurset, E. M., & Prasolova-Førland, E. (2016). Creating a smart VR simulator for sports training and education. *Proceedings of the Smart Education and e-Learning 2016*, 423-433. Springer. https://doi.org/10.1007/978-3-319-39690-3_38

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology, 7*(10), 1006-1013. https://doi.org/10.1002/alr.21986

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication, 42*(4), 73-93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x

Stevens, J., Kincaid, P., & Sottilare, R. (2015). Visual modality research in virtual and mixed reality simulation. *The Journal of Defense Modeling and Simulation, 12*(4), 519-537. https://doi.org/10.1177/1548512915569742

Spanlang, B., Navarro, X., Normand, J.-M., Kishore, S., Pizarro, R., & Slater, M. (2013). Real time whole body motion mapping for avatars and robots. *Proceedings of the 19th ACM Symposium on VR Software and Technology-VRST'13*, 175-178. ACM. https://doi.org/10.1145/2503713.2503747

Spanlang, B., Normand, J.-M., Borland, D., Kilteni, K., Giannopoulos, E., Pomes, A., González-Franco, M., Perez-Marcos, D., Arroyo-Palacios, J., Muncunill, X. N., & Slater, M. (2014). How to build an embodiment lab: achieving body representation illusions in virtual reality. *Frontiers in Robotics and AI, 1*, 9. https://doi.org/10.3389/frobt.2014.00009

Stackpath (2019). *What is latency?* https://blog.stackpath.com/latency/

Stark, L. W. (1995). How virtual reality works! The illusions of vision in real and virtual environments. In *Human vision, visual processing, and digital display VI*, 277-287. https://doi.org/10.1117/12.207546

Steed, A., & Oliveira, M. F. (2009). *Networked graphics: Building networked games and virtual environments*. Elsevier.

Steed, A., Spante, M., Heldal, I., Axelsson, A.-S., & Schroeder, R. (2003). Strangers and friends in caves: an exploratory study of collaboration in networked IPT systems for extended periods of time. *Proceedings of the 2003 Symposium on Interactive 3D Graphics*, 51-54. ACM. https://doi.org/10.1145/641480.641492

Steptoe, W., Steed, A., Rovira, A., & Rae, J. (2010). Lie tracking: social presence, truth and deception in avatar-mediated telecommunication. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1039-1048. ACM. https://doi.org/10.1145/1753326.1753481

Steptoe, W., Steed, A., & Slater, M. (2013). Human tails: ownership and control of extended humanoid avatars. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 583-590. https://doi.org/10.1109/TVCG.2013.32

Steptoe, W., Wolff, R., Murgia, A., Guimaraes, E., Rae, J., Sharkey, P., Roberts, D., & Steed, A. (2008). Eye-tracking for avatar eye-gaze and interactional analysis in immersive collaborative virtual environments. *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work*, 197-200. ACM. https://doi.org/10.1145/1460563.1460593

Stoffregen, T. A., Hettinger, L. J., Haas, M. W., Roe, M. M., & Smart, L. J. (2000). Postural instability and motion sickness in a fixed-base flight simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*(3), 458-469. https://doi.org/10.1518/001872000779698097

Stranger-Johannessen, E. (2018). Exploring math achievement through gamified virtual reality. *Proceedings of the European Conference on Technology Enhanced Learning*, 613-616. Springer. https://doi.org/10.1007/978-3-319-98572-5_57

Strasburger, H., & Pöppel, E. (2002). Visual field. *Encyclopedia of Neuroscience*, 2127-2129.

Strasburger, H., Rentschler, I., & Jüttner, M. (2011). Peripheral vision and pattern recognition: A review. *Journal of Vision, 11*(5), 13-13. https://doi.org/10.1167/11.5.13

Sun, Q., Mirhosseini, S., Gutenko, I., Park, J. H., Papadopoulos, C., Laha, B., & Kaufman, A. (2015). Buyers satisfaction in a virtual fitting room scenario based on realism of avatar. *Proceedings of the 3D User Interfaces (3DUI), 2015 IEEE Symposium*, 183-184. IEEE. https://doi.org/10.1109/3DUI.2015.7131761

Sun, F. R., Pan, L. F., Wan, R. G., Li, H., & Wu, S. J. (2018). Detecting the effect of student engagement in an SVVR school-based course on higher level competence development in elementary schools by SEM. *Interactive Learning Environments*, 1-14. https://doi.org/10.1007/s10984-017-9243-z

Sundar, S. S., Oh, J., Kang, H., & Sreenivasan, A. (2013). How does technology persuade? Theoretical mechanisms for persuasive technologies. In J. P. Dillard & L. Shen (Eds.), *The SAGE handbook of persuasion: Developments in theory and practice* (pp. 388-404). SAGE. https://doi.org/10.4135/9781452218410.n23

Sundstedt, V., Chalmers, A., & Martinez, P. (2004). High fidelity reconstruction of the ancient Egyptian temple of Kalabsha. *Proceedings of the 3rd International Conference on Computer Graphics, VR, Visualisation and Interaction in Africa*, 107-113. ACM. https://doi.org/10.1145/1029949.1029970

SuperData (2020). *SuperData XR Q4 2019 Update*. https://www.superdataresearch.com/blog/superdata-xr-update

Sutherland, I. E. (1968). A head-mounted three dimensional display. *Proceedings of the Fall Joint Computer Conference*, *Part I, 33*, 757-764. ACM. https://doi.org/10.1145/1476589.1476686

Taiwo, R. (Ed.). (2010). *Handbook of research on discourse behavior and digital communication: Language structures and social interaction*. IGI Global. https://doi.org/10.4018/978-1-61520-773-2

Takala, T., (2017). *CS-E4170 - Mobile Systems Programming*. University of South Australia.https://mycourses.aalto.fi/pluginfile.php/548984/mod_resource/content/3/Aalto-Lecture4-Tracking.pptx.pdf

Tam, M. (2000). Constructivism, instructional design, and technology: Implications for transforming distance learning. *Journal of Educational Technology & Society, 3*(2), 50-60.

Tamaddon, K., & Stiefs, D. (2017). Embodied experiment of levitation in microgravity in a simulated virtual reality environment for science learning. *Proceedings of the EEE VR Workshop on K-12*

*Embodied Learning through Virtual & Augmented Reality* (KELVAR), 1-5. IEEE. https://doi.org/10.1109/KELVAR.2017.7961560

Tan, C. T., Leong, T. W., Shen, S., Dubravs, C., & Si, C. (2015). Exploring gameplay experiences on the oculus rift. *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play,* 253-263. ACM. https://doi.org/10.1145/2793107.2793117

Taylor, G. S., & Barnett, J. S. (2013). Evaluation of wearable simulation interface for military training. *Human Factors, 55*(3), 672-690. https://doi.org/10.1177/0018720812466892

Tecchia, F., Carrozzino, M., Bacinelli, S., Rossi, F., Vercelli, D., Marino, G., Gasparello, P., & Bergamasco, M. (2010). A flexible framework for wide-spectrum VR development. *Presence: Teleoperators and Virtual Environments, 19*(4), 302-312. https://doi.org/10.1162/PRES_a_00002

Teranishi, S., & Yamagishi, Y. (2018). Educational effects of a virtual reality simulation system for constructing self-built PCs. *Journal of Educational Multimedia and Hypermedia, 27*(3), 411-423.

The Glossary of Education Reform (2013). *Learning experience*. https://www.edglossary.org/learning-experience/?fbclid=IwAR1h8r4Lwp5_RD0v2ZOtKqyUOEgECyxETK2shvMValEiWJcsMEJuc5HWVR4

Thisgaard, M., & Makransky, G. (2017). Virtual learning simulations in high school: Effects on cognitive and non-cognitive outcomes and implications on the development of STEM academic and career choice. *Frontiers in Psychology, 8*(805), 1-13. https://doi.org/10.3389/fpsyg.2017.00805

Thomson, J. J. (1976). Killing, letting die, and the trolley problem. *The Monist, 59*(2), 204-217. https://doi.org/10.5840/monist197659224

Thompson, J. I. (2005). *A three dimensional helmet mounted primary flight reference for paratroopers*. Thesis for Air Force Institute of Technology.

Thompson-Butel, A. G., Shiner, C. T., McGhee, J., Bailey, B. J., Bou-Haidar, P., McCorriston, M., & Faux, S. G. (2019). The role of personalized virtual reality in education for patients post stroke-A qualitative case series. *Journal of Stroke and Cerebrovascular Diseases*, *28*(2), 450-457. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.10.018

Tiainen, T., Ellman, A., & Kaapu, T. (2014). Virtual prototypes reveal more development ideas: comparison between customers' evaluation of virtual and physical prototypes. *Virtual and Physical Prototyping, 9*(3), 169-180. https://doi.org/10.1080/17452759.2014.934573

Tokel, S. T., & İsler, V. (2015). Acceptance of virtual worlds as learning space. *Innovations in Education and Teaching International, 52*(3), 254-264. https://doi.org/10.1080/14703297.2013.820139

Tamaddon, K., & Stiefs, D. (2017). Embodied experiment of levitation in microgravity in a simulated virtual reality environment for science learning. *Proceedings of the EEE VR Workshop on K-12 Embodied Learning through Virtual & Augmented Reality* (KELVAR), 1-5. IEEE. https://doi.org/10.1109/KELVAR.2017.7961560

Tolhurst, D. (1992). A checklist for evaluating content-based hypertext computer software. *Educational Technology, 32*(3), 17-21.

Tom's Hardware (2018). *VR lens basics: Present and future*. https://www.tomshardware.com/news/virtual-reality-lens-basics-vr,36182.html

Topu, F. B., & Goktas, Y. (2019). The effects of guided-unguided learning in 3d virtual environment on students' engagement and achievement. *Computers in Human Behavior, 92*, 1-10. https://doi.org/10.1016/j.chb.2018.10.022

Tran, C., Smith, B., & Buschkuehl, M. (2017). Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cognitive Research: Principles and Implications, 2*, 16. https://doi.org/10.1186/s41235-017-0053-8

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., Levac, D., Ng, C., Sharpe, J. P., Wilson, K., Kenny, M., Warren, R., Wilson, C., Stelfox, H. T., & Straus, S. E. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology, 16*(1), 15. https://doi.org/10.1186/s12874-016-0116-4

Trindade, J., Fiolhais, C., & Almeida, L. (2002). Science learning in virtual environments: a descriptive study. *British Journal of Educational Technology, 33*(4), 471-488. https://doi.org/10.1111/1467-8535.00283

Tromp, J., Bullock, A., Steed, A., Sadagic, A., Slater, M., & Frecon, E. (1998). Small group behavior experiments in the Coven project. *IEEE Computer Graphics and Applications, 18*(6), 53-63. https://doi.org/10.1109/38.734980

Upload VR (2017). *What's next for VR audio*. https://uploadvr.com/world-vr-audio-perspective/

Van Broekhuizen, L. (2016). *The paradox of classroom technology: Despite proliferation and access, students not using technology for learning*. *AdvancED research*. AdvancED.

Van der Hoort, B., Guterstam, A., & Ehrsson, H. H. (2011). Being Barbie: the size of one's own body determines the perceived size of the world. *PLoS One*, *6*(5), e20195. https://doi.org/10.1371/journal.pone.0020195

Vacharkulksemsuk, T. & Fredrickson, B. L. (2013). Looking back and glimpsing forward: The Broaden-and-Build Theory of Positive Emotions as applied to organizations. *Advances in Positive Organizational Psychology, 1*, 45-60.

Vaughan, N., Dubey, V. N., Wainwright, T. W., & Middleton, R. G. (2016). A review of virtual reality based training simulators for orthopaedic surgery. *Medical Engineering & Physics, 38*(2), 59-71. https://doi.org/10.1016/j.medengphy.2015.11.021

Vignais, N., Bideau, B., Craig, C., Brault, S., Multon, F., & Kulpa, R. (2009). Virtual environments for sport analysis: perception-action coupling in handball goalkeeping. *International Journal of VR, 8*(4), 43-48. https://doi.org/10.20870/IJVR.2009.8.4.2748

VR Society (n. d.). History of VR. https://www.vrs.org.uk/virtual-reality/history.html

VR Times (2020). *Top 5 haptic VR devices Set to launch in 2020*. https://virtualrealitytimes.com/2020/02/23/top-5-haptic-vr-devices-set-to-launch-in-2020/

Vrscout (2019). *Hands-on: Oculus Quest hand tracking feels great, but it's not perfect.* https://vrscout.com/news/hands-on-oculus-quest-hand-tracking/

Wang, Z., Giannopoulos, E., Slater, M., Peer, A., & Buss, M. (2011). Handshake: realistic human-robot interaction in haptic enhanced virtual reality. *Presence: Teleoperators and Virtual Environments, 20*(4), 371-392. https://doi.org/10.1162/PRES_a_00061

Warburton, E. C., Wilson, M., Lynch, M., & Cuykendall, S. (2013). The cognitive benefits of movement reduction: Evidence from dance marking. *Psychological Science, 24*, 1732-1739. https://doi.org/10.1177/0956797613478824

Webel, S., Olbrich, M., Franke, T., & Keil, J. (2013). Immersive experience of current and ancient reconstructed cultural attractions. *Proceedings of the Digital Heritage International Congress (DigitalHeritage), 2013*, 395-398. IEEE. https://doi.org/10.1109/DigitalHeritage.2013.6743766

Webster, R. (2016). Declarative knowledge acquisition in immersive virtual learning environments. *Interactive Learning Environments, 24*(6), 1319-1333. https://doi.org/10.1080/10494820.2014.994533

Webster, R., & Dues Jr, J. F. (2017). System Usability Scale (SUS): Oculus Rift® DK2 and Samsung Gear VR®. *Proceedings of the 2017 ASEE Annual Conference & Exposition*, 1-12. ASSE.

Weissberg, R. P., Durlak, J. A., Domitrovich, C. E., & Gullotta, T. P. (2015). Social and emotional learning: Past, present, and future. In J. A. Durlak, C. E. Domitrovich, R. P. Weissberg, & T. P. Gullotta (Eds.), *Handbook of social and emotional learning: Research and practice* (pp. 3-19). The Guilford Press.

Wellner, M., Sigrist, R., Von Zitzewitz, J., Wolf, P., & Riener, R. (2010). Does a virtual audience influence rowing. *Journal of Sports Engineering and Technology, 224*(1), 117-128. https://doi.org/10.1243/17543371JSET33

Wheatstone, C. (1838). Contributions to the physiology of vision-Part the first. On some remarkable, and hitherto unobserved phenomena of binocular vision. In surname missing, initials missing (Eds.) 1838, *no title given*.

Wheeler, A. (2016). *Understanding virtual reality headsets*. Engineering.com.

Wilcox, L. M., Allison, R. S., Elfassy, S., & Grelik, C. (2006). Personal space in virtual reality. *ACM Transactions on Applied Perception (TAP), 3*(4), 412-428. https://doi.org/10.1145/1190036.1190041

Wilson, R. A., & Foglia, L. (2011). Embodied cognition. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy*. Stanford University.

Winn, W. (1993). *A conceptual basis for educational applications of virtual reality*. *Technical Publication R-93-9*. Human Interface Technology Laboratory of the Washington Technology Center, University of Washington.

Wirth, W., Hartmann, T., Böcking, S., Vorderer, P., Klimmt, C., Schramm, H., Saari, T., Laarni, J., Ravaja, N., Gouveia, F. R., Biocca, F., Sacau, A., Jänck, L., Baumgartner, T., & Jäncke, P. (2007). A process model of the formation of spatial presence experiences. *Media Psychology, 9*(3), 493-525. https://doi.org/10.1080/15213260701283079

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7*(3), 225-240. https://doi.org/10.1162/105474698565686

World Travel and Tourism Council. (2015). *Travel and tourism - Economic impact 2015 - World*. https://wttc.org/Research/Economic-Impact

Worrall, M., & Hutchinson, D. (2014). Exploring a model for training simulations. *Proceeding of the Asian-Pacific Simulation Training Conference and Exhibition (SimTecT 2014),* 173-176.

Wright, P., McCarthy, J., & Meekison, L. (2004). Making sense of experience. In M. Blythe, C. Overbeeke, A. F. Monk, & P. C. Wright (Eds.), *Funology: From usability to enjoyment* (pp. 43-53). Kluwer. https://doi.org/10.1007/1-4020-2967-5_5

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. *British Journal of Educational Technology, 51*(6), 1991-2005. https://doi.org/10.1111/bjet.13023

Xu, D., & Jaggars, S. (2011). *Online and hybrid course enrollment and performance in Washington State community and technical colleges*. https://pdfs.semanticscholar.org/69e9/36fbd521711c812dfe2b63723bb71268813d.pdf

Yassien, A., El Agroudy, P., Makled, E., & Abdennadher, S. (2020). A Design space for social presence in VR. *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society* , 1-12. https://doi.org/10.1145/3419249.3420112

Yee, N., & Bailenson, J. N. (2007). The Proteus effect: the effect of transformed self-representation on behavior. *Human Communication Research, 33*(3), 271-290. https://doi.org/10.1111/j.1468-2958.2007.00299.x

Yousef, A., M., F., Chatti, M., A., Schroeder, U., Wosnitza, M. & Jakobs, H. (2014). MOOCs: A review of the state-of-the-art. *Proceedings of the CSEDU 2014, 6th International Conference on Computer Supported Education*, 9-20.

Yun, H., Park, S., & Ryu, J. (2019). Exploring the influences of immersive virtual reality pre-service teacher training simulations on teacher efficacy. *Proceedings of the Society for Information Technology & Teacher Education International Conference*, 1858-1862. Association for the Advancement of Computing in Education (AACE).

Zaho, Z. X. (2002). Virtual reality technology: an overview. *Journal of Southeast University, 32*(2), 1-10.

Zendejas, B., Brydges, R., Hamstra, S. J., & Cook, D. A. (2013). State of the evidence on simulation-based training for laparoscopic surgery: a systematic review. *Annals of Surgery, 257*(4), 586-593. https://doi.org/10.1097/SLA.0b013e318288c40b

Zhang, K., Suo, J., Chen, J., Liu, X., & Gao, L. (2017). Design and implementation of fire safety education system on campus based on virtual reality technology. *Proceedings of the 2017 Federated Conference on Computer Science and Information Systems (FedCSIS)*, 1297-1300. IEEE. https://doi.org/10.15439/2017F376

Zhao, S. (2003). Toward a taxonomy of copresence. *Presence: Teleoperators and Virtual Environments, 12*(5), 445-455. https://doi.org/10.1162/105474603322761261

Zhou, N. N., & Deng, Y. L. (2009). Virtual reality: A state-of-the-art survey. *International Journal of Automation and Computing, 6*(4), 319-325. https://doi.org/10.1007/s11633-009-0319-9

Zhou, Y., Ji, S., Xu, T., & Wang, Z. (2018). Promoting knowledge construction: A model for using virtual reality interaction to enhance learning. *Procedia Computer Science, 130,* 239-246. https://doi.org/10.1016/j.procs.2018.04.035

Zikky, M., Fathoni, K., & Firdaus, M. (2018). Interactive distance media learning collaborative based on virtual reality with solar system subject. *Proceedings of the 2018 19th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD),* 4-9. IEEE. https://doi.org/10.1109/SNPD.2018.8441031