Virtual and Augmented Reality

An Educational Handbook

Zeynep Tacgin

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By

Zeynep Tacgin

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Preface

What is this book about?

The purpose of this book is to explain the related concepts of mixed reality and clarify what it is and how it works. Mixed reality has in fact been part of our lives since first we started to imagine and enhance information to achieve understandable concepts and creatively expand upon our more basic thoughts. Terms and classifications have fast been established for the description of the processes of the construction of imagined worlds in conventional systems using developing technologies. We now integrate high-tech products into our lives to expand perception, thereby becoming able to see details beyond physical reality to reach a more vivid vision. The real and the virtual can be joined intimately in each field of today's world.

The widespread usage of mixed reality creates new professions and opportunities but also results in misconceptions because of the sophomoric presentation of human beings in it. In my opinion, the Reality–Virtuality Continuum of Milgram provides the best categorisation of mixed reality. This model indicates there are various shades of virtuality in the physical world that exist between the virtual and real.

Virtuality should be immersive to completely abstract users' perceptions from the perceived physical world. Although today's technologies are not sufficient to encompass perceptions entirely via virtual content to gain any desired degree of immersion, the technology is quickly approaching this level. Technological, physical, and financial challenges have not barred us from creating our artificial worlds using various digital components. Many organisations and researchers have already structured several virtual worlds. The observation of virtuality without presence is called non-immersive virtual reality. This phenomenon can be explained by the need of certain types of virtual environment to be completely structured; however, this is not the virtual reality that we mean today. The question is; which technological equipment, systems, or environments have the potential to reach a completely immersive virtual reality? This book explains the main terms and core requirements, and references suitable examples.

This book also explains the integration of virtual content into the physical world under the sub-concept of mixed reality that is augmented reality. Easy-to-understand content creation, accessibility, and the popularity of augmented reality provide large-scale samples for both users and developers. This chapter explores the capacity to develop augmented reality with emerging technologies.

I believe that these terms should be understood before using or developing virtual or augmented reality applications. Then, the reader should study the best variety of samples to ignite their imagination and structure useful applications. This book offers many examples from the fields of education, architecture, engineering, medicine, entertainment, and more. The later chapters focus on educational mixed reality applications and usage, and the potential for enhancing personal or professional learning needs.

What is this book not about?

This book is not for learning how to develop augmented or virtual reality applications with regards to graphic design and coding. I have aimed to guide readers to an understanding of related terms and techniques by which to select the proper methods and technologies during preliminary analysis with which to structure a mixed reality environment in its design phase. I hope this knowledge can be helpful throughout all stages of decision-making to suit your specific requirements.

Detailed descriptions and specialist usage of technologies and instruments are not explained in this book because the professional application of each tool would be a book unto itself. The material development for mixed reality environments is highly multidisciplinary and practice-based. Readers of this book will be able to select compatible hardware and software components to apply to their disciplines and enhance their skills. There is a wealth of online tutorials already available for each particular element by which to achieve desired outcomes.

Who is this book for?

This book is a handbook for those who wish to learn both virtual and augmented reality terms, technologies, tools, and examples. This textbook guides graduate and undergraduate students in every field, for example, computer science, education, training, medicine, or science, as mixed reality has become increasingly prevalent across all disciplines.

This book focuses on educational mixed reality applications for various disciplines. After reading this book, teachers can design and develop their particular low-cost educational materials without coding.

The conceptual structure of this book gathers fundamental terms and usages of mixed reality technologies so that researchers can find compiled knowledge from a holistic perspective.

Entrepreneurs can be inspired to plan their projects using a broad set of examples as a guide and can choose well-suited components for their projects.

This book is also useful for hobbyists because it explains mixed reality concepts from beginner to intermediate levels using simple language.

How is this book used?

This handbook adopts a sequential structure in explaining the terminology of mixed reality. Each chapter has its sub-headings according to the topic. It is possible to read each chapter separately, but readers should follow up on cross-references to better understand interrelated terms.

The first part of this book is designed to explain fundamental terms and to provide comprehension of perceived virtuality and reality. The historical background of related systems is presented chronologically with notable milestones of emerging technologies. Then, the mixed reality concept is explained in reference to Milgram's Virtuality Continuum using samples and cases to emphasise the main differences among these terms.

The second chapter focuses on virtual reality definitions and terminology to reveal the nuances and developments during its history thus far. The types and features are explained, along with a description of immersive and non-immersive virtual reality. The chapter introduces emerging hardware requirements, head-mounted display technologies, and systems with detailed specifications and functionalities. Fundamental software components are explained, such as 3D modelling, 360° video production, and game engines. This section lists the benefits and disadvantages of virtual reality applications, along with sample studies and applications from several fields.

Augmented reality terms, definitions, benefits, and disadvantages are explained in chapter three. The interfaces and interactions of augmented reality have various forms as a result of the combining of physical and virtual components. The chapter explains tracking and sensor technologies and interface types and features, along with their software and hardware requirements. The reader will learn how a diverse range of industries applies augmented reality applications and studies across disciplines.

The fourth chapter focuses on mixed reality applications and studies within the education discipline from preschool to high school. The chapter introduces mixed reality applications and potential usage areas for in-service and professional training. Lastly, instructional design and 3D interactive design requirements and methods are discussed to provide an independent learning pathway for readers.

The final chapter includes one of my immersive virtual reality applications as a bonus example. A scientific background might help in reading about this experiential research. Ultimately, in sharing these interests and insights it is my hope that readers are inspired to investigate the design features of an immersive virtual reality application of their own.

The specific contribution of this book

Mixed reality contains multiple disciplines, terms, and professions, such as optics, mechanics, programming, designing, and engineering. Though it is possible to find specific books regarding exclusive components of mixed reality, this book presents the fundamentals of mixed reality in order to explain the differences and relationships among related concepts. This book is organised to facilitate and clarify mixed reality terms, systems, and applications from beginner to intermediate level for those interested in the field.

Numerous pictures and diagrams are provided to help visualise concepts and stimulate the imagination. Both virtual and augmented realities have many intangible systems and even interfaces, which can make it hard to understand or conceptualise relationships among them. In such instances, comparison tables are used to identify the main differences concerning features of related hardware and software components.

The purpose of this book is to provide useful material to facilitate technology and software selection processes for mixed reality environments using adequate interfaces and designs. Aiding the understanding of emerging technologies and capabilities is an essential element of this book. I hope to encourage teachers, lecturers, and academics to design and implement their own applications inside or outside of the classroom to facilitate their learning processes.

Acknowledgements

I wrote this book during my post-doctoral research and would like to express my appreciation to the Scientific and Technological Research Council of Turkey, which provided academic and financial support. I also wish to thank Marmara University and my co-workers for supporting my research and arranging the required permissions. I also thank Barney Dalgarno for his support.

Thanks to Andrew Hagan, Jane Harrison, and John Jacobs for their contributions to the proofreading of this book. I especially thank Andrew for supporting and encouraging me both professionally and psychologically during this process.

Lastly, my sincere thanks go to my precious family and especially my dear mom and dad. I am lucky to have you.

CHAPTER ONE

WHAT IS MR?

1.1 Introduction

MR, which stands for Mixed Reality, is an inclusive term that encompasses Virtual Reality, Augmented Reality, Augmented Virtuality, and variants of all these concepts. If we want to understand what MR is, we should first understand what reality is.

The five primary senses – sight, hearing, smell, taste, and touch – structure the individuals' perception of reality. They help us to comprehend the physical components of this world as sense perceptions stimulate the related neurological fields of the human brain via the nervous system. This process occurs so fast that human beings do not have time to perceive it.

Every individual has their unique mental models to interpret the perceived reality, and these models persist over a long period in the form of personal experiences and memories. The current science indicates that human beings can perceive less than 5% of the universe. The remaining 95% consists of 27% dark matter and 68% dark energy (NASA 2019). If we use the potential of all our senses, our brains can still only perceive less than 5% of the universe. This meagre perceived ratio constitutes our reality!

The human brain structures every concept within the limitations of the individuals' perceptions. Some studies in cognitive psychology have focused on imagery that indicates the dual coding process of the brain, wherein relational pathways link sight and memory. An example is the linking of a face to a name. fMRI-based imagery research shows that when someone focuses on a particular memory, their active brain areas are the same as if they were truly experiencing the event at that time. This fantastic investigation concerning hidden brain mechanisms opens up the possibility for us to control our perceptions. Virtuality gains a different meaning for the experiencing of reality in a divergent way.

What is the virtual? Virtuality can be expressed as an essence that is not formally recognised. Supplementary materials and devices are used to reflect virtual components. We become able to identify rendered virtual outputs via complementary technologies. Every individual can interpret the virtual output differently, just like with physical reality. Virtuality not only provides duplication of the physical reality, but it also offers us an imaginative vision to see what is beyond it. Thus we can perceive enhanced virtual representations of concepts, phenomena, systems, and mechanisms. Both tangible and intangible environments can be designed and developed in virtuality.

The short history of computer technologies has resulted in a dazzling revolution for visualisation, interaction, data transfer, and usage. The game industry has built Virtual Worlds (VWs), and visualisation has become essential to reaching a broad audience. The visualisation power of computer technologies has been so pervasive that even mobile phones are expected to feature a high-quality computer display. With current technological improvements, VWs have transformed from 2D to 3D and from single-player to multiplayer, and new sub-concepts have been defined to increase perceptions that support virtual technologies. Today, goggles and various other wearable technologies have become much more effective at visualising virtuality, allowing us to experience and interact with high-fidelity VWs.

The research shows that MR developments have touched our lives profoundly, and its spreading is inevitable. According to Gartner's hype cycle for emerging technologies (Gartner 2018), MR has now left the ‘peak of inflated expectation’ stage, and it has entered the ‘trough of disillusionment’ stage.

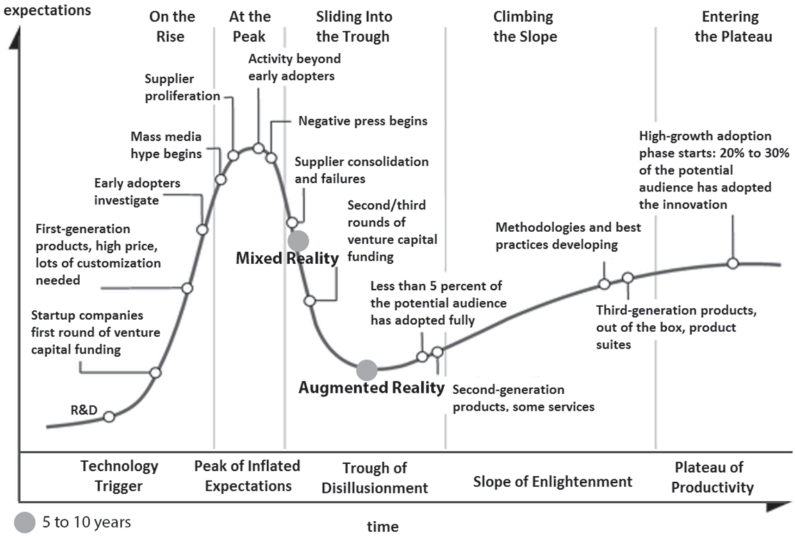


Fig. 1-1. Hype cycle of emerging technologies adapted from Gartner (2018)

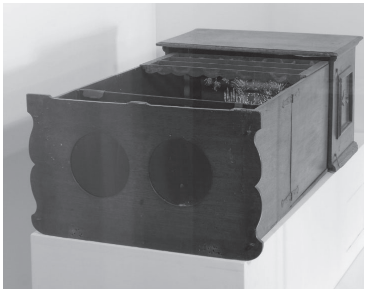
The three main reasons for disillusionment, in this case, are (1) the difficulty of 3D interface design, (2) the massive adaptation problem of VR because of convenience and control, and (3) increasing interest in AR through smartphone competition. Cheaper goggles and sensor technologies, 3D laser scanners, and 360° videos may be emerging solutions for working around these limitations. Gartner’s prediction indicates that 5 to 10 years will be necessary to reach the ‘plateau of productivity’ stage, although we might require more time to reach fully immersive VEs as readily accessible as our smartphones.

1.2 A history of MR technologies

Authors have different ideas about the initial philosophical background of MR technologies. According to Sherman and Craig (2018), cave paintings were the ancient reflection of VR because they are virtual manifestations of physical objects.

One of the first attempts to reflect virtual living images was pioneered by Herman Casler (Casler 1901) with a motion picture device called a Mutoscope. A series of static photographic images appeared animated when played back in a rolling drum. The Peep Box, another similar device, was portable and released for handheld users. The Zoogyroscope type of device was used to display moving objects, and several similar optical devices were introduced, pioneering the way and enabling the future film industry.

Mutoscope



Peep Box

Fig. 1-2. Antique visualisation devices

The first television was released in the 1940s by engineers and industrialists and was then rapidly adopted for general usage (Biocca 1992). Researchers during this time had no reference to VR or VE concepts because they did not yet exist. However, they were still defining the essentials of VR (Mazuryk and Gervautz 1996). In the 1960s, these terms started to indicate a variety of concepts and sub-concepts which were to evolve as the technologies and functionalities continued to develop.

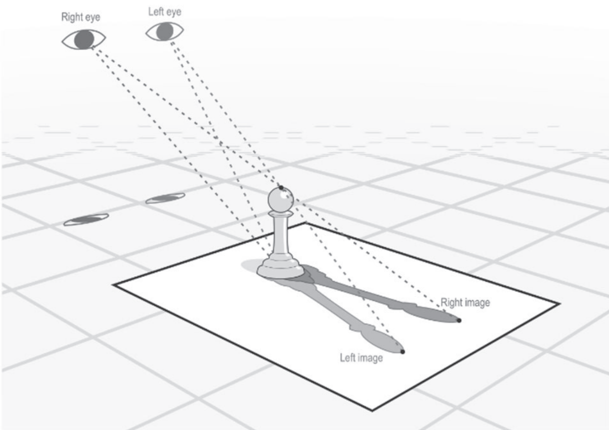


Fig. 1-3. One early 3D illustration technique

A computer scientist named Jaron Lanier initiated the concept of VR in 1989, based on a study of Ivan Sutherland (Schroeder 1993, Ma and Choi 2007). The pioneer of MR systems was the filmmaker Morton Heilig (Heilig 1962), who developed the first multi-modal theatre cabinet for a motorcycle experience and patented his product in 1962. He called this product, which presented a stereoscopic 3D object, the Sensorama. The Sensorama simulator augmented the virtual film environment using vibration, wind, and scent (Mazuryk and Gervautz 1996). The Sensorama simulator was the first AR system.

Fig. 1-4. Sensoroma

Then, the core abilities of VR were defined by MIT PhD student Ivan Sutherland for artificial worlds: interactive graphics, force feedback, sound, smell, and taste (Sutherland 1965). He designed the Scratchpad software in 1963 in order to provide human-computer interaction, and this significant leap in computer visualisation laid a foundation for future AR possibilities. The subsequent research of Sutherland presented a simple but innovative device for VR experiences using a head tracking system; the world met with the first head-mounted display (HMD) in 1968 (Sutherland 1968).

Fig. 1-5. Sword of Damocles

Military and scientific initiatives increased the development of VR technologies, and in the same years, VR started to become well-known for pilot training and NASA simulations. The 'grandfather of VR', Thomas Furless, developed the first flight simulator for the US army in 1968 (Robert Banino 2016). Then, in the mid-60s, VR technologies started to be used in universities for developing new technologies and research. This effort included early pioneering work to investigate brain perception systems and to use VR as a supporting tool in other ways within the cognitive psychology field.

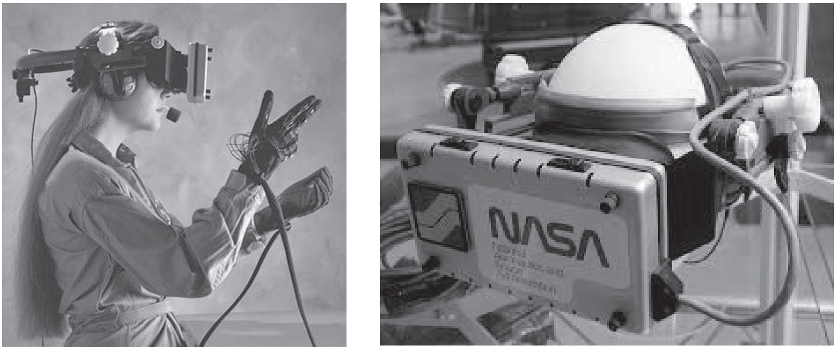


Fig. 1-6. NASA's first HMD prototype

Later investigations concerning wearable technologies, optical devices, tracking systems, and sensors have structured the fundamentals of today's AR and VR technologies. The MIT research lab focused on hand tracking systems, and in the 1970s, they released the Polhemus 3. The system featured a space tracking sensor which employed data from users' real hand positions to structure human-computer interaction. This idea stimulated more research into position tracking systems such as optical tracking, marker systems, silhouette analysis, magnetic tracking, and acoustic tracking. The tracking studies and the desire to interact with VWs via physical hand motions resulted in glove-based input systems. Daniel Sandin and Thomas Defandi developed the Sayra Glove using light emitters and photocells. The inspiration for this technology originated from Richard Sayra, whose glove system transferred the finger movements of users using an electric signal. The motion-capture-based MIT LED glove was developed in the early 1980s, and in 1983 the digital data entry glove was designed by Gary Grimes as an aid for the deaf (Robert Banino 2016, Sturman and Zeltzer 1994, Sherman and Craig 2018).

The DataGlove was released in 1987 and patented in 1991 by the team of Thomas Zimmerman and Jaron Lanier. The glove provided tactile feedback thanks to magnetic flux sensors. Nintendo introduced the Power Glove, an idea inspired by DataGlove and an early example of low-cost gloves that entered into the game industry. The CyberGlove was developed in the 1990s by Stanford University, and glove technologies started to become more portable and ergonomic. The CyberGlove had 22 sensors and could detect movements of less than one degree (Sturman and Zeltzer 1994, Robert Banino 2016, Zimmerman et al. 1987, Zimmerman and Lanier 1991).

In this short historical account, we can see that there was some attempt to initiate wide-scale usage of VR. However, no company could release a successful VR product to end-users in the market during this era, and even the most enthusiastic attempts failed. In 1983, for example, the Atari Shock was unsuccessful. Another attempt that came from Nintendo was the Virtual Boy, but this pioneering goggles-based system could not spread through the world. It only briefly survived and then disappeared in Japan. The main reason for this collapse was that the weak head tracking caused cybersickness (Robert Banino 2016).

All these technological improvements reshaped the definition of MR, and new concepts were derived from their increasing interactivity. AR was a term coined by Thomas Caudell in 1990 (Ma and Choi 2007), and AR became a research field in the late 1990s (Van Krevelen and Poelman 2007). It has to be emphasised that the first HMD of Ivan Sutherland was the starting point for AR (Ma and Choi 2007). After the AR term gained currency, the Boeing Corporation developed an experimental AR system to help workers put together wiring harnesses (Van Krevelen and Poelman 2007).

Developments in mobile and computer technologies were based on the various emerging types of AR systems. The first 3D MARS was developed as a system that could introduce people to a university campus 'using a head-tracked, see-through, head-worn, 3D display, and an untracked, opaque, hand-held, 2D display with stylus and trackpad' (Feiner et al. 1997). This prototype of the campus information system included a massive backpack computer, cables for the interactive component, a connected long aerial antenna for location tracking, and a hand display for system interaction. This device, albeit bulky, was still a true pioneer.

Fig. 1-7. A prototype of the campus information system (Höllerer et al. 1999)

At the beginning of the 2000s, the development and integration of GPS-based systems into mobile technologies (Loomis et al. 1994) led to the widespread adoption of portable AR systems in pocket-size devices.

1.3 Where does the MR concept come from?

The definition of the 'computer-mediated real' and the meaning of VW are usually confused (Sherman and Craig 2018). As seen in the historical account given earlier, there were no references to these terms until the 90s. All the technological improvements had similar purposes, even though their differentiation was hard to understand. The MR concept was clarified by Milgram and Kishino (1994) using a schematic representation of the reality–virtuality continuum taxonomy. They also shared their Extent of World Knowledge diagram to explain the modelled parts of virtual and physical reality. The combined version of these schemes is presented in figure 1-8.

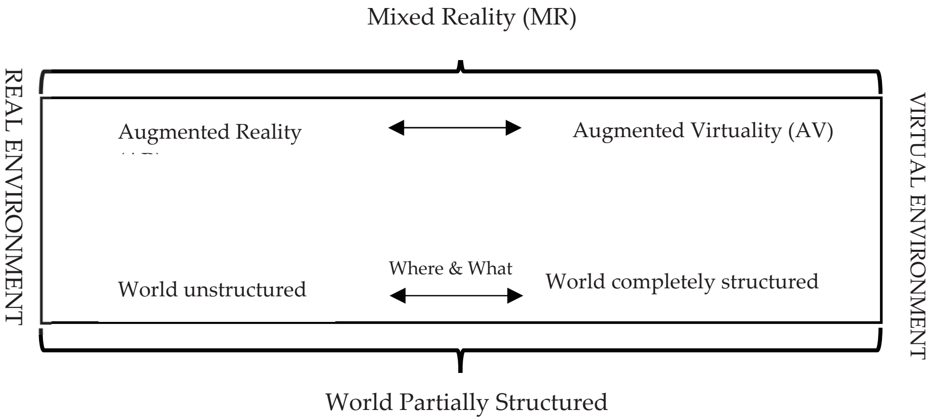


Fig. 1-8. The combination of Milgram's Reality–Virtuality (RV) Continuum model and the Extent of World Knowledge (EWK) (Taçgın and Arslan 2017)

Technology provides a virtual reinforcement that can initiate virtual and real outputs to scrutinise both virtuality and reality. We can think of this structure as a slider from 0 to 1. In this analogy, 0 refers to the real world, and 1 represents the VW. VR creates imaginary, fanciful, and extraordinary reflections, and uses computer technologies to provide more realistic or mimetic representations of point 1 on the scale (Ma and Choi 2007). As understood from the scheme, if the environment includes both physical and virtual components, this can be called MR. MR environments consist of modelled virtual objects and at least a physical location for those objects' implementation. If the users of these technologies are entirely cut off from perceptions of the physical world, this means they are in VRs. Complete VR immersion would be indistinguishable from reality, as fictionalised by such feature films as ‘The Matrix’.

AR and VR both employ 3D representations of virtual objects and interactivity via physical inputs to manipulate the environment, but the main discrepancy sticks out like a sore thumb (Sherman and Craig 2018, Ma and Choi 2007). Let us explain these terms using an example. Imagine that you are in a science fiction movie set in the 2040s. You have a smart house, and you are working from home, joining meetings with hologram technology via portable invisible goggles. You can see each of your co-workers during the conference and can communicate using real facial expressions. You are making a presentation in your best suit, but you are actually sitting on the sofa in your pyjamas. After the meeting, you decide to play a game using another pair of goggles for fun! In this highly immersive world, you can touch, feel, interact, smell, see, and live in another world. You are forgetting every detail about your real life and have a second life there. What is this? Are you hungry? Of course, you still have your body, and this stimulus calls you to eat. You decide to take a little break to eat and remove the goggles. Now, you are in the kitchen looking at the screen with your preferences, and the kitchen offers you alternative meals using currently available ingredients. Five minutes after you choose your meal, it is on the table. What an amazing life it is!

In this scenario, the office situation entails AV – that is, Augmented Virtuality, physical objects being embedded in the virtual environment – thanks to the reflection of authentic facial expressions in the virtual meeting. Your game was an IVR (Immersive Virtual Reality), and that fantastic kitchen used AR systems. As can be seen, the actual VR surrounds and penetrates all the perceptions of users (Ma and Choi 2007). AR systems are structured in the physical world and use virtual objects to enhance the components of the real world. In light of today’s technologies, AR environments can track the movements or bodies of users via sensors and navigation systems. If we want to enhance VR, we should use physical components as indicated in AV.

The question is, how much of the physical or VW (virtual world) can be perceived in MR? Everything has a reality and virtuality (Ma and Choi 2007), but the answer to this question indicates which reality you have. If one can suppress real hunger by being fully immersed in VR, the scenario becomes an ideal virtual reality.

It can be hard to explain nuances among these terms, and there is little consensus about exact definitions. Still, an inclusive MR concept can be posited with some help from inductive reasoning.

1.4 Summary of Chapter 1

- MR environments have a combination of virtual and physical components.
- VR environments require a completely structured environment.
- AR integrates digital content into physical reality and requires tracking systems to integrate digital and physical content with each other.
- Sutherland developed the first HMD under the Sword of Damocles project.
- The first AR, named Sensoroma, was developed for the film industry.
- MR technologies developed rapidly in the military and scientific fields.
- Jaron Lanier defined the concept of VR in the 1960s.
- Thomas Caudell defined the concept of AR in the 1990s.

- The Reality–Virtuality Continuum was defined by Milgram to differentiate MR terms.

CHAPTER TWO

WHAT IS VR?

The concept of VR has evolved through developing technologies, and its definition is still in flux (Sherman and Craig 2018). Successive developments have led to the derivation of new sub-concepts of VR. We can define VR as a notable digital representation of a perceived reality that is not reality. Some essential terms have been established to explain differences among the subcategories of VR. Understanding these terms has a vital role in describing the main specifications of any particular VR environment.

We should take a glance at VR definitions in their chronological sequence before explaining the related sub-terms. Then, we can evaluate and comprehend the differences among these terms. This section examines the definitions, sub-terms, types, benefits, disadvantages, and technologies of VR.

VR is a medium that consists of virtual objects and interactions in cyberspace that become a presence that can influence the perception of an individual. The effectiveness of that presence can be reinforced via graphics, audio, and haptic feedback using computer technologies such as monitors, HMDs, goggles, or CAVEs (Cave Automatic Virtual Environment).

Some of the definitions for VR are:

> VR has many features that combine to make it a truly unique medium. These features include the ability to manipulate the sense of time and space, the option of interactivity and multiple simultaneous participants, and the potential for participants to drive the narrative flow of the experience. VR brings all of these components together into a single medium, creating the opportunity for a

> dynamic relationship between the recipient (participant) and the medium (Sherman and Craig 2018).
>
> VR is something imaginative, graphical, auditory, and interactive. *Jaron Lanier*
>
> 'Virtual Realism' means an art form, a sensibility, and a way of living with new technology (Michael Heim, cited in Ma and Choi 2007)
>
> VR is a technology that immerses a user into a computer-generated VW by replacing the real world around the user with a virtual one… With the ultimate virtual reality system, a user would not be able to distinguish the virtual world from the real (Orlosky, Kiyokawa, and Takemura 2017).
>
> VR completely consists of computer-generated factors, which makes a user totally immersed in it. In other words, a simulated, artificial environment replaces the real one in a VR system (Ma and Choi 2007).
>
> Using visual, aural, and haptic devices, the user can experience the environment as if he/she was part of the world (Riva et al. 2007).

The five essential qualities of VR have been defined as intensive, interactive, immersive, illustrative, and intuitive; these elements are called the 5 Is of VR (Sherman and Judkins 1992, El Araby 2002).

- **Intensive**: Amplification of senses via multiple channels
- **Interactive**: Providing human-computer interaction via a virtual interface
- **Immersive**: Capturing the perceptions of users
- **Illustrative**: Explaining tangible and intangible concepts descriptively

- **Intuitive**: Easily accessible interface via heuristic perceptions

If the environment is called VR, it should have all of these elements, but to what extent?

2.1.1 Terms for understanding VR

2.1.1.1 Virtuality

Virtual as a computing term is defined as 'not physically existing as such but made by software to appear to do so' by the *Oxford Dictionary*. From this point of view, virtuality is referring to the extent of the being virtual, the existence, or the potential, and it 'includes conceptual structure and feeling of everything' (Ma and Choi 2007).

2.1.1.2 Virtual object/image

Virtual images are designed with computer software to describe or represent the specific concept in 2D or 3D. A virtual image 'refers to the objects in the VR environment that appear to exist through a lens or mirror' (Sherman and Craig 2018). The virtual object is the smallest component of a structured environment that is created by combining these objects to organise the entire world.

2.1.1.3 Virtual world/environment

VWs do not have to be entire worlds; they can refer to partial representations of specific areas, but they have to be in virtual spaces (Bell 2008). VW is a comprehensive concept that consists of both 2D and 3D online virtual environments and combines virtual objects (Sherman and Craig 2018). A VW offers a synchronous and persistent network of individuals via the presentation of avatars and facilitated computer networks (Bell 2008). VWs can exist without being displayed in a VR system for use in play or film scripts (Sherman and Craig 2018). Under the concept of today's VR technologies, VW has generally indicated the 3D immersive form, and it has many capabilities, such as interaction, navigation, communication, and embodiment (Gregory et al. 2016). The current capabilities of VWs make them conducive to the illustration of essential traits of human interaction, behaviour, and group processes (Johnson and Levine 2008).

2.1.1.4 Presence

The concept of presence for emerging IVR technologies can be defined as the sense of being in a VW. The main specification of presence is that the computer-generated environment induces the feeling of presence through the impact of sensory perceptions that can be visual, aural, or haptic experiences. Thanks to these inputs, users can interact with the VW in real-time, and the reactions and movements of users can be transferred to the VW to create immersed synthetic illusions (Riva et al. 2007). High-fidelity 3D VW designs lead to a high level of presence that supports the transfer of knowledge from the VW to real experience (Dalgarno and Lee 2010). In other words, presence is directly related to cognitive processes and their emotional impacts on the users (Dalgarno and Lee 2010, Riva et al. 2007). The highest quality IVR environments should provide a physiological immersion that induces place illusion, which is key to the virtual presence (Liu et al. 2017).

According to Slater (2017, Slater and Sanchez-Vives 2014, Sanchez-Vives and Slater 2005, Slater, Usoh, and Steed 1995), presence is rendered by VR technologies with two different illusions: (1) place illusion and (2) plausibility illusion. Place illusion can be provided by VR displays and supports a sense of 'being there' through head-based natural sensorimotor contingencies. Place illusion is generally supplied via head or eye-tracking systems, and it manipulates the perceptions of users through physical body movements such as looking around, bending down, or listening. The plausibility illusion requires interactivity during the VR experience and generates spontaneous responses for the users' actions. The plausibility illusion extends the perception of users that what they are doing and experiencing is happening (e.g. the user smiles and reacts in the real world).

Presence has various sub-concepts according to different researchers (Schuemie et al. 2001). These sub-concepts will be analysed using case studies of VR examples later in this chapter.

2.1.1.5 Telepresence

The term telepresence is rooted in the research of Marvin Minsky (Minsky 1980) on teleoperator systems. It was used to define the remote manipulation and control of real objects. In other words, the presence of experience in an environment is defined as telepresence. The main differences between presence and telepresence depend on the perception of the situation. Presence refers to natural perception and telepresence refers to mediated perception (Steuer 1992). Telepresence was defined for VR as the ability to effect changes in the VW through computer-controlled display systems (Sanchez-Vives and Slater 2004).

2.2 Types of VR

Throughout the history of VR, there has been no consensus on the types or the definitions separating elements. The types and categories of VR have followed paths of evolution that depend on the technologies used to create them and the degree of presence they provide. The only consensus about VR categories is that there are two main ones: immersive and non-immersive.

A literature review indicates that other, different types of VR can be organised under different main categories than those defined by previous writers on the subject. The level of presence can be categorised under a more general structure, as presented in figure 2-1.

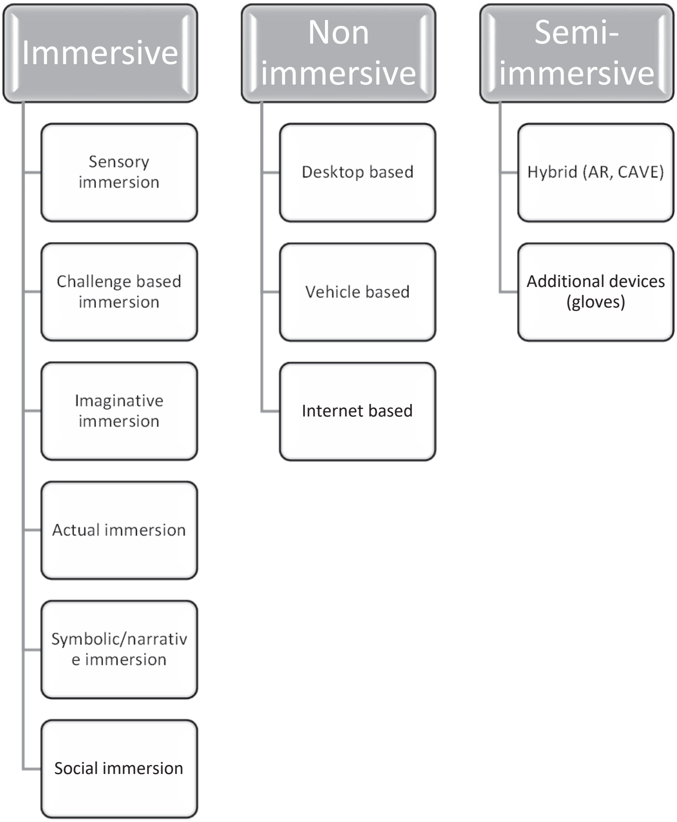


Fig. 2-1. VR types and categories adapted from (Bamodu and Ye 2013, Ermi and Mäyrä 2011, Ermi and Mäyrä 2005, Liu et al. 2017, Aguinas, Henle, and Beaty Jr 2001, Mahmoud 2001, El Araby 2002, Halarnkar et al. 2012, Muhanna 2015, Cohen et al. 2013, Buttussi and Chittaro 2018, Johnson 2010)

As an up-to-date term, the ideal VR should be an IVR providing a high level of presence. The immersion can be provided via sensory, challenge-based, imaginative, actual, symbolic/narrative, and social components that are directly related to the technology and interaction type of the VR environment. There are constraints – such as expenses, the spread of usage, lack of software, and content creation – that are challenges in producing IVR environments. Non-IVR technologies can handle these limitations, but if the effectiveness of immersive environments and that of non-IVR environments are compared, the winner is IVR.

2.2.1 Immersive VR

'Immersion in a digital experience involves the willing suspension of disbelief' (Dede 2009). 'Total immersion' refers to the situation whereby the user is completely immersed in the virtual environment and is removed from influences coming from outside of the VW (Mills and Noyes 1999a). Physical and physiological components can support the sense of immersion for users. According to Sherman, immersion in VR environments begins with physical rather than mental awareness (Sherman and Craig 2018). The hardware dependency of IVR environments can be the reason for this argument since physical stimuli are useless if they do not affect mental perceptions. The majority of research indicates that an essential parameter of IVR environments is a high level of presence that is wholly related to psychological immersion. The primary purpose of IVR environments is encapsulating all perceptions to support the feeling of presence for all users. So understood, psychological immersion genuinely captures the senses to provide the willing suspension of disbelief.

The level of both mental and physical immersion influences the belief and trust of users in the VR environment. It is necessary to support the presence of individuals by adequately arranging their cognitive states and physical sensations. The use of senses such as touch, hearing, and sight, and the giving of emotional feedback, help people to assimilate to VWs (Hanson and Shelton 2008b).

IVR is an emerging multidisciplinary field that includes human-computer interaction, interaction design, user experience and interface, and affective computing (Rubio-Tamayo, Gertrudix Barrio, and García García 2017). At the merging point of these fields, new terms concerning both hardware and software for VR systems have been derived, and the preferences of these systems engender the types of sub-immersion.

VR cannot exist without hardware and software. Hardware components support physical immersion and reinforce psychological immersion through software that should present high fidelity 3D virtual objects, environments, and interactions. The fidelity of VR environments can be evaluated according to three main criteria: (1) interaction fidelity, (2) display fidelity, and (3) scenario fidelity. Interaction fidelity is directly related to the input devices of VR systems and the users' ability to observe the result of their interactions via output devices using a display system. Display fidelity is significant for increasing the perceived presence in a VW. Scenario fidelity considers both of the other types of fidelity through the representation of simulated scenarios and offers realistic outputs as a result of users' interactions (Buttussi and Chittaro 2018).

A study conducted by Heydarian et al. (2014) indicates that there is a strong relationship between presence and high-fidelity VR design. The high degree of physical and psychological immersion of VR offers better learning outcomes to be reached because the details of learning experiences (LE) are chiselled with increased fidelity (Goodwin, Wiltshire, and Fiore 2015, Ke, Lee, and Xu 2016, Kleinert et al. 2015).

VR systems can be classified according to the technology utilised and the provided degree of mental immersion (Muhanna 2015). Mental immersion is related to VR fidelity, and this is supported by the hardware, software, and design specifications that have an impact on the types and categories of IVR.

- **Sensory immersion**: From a gaming perspective, there are audio-visually impressive 3D VWs that comprehensively surround players (Ermi and Mäyrä 2011, Ermi and Mäyrä 2005). Sensory immersion uses technological equipment like HMDs that can employ immersive displays, or VR rooms such as CAVEs or domes (Dede 2009, Liu et al. 2017). VR experiences are the result of sensory immersion (Dalgarno and Lee 2010), and they surround users with a sense of presence. By integrating the forces, vibrations, and motions of users, total sensory immersion could provide ambisonic or otherwise 3D-spatialised sound and haptic devices that permit them to interact with virtual objects. Sensory feedback is one of the essential factors that can be supplied by tracking users' physical positions or spatial gestures (e.g. hand movements) to interact with the VW (Sherman and Craig 2018). From a learning perspective, sensory immersion can be evaluated using a subcategory of challenge-based immersion (Dede 2009).

- **Challenge-based immersion:** Challenge-based immersion is based on interaction, and it is useful in the development of motor and mental skills (Ermi and Mäyrä 2011, Ermi and Mäyrä 2005).

- **Imaginative immersion:** VR creates an opportunity to act out our dreams, thoughts, or alternative experiences, which can serve as prototypes for real situations. The environment qualifies as providing imaginative immersion if it was designed to allow users to experience events from someone else's perspective by presenting their thoughts and dreams (Sherman and Craig 2018) and if it depends on stories and role-playing using avatars (Dede 2009). This kind of VR environment allows you to create scenarios that are not possible to experience in the real world, especially by reducing the physical danger of those experiences.

- **Actual immersion**: This type of immersion presents an opportunity to experience virtual actions in the physical world. The users can experience and observe the real, unplanned, and intriguing consequences of their actions (Dede 2009).

- **Symbolic/Narrative Immersion**: If an IVR environment triggers users' semantic and psychological associations concerning their experiences, these VR environments can be evaluated as symbolic IVR (Dede 2009). As Liu et al. (2017) state, 'the narrative is a significant motivational and intellectual component of all forms of learning. Invoking intellectual, emotional, and normative archetypes deepens the experience by imposing an intricate overlay of associative mental models'. Narrative IVR offers opportunities to switch between different interfaces by manipulating options (Sherman and Craig 2018).

- **Social Immersion:** VR environments can be designed to be single or multi-user. Multi-user VR usually has a connection to the Internet so participants can share a similar experience in the VW at the same time. This type of environment generally uses interactive avatars (Sherman and Craig 2018).

'Psychological immersion is achievable in any of these interfaces by design strategies that combine action, social, symbolic, and sensory factors' (Liu et al. 2017). Head and eye-tracking systems of HMDs can provide the presence illusion of IVR. Users can observe the VR environment by looking around and can even see their virtual bodies. The high-fidelity design of VR has two components. One of them is the high-resolution visual factor that is usually provided by HMDs. Computer-generated inputs and haptic feedback produce sounds that are used to reinforce users' sensory perceptions. The other component is the use of real-time head tracking with six degrees of freedom (6DoF) based on users' head gaze direction (Slater and Sanchez-Vives 2014).

2.2.2 Non-Immersive VR

Non-IVR environments are usually desktop-based VR systems that employ monitors or hand devices to render 2D or 3D virtual objects (Muhanna 2015, McMahan 2003, Adamo-Villani and

Johnson 2010). Standard 2D computer monitors are used as an output display device to represent VW to the users. The input devices can allow for highly restricted interaction within the VW, through the use of keyboards, mice, trackballs, joysticks, or perhaps a SpaceBall or DataGloves –haptic devices- (Adamo-Villani and Johnson 2010).

These non-IVR environments can be networked to provide multi-user opportunities in a VW, such as in SecondLife. Non-IVR simulations have been used for vehicle training, such as for flying planes or driving cars, since the 1960s.

Even though these VR environments are often called non-immersive, they consist of a low degree of immersion and presence (Mahmoud 2001, Muhanna 2015). The degree of immersion can be changed with larger display size, higher resolution, better graphics fidelity, and improvements to other related factors of VR systems. Computer games demonstrate specific levels of immersion in VR environments, such as in the 2D 'Super Mario' and the 3D 'World of Warcraft' games. If a 'World of Warcraft' player uses two large monitors and a surround sound system, her relatively low degree of immersion will be more than if she had a single medium-sized monitor and a stereo sound system. The quality of each computer game can be differentiated by their design features, scenarios, interactivity features, and design (egocentric and exocentric). According to McMahan (2003), there are three main conditions that affect the sense of immersion in a 3D computer game-based VR environment: (1) the harmony between users' expectations of the game environment and the actual game design, (2) the impact of users' actions in the VW, and (3) the consistency of the conventions employed in the VW.

Similar variables impact the degree of perceived presence in both immersive and non-IVR environments. IVR provides more visualisation and other stimuli than non-IVR systems. The quality of output is directly related to the technology utilised and how it affects our perceptions. In my opinion, the presence and immersion concept is not the same for immersive and non-IVR environments. The current and ideal definition of VR is usually restricted to IVR environments, but non-IVR still falls under the rubric of its definition. The limitations of IVR make the use of non-IVR a reasonable VR option. In non-IVR environments, it is easier to create high-quality content and employ more cost-effective software and hardware. This situation will continue to be the case until IVR technologies become cheaper and more accessible. The main goal of the following section is to explain the current IVR systems and environments because the concept of non-IVR has not been conceptualised deeply enough.

2.3 Current VR Technologies

2.3.1 Hardware

Every piece of hardware has input and output functionalities. We can use this separation for VR systems as well. The output machines transfer the digital information to our perceptions and are usually related to the visual components. The input provides communication and interaction with related technologies, which we can manipulate with the digital elements.

2.3.1.1 HMDs (Head-Mounted Displays) as an Output

Historically, HMDs have been accepted as an essential output component of VR technologies. Sight is the most dominant sense used to perceive the environment in humans. HMDs attempt to surround the individuals' view and represent the VR content via display systems. Today, there are three types of HMDs: 1) tethered HMDs, 2) mobile phone integrated HMDs, and 3) stand-alone HMDs.

2.3.1.1.1 Understanding HMDs

The quality of sight perception in the VR environment is related to the specifications of the display systems, optics (lenses), the field of view (FoV), tracking systems (head and eye), motion, latency, frame rate, and the other sensors present in the case of the tethered HMD.

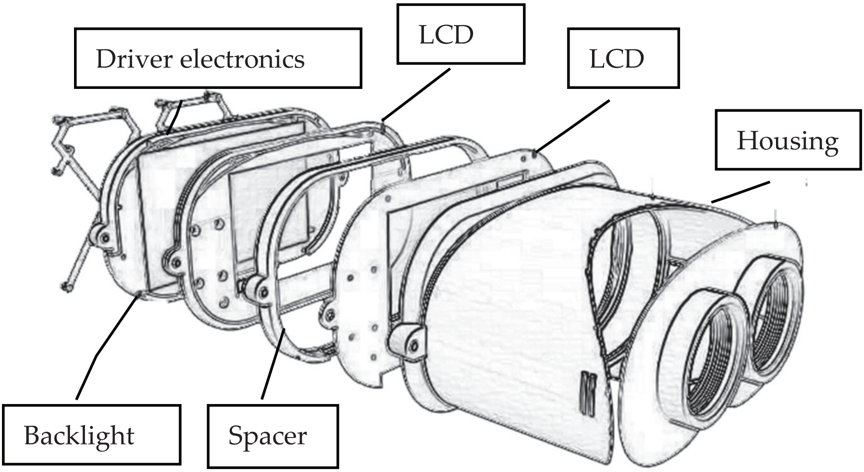


Fig. 2-2. Binocular structure of an HMD (2 LCD), adapted from Huang, Luebke, and Wetzstein (2015)

The four main types of display technologies used for HMDs include: (1) LCD, (2) Single Column LED, (3) Projected, and (4) Small CRT (Onyesolu, Ezeani, and Okonkwo 2012). The LCD and OLED display systems are usually preferred in current HMD systems. The optical illusion of an IVR experience is provided with special stereoscopic lenses that display the VW to the users' eyes. There is a strong relationship between the quality of the lenses and the 3D visuals.

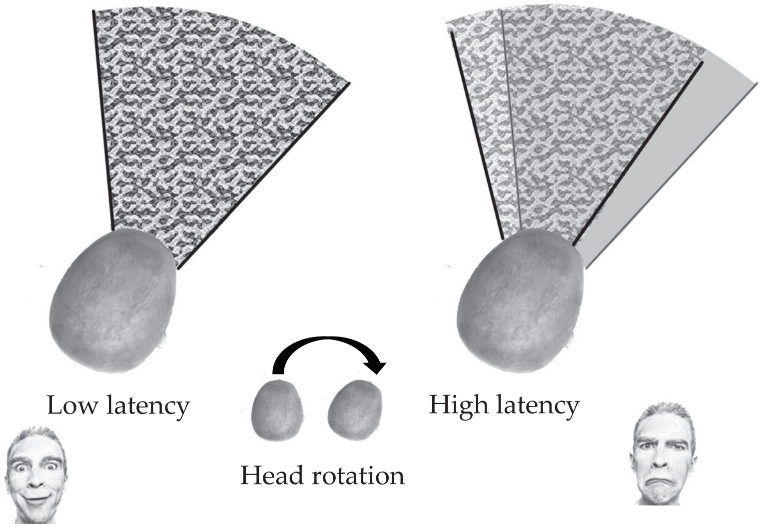


Fig. 2-3. Latency and other effects on VR

Latency and frame rates are essential factors for high-quality VR display. Low latency speed positively affects the quality and harmony with the display and reduces delays in tracking the user's movements concerning visuals. Decreased M2P (motion-to-photon) latency is ideal for providing a fluent representation of the VR environment, and it is measured in milliseconds (ms). High latency is the main reason for cybersickness when it occurs; keeping latency lower than 20 ms is suggested to avoid this side effect of VR systems (Quach et al. 2018). Another term related to display systems is the frame rate, which is a significant factor for all kinds of display systems, including televisions, game consoles, and goggles. Frame rate, the refresh rate of moving visuals, is measured in frames-per-second or fps. High-quality VR systems, which provide more realistic and fluent visual experiences, should maintain at least 90 fps (Sung et al. 2018, Hecht 2016).

Typically, healthy human eyes have a 200- to 220-degree FoV. Meanwhile, the FoV of current HMD technologies usually ranges between 90 and 110 degrees (Pohl, Choudhury, and Achtelik 2018). FoV can be stable or lower than expected for some HMDs even though systems of integrated sensors and head position tracking can increase the efficiency of the view. For this reason, the degree of freedom (DoF) is the other factor for visually perceiving VR effectively (Hosseini 2017, Yamaguchi et al. 2019, Fan et al. 2017).

Considering the tracking functionality of HMDs, we can evaluate HMDs as both input and output devices. Sensor technologies support all tracking systems. Users can manipulate or interact with the VR environment thanks to internal or external sensors. There are three main types of tracking system for HMDs: (1) head tracking, (2) eye tracking, and (3) motion tracking. Head tracking systems in the 3D VR environment should idealistically support 6DoF, meaning that both the head and body movements of users can be tracked in both directions on the x, y, and z axes.

As mentioned previously, synchronisation and calibration of head tracking should produce a realistic, sufficient VR experience with low latency. The tracking is done through gyroscope, accelerometer, and magnetometer technologies. Eye-tracking systems are the other tracking component of HMDs, and they are even used for desktop monitors. The eye-tracking systems of HMDs are also used for interaction (e.g. gaze interaction) with the VR environment. The optimum eye-tracking systems require 200-300 refreshes per second to provide adequate alignment and relativity (Piumsomboon et al. 2017).

Except in the case of 6DoF HMDs, motion tracking systems for HMDs generally require additional input hardware. The typical motion tracking systems are used to determine users' actual positions and represent their movements in the VR environment. Motion tracking systems are highly popular for hand tracking to provide natural gestural interaction. Additional sensor technologies and related devices are used to attain sensitive motion recognition and interaction.

2.3.1.1.2 Tethered HMDs

Tethered HMDs are rather bulky devices that require direct connection to the PC; hence, users are forced to struggle with several cables. Developers generally prefer the tethered HMDs because of the high-quality displays, GPUs, CPUs, and applications provided. A comparison of the features of today's most popular tethered HMD devices and their specifications are offered in table 2-1.

Table 2-1. The most popular tethered VR HMDs and their features

HMD	Display	Resolution (per eye)	FoV	Latency	DoF	Sensor systems	Refresh rate	Price	OS	Release date	Website
Oculus Rift DK2	OLED	960 x 1080	100 (nominal)	30ms	6DoF	Gyroscope & Accelerometer & Magnetometer	60-75 Hz	$350	Windows & Mac & Linux	2016	https://www.oculus.com/rift/#oui-csl-rift-games=mages-tale
Oculus Rift S	Fast-switch LCD	1280 × 1440	Slightly larger	unknown	6DoF	unknown	80 Hz	$399	Windows, Mac, & Linux	2019	https://www.oculus.com/rift-s/?locale=en_US
HTC Vive Pro	Dual OLED	1440 × 1600	110 (diagonal)	M2P 7ms	6DoF	Gyroscope, Accelerometer, Magnetometer, & Laser Position Sensor	90 Hz	$799	Windows	2018	https://www.vive.com/us/product/vive-pro/
HTC Vive	Dual OLED	1080 x 1200	110 (diagonal)	M2P 7-15ms	6DoF	Gyroscope, Accelerometer, Magnetometer, & Laser	90 Hz	$499	Windows	2016	https://www.vive.com/us/product/vive-virtual-

						Position Sensor					reality-system/
Sony PlayStation VR	OLED	960 x 1080	100	<18ms	6DoF	Gyroscope & Accelerometer	90-120 Hz	$399	PlayStation 4 & PlayStation Vita	2016	https://www.playstation.com/en-au/explore/playstation-vr/
Samsung Odyssey	OLED	1440 x 1600	110	>7ms	6DoF x2	Gyroscope, Accelerometer, Compass, Proximity Sensor, & IPD Sensor	60-90 Hz	$249	Windows	2017	https://www.samsung.com/us/computing/hmd/windows-mixed-reality
Dell Visor	LCD	1440 × 1440	105-110	unknown (low)	6DoF (users have trouble 3DoF)	Gyroscope, Accelerometer, & Magnetometer	90Hz	$350	Windows	2017	https://www.microsoft.com/en-us/p/dell-visor/9n1c1p629dr9?activetab=pivot:overviewtab
Razer HDK2	OLED	1080 × 1200	110	unknown (low)	3DoF-6DoF	Gyroscope, Accelerometer, & Magnetometer	90 Hz	$399	Open source	2016	http://www.osvr.org/hdk2.html

Acer Windows MR	LCD	1440 × 1440	95	M2P <10ms	6DoF	Gyroscope, Accelerometer, & Magnetometer	90 Hz	$243	Windows	2017	https://www.acer.com/ac/en/US/content/series/wmr
HP Windows MR	LCD	1440 × 1440	95	unknown	6Dof and inside tracking	Accelerometer, Gyroscope, & Proximity sensor	>90 Hz	$329	Windows	2017	http://store.hp.com/us/en/cv/mixed-reality-headset

The typical prices and maximum affordances of various tethered HMD devices are offered in table 2-1. As noted, the price information is presented only for HMDs without controllers. There have been several successful and unsuccessful attempts to develop HMD devices to provide IVR experiences. Sometimes initially successful products have vanished because of discrepancies between hardware and software or for financial reasons. For instance, despite its satisfying VR experience and cost-effectiveness, the Lenovo Explorer did not sell because of display problems after a software update.

To begin with, the HMD devices were released only for developers, who would gradually develop the technology to the point where it could reach mass usage and meet futuristic expectations. The main goal of this phase was to help increase the number of applications and technologies. After a while, several relatively cheaper tethered HMDs were released for end-users. The hardware capabilities of these HMDs (such as the Samsung Gear or Acer MR) were reduced to provide cost-effective products, but they were still sufficient to meet the expectations of end-users.

Oculus Rift

HTC Vive

Razer

Dell Vizor

Fig. 2-4. Some examples of tethered VR HMDs

Nonetheless, the futuristic wishes of the developers of HMDs are persistent, and if the hardware does not carry out what they have imagined, they can continue to develop their products. These attempts are helping to increase the variety even though, due to hardware and financial limitations, they have not yet reached a large consumer market. StarVR, one recent example of such innovative and relatively sustainable technologies, has the largest (210 degrees horizontal, 130 degrees vertical) FoV and perfect colour quality owing to its crystallised OLED display. StarVR offers not only today's highest quality goggles for developers but also the most expensive ones ($3200).

The main challenge of tethered HMDs for end-users is the high expense. As a result, companies are competing fiercely to release cheaper and higher quality numerous models. The setup process for tethered HMDs can require some technical knowledge such as knowing how to make a PC connection, but the user manuals are usually adequate in this regard and can satisfy entrepreneurs in their handling of such issues. Tech bloggers have compared tethered HMDs in various ways, but they often end up focusing on two big actors: Oculus and HTC. Although these discussions usually find the HTC Vive to be better than Oculus Rift, it can be said that Oculus Rift has an apodictic advantage thanks to its OS compatibility. The Oculus company announced its new product Oculus S in March 2019, and it met with end-users in November 2019 (with this book in press). It looks like Oculus S will turn up the heat on the competition by offering a cost-effective alternative product.

2.3.1.1.3 Mobile phone integrated HMDs

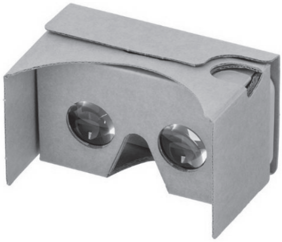
Tethered HMDs are the best option by which to experience high-quality IVR, but the high expense and PC dependency of tethered HMDs are the significant challenges in the way of IVR reaching mass audiences. The imaginings and wishes of organisations regarding VR implementation, especially for the adapting of them to their working practices, cannot happen because of these issues.

In mobile-phone-integrated HMDs, 3D visualisation is provided by the phone's stereo display outputs, which show the same view from different perspectives for each of the eyes. At first, the fundamental 3D visualisation was applied to pictures to give depth. Subsequently, one of the leading spreading technologies, smartphones, has started to be used for the rendering of 3D VR environments.

Google first made a brilliant and portable solution in their Cardboard product. Then, it was noticed that this easy technique could be adapted so that anyone could make their own hand made goggles with paper. The idea of Cardboard offered an optimum solution to the ordinarily high costs, and VR became something attainable for smartphone users. However, the visual quality was not good enough, and there was no possibility to provide stereo sound to reinforce the perceived immersion. Various technology companies turned this simple technology to their advantage, releasing mobile-phone-integrated HMDs. The display quality of these HMDs is generally related to the smartphone's capabilities, meaning that sometimes they do not meet the high-quality IVR experience expectations of users. These user expectations can be satisfied by using high-quality lenses, audio outputs, and integrated joysticks. These requirements bring new improvements, and the new HMD bazaar has been created.

There are more than a hundred smartphone-integrated HMD models and brands for every budget, and their quality is usually measured in terms of features, especially FoV. FoV ranges between 45 and 110 degrees among these devices, and they are usually made out of plastic. One exception is the Google Cardboard.

The mobile phone integrated HMDs use the smartphone's gyroscopes to interact with the VW. These HMDs can also be produced with joystick controllers as well. The gyroscopes of smartphones track the head movements of users by integrated sensors. In this way, users become able to interact with the VR environment through the indication of their gazes. This tracking technique is not an exact head or eye-tracking system, but it is better than nothing. Joystick-supported mobile HMDs are either sold with controllers or users can buy the controllers separately and connect them to their HMDs with Bluetooth, but this integration is not possible for all models.



Google Cardboard

MergeVR

Samsung Gear VR

Google DayDream

Fig. 2-5. Some examples of mobile-phone-integrated HMDs

Technological developments have continued in a variety of areas like smartphones, and their CPU sophistication and screen resolution have been increasing to support compatibility with mobile VR HMDs.

Some of the most common mobile-phone-integrated HMDs are offered in table 2-2.

Table 2-2. The most used mobile VR HMDs

Mobile HMD	Supported Screen Size	FoV	OS	Sensor	Price	Lens	Release Date	Web Site
Google Cardboard V2	4.0-6.0″	45	iOS & Android	Smartphone based	$15	High Quality Resin Lens	2015	https://vr.google.com/cardboard/get-cardboard/
Veer Google Cardboard	3.5-6.0″	95	iOS & Android	Smartphone based	$9	High Quality Resin Lens	2016	https://store.veer.tv/products/veer-vr-google-cardboard-box
VRBox 2.0	4.5-6.0″	70	iOS & Android	Smartphone based	$11	HD optical resin lens	2016	https://www.amazon.com/VR-BOX-2-Virtual-Reality-Goggle/dp/B01HUW65LI
Samsung Gear VR	5.1-6.9″	101	Android (only specific Samsung SmartPhones)	Accelerometer. Gyrometer. & Proximity	$130 (+ $40 with controller)	unknown	2018	https://www.samsung.com/global/galaxy/gear-vr/

Google Daydream VR	5.7-6.9″	90	Android (only specific SmartPhones)	Accelerometer, Gyrometer, & Proximity	$100 (without controller)	unknown	2017	https://vr.google.com/daydream/
MergeVR	4.8-6.2″	96	iOS & Android	Smartphone based	$30	Adjustable	2017	https://mergevr.com/headset#
IDudu VR	4.0-6.2″	120	iOS & Android	Smartphone based	$55	HD optical resin lens	2016	http://www.myidudu.com/index.php?route=product/product&product_id=42
DestekVR	4.5-6.0″	103	iOS & Android	Smartphone based	$38 (with controller)	Eye Protected Anti-blue Light HD Lenses	2017	https://www.destekgear.com/destek-v4-vr-headset-w-controller

These HMDs are suitable for smartphones of screen sizes between 3.5 and 6 inches, and they have either 3DoF or 6DoF. Users should be careful about compatible screen size and OS before ordering their mobile VR HMDs. The prices range between $6 and $150. These HMDs usually work in any OS because they do not have a processor. However, Google Daydream and Samsung Gear VR have their compatibility factors for OS and smartphone models. If you have a smartphone, you can straightforwardly test one of the 360° stereo videos using 360° YouTube without the setup process. From observation, the best usage of mobile-integrated HMDs is making 360° panoramic videos rather than generating an authentic IVR experience. Because of that fact, stand-alone HMDs are still being released to satisfy users who want high quality and portable IVR experiences.

2.3.1.1.4 Stand-alone HMDs

Until 2017, IVR experiences were dependent on PCs or mobile phones. In particular, the users of tethered HMDs still have to struggle with several cables during their VR experiences. The most dominant VR HMD companies have released new all-in-one products as a solution. These stand-alone HMDs include integrated processors, sensors, lenses, and batteries to provide a VR experience without cables.

Oculus Go HTC Vive Focus

Fig. 2-6. Stand-alone HMDs

Stand-alone HMDs entered the goggles market only two years ago, and although there is not much variety in these devices at the moment, it is rapidly increasing. These HMDs and wands can support 3DoF or 6DoF using integrated sensors. Making data connections and interaction with applications require a wireless connection. In my opinion, wireless technology will be used for battery charging too before long.

The two most used stand-alone HMDs are the Oculus Go and HTC Focus. The Oculus Go supports 3DoF, which means that users cannot walk around in the VR environment. They can, however, observe the VW with their head movements. The interaction is provided via one controller that consists of a touchpad, trigger, and menu buttons. The users log into their Oculus account using their mobile phone and the application, and then they pair the Go using a Bluetooth connection.

The HTC Focus presents 6DoF, meaning that users can walk around in the VR environment within the boundaries of virtual walls. The Focus uses similar controller technology for interaction, but it uses a direct wireless connection to the device instead of phone application control.

I should mention that these devices become useless without a good quality Internet connection and that the majority of available applications require the user to pay additional money. In my opinion, the HTC is a bit heavier than the Oculus and harder to use for a long time. Additionally, Oculus released the Oculus Quest, which has 6DoF, in May 2019. The ergonomic and easy to use Oculus Quest has become a strong candidate.

Table 2-3. The best known stand-alone VR HMDs

Stand-alone HMD	Resolution (per eye)	Display	DoF	FoV	Refresh	OS	Inputs	Price	Release Date	Website
Oculus Quest	1440 x 1600	OLED	6DoF	95-100	72 Hz	Android	3D sound & Controllers (6DoF)	$399	April 2019	https://www.oculus.com/quest/?locale=en_US
Oculus Go	1280 x 1440	LCD	3DoF	100	60-72 Hz	Android	Built-in & controllers	$299	2018	https://www.oculus.com/go/
HTC Vive Focus	1440 x 1600	OLED	6DoF	110	75 Hz	Android	Built-in & controller (3DoF)	$735	2018	https://www.vive.com/cn/product/vive-focus-en/
Vive Focus Plus	1440 x 1600	OLED	6DoF	110	75 Hz	Android	Built-in & controllers (6DoF)	$799	2019	https://enterprise.vive.com/au/focus-plus/

Lenovo Mirage (uses DayDream platform)	1280 x 1440	LCD	6DoF	110	75 Hz	DayDream 2.0	Audio Jack w dual microphones & controller (3DoF)	$399	2018	https://www.lenovo.com/au/en/virtual-reality-and-smart-devices/virtual-and-augmented-reality/lenovo-mirage-solo/Mirage-Solo/p/ZZIRZRHVR01
Pico Neo	1440 x 1600	OLED	6DoF	101	90 Hz	Android	Audio Jack w dual microphones & controllers (6DoF)	$749	2018	https://www.pico-interactive.com/neo
Pico Goblin	1280 x 1440	LCD	6DoF	92	70 Hz	Android	Built-in & controller (3DoF)	$269	2017	https://www.pico-interactive.com/goblin

Xiaomi Mi VR	1280 x 1440	LCD	3DoF	103	60-72 Hz	Android	Built-in & controller (3DoF)	$289	2018	-
VIULUX V6	1280 x 1440	LCD	6DoF	110	75 Hz	Android	Audio Jack & touch panel & button	$178	2018	http://en.3dinlife.com/prod_view2.aspx?FId=t3:72:3&Id=85&TypeId=72&IsActiveTarget=True

2.3.1.2 Inputs

The sense of sight is the most effective perception via which to control the awareness and environmental recognition of the human brain. For this reason, the majority of IVR environments use HMDs to give visual outputs. It must be highlighted that visual outputs alone are not adequate to guarantee a high degree of presence and the pleasant surrounding of the perception of users. Total immersion, sensory feedback, and interaction are the essentials of high-quality IVR. VR visual output devices must present high-fidelity displays and scenarios for the VWs experienced to support total immersion.

Also, high-fidelity interaction and sensory feedback require additional or integrated input devices to reinforce the emotional and psychological presence of VR users. These reinforcers of VR experience require different kinds of input device to stimulate users realistically. The typical input devices and types are presented in figure 2-7.

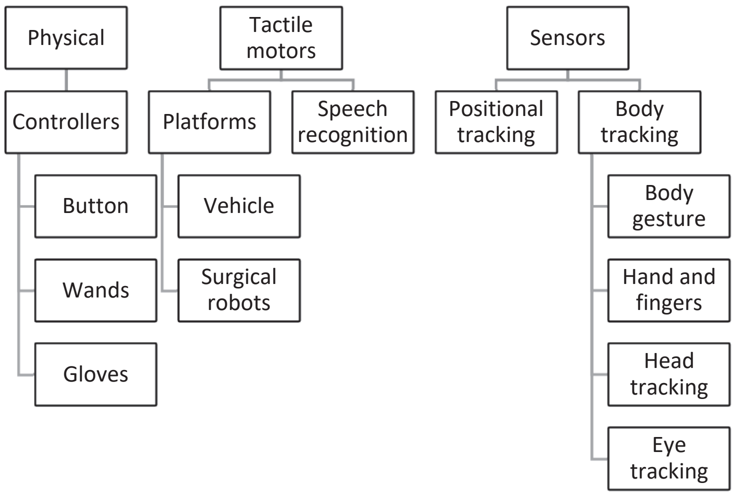


Fig. 2-7. Input devices for VR

Providing sensory feedback after the interaction is a hallmark of the IVR experience and several kinds of input devices can be used to enhance it. This interaction is commonly provided using physical controllers such as buttons, wands, and joysticks. These controllers symbolise the hands of users as virtual hands, and button or touchpad interaction helps to manipulate the VR environment, thereby facilitating scenario fidelity. The majority of the HMDs have their own controllers, which lowers the cost.

VR experience cannot be realistic without sensor technologies; even the most basic VR devices, mobile VR HMDs, use internal or external sensors. If the VR user has a controller to interact with the VR environment, the controller should track hand motion to calibrate interactions at the correct points in the VW.

DoF is directly related to this positional tracking technology for the recognising of movement and the transferring of it to the VW. Positional tracking is provided using different sensor technologies that can include electromagnetic, mechanical, optical, or ultrasonic systems. The working principles of these systems are offered below (Sherman and Craig 2018, Strickland):

- **Electromagnetic tracking**: These systems create electromagnetic fields using small coils to measure the generated magnetic area to determine direction and orientation.
- **Mechanical tracking**: A typical example of mechanical tracking systems is that of the BOOM type that requires a physical hardware connection with the HMD. These systems recognise the position and orientation of users by following their physical arm movements.
- **Optical tracking**: Optical tracking systems mostly use infrared LEDs to generate light pulses that are scanned by the camera to determine the position and orientation.

- **Ultrasonic tracking**: These systems measure sound waves to recognise the position or orientation of VR users.

As mentioned above, both tethered and stand-alone HMDs use gyroscopes, accelerometers, magnetometers, or proximity sensors to support DoF and motion tracking. Thanks to these sensors, the movements of controllers are recognised and transferred synchronously to the VW, providing button interaction. Without such sensors, the VR experience cannot satisfy users.

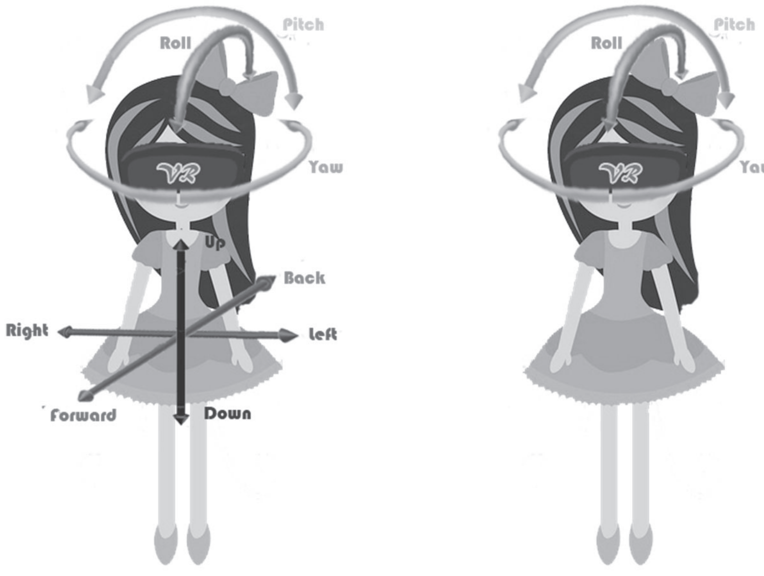


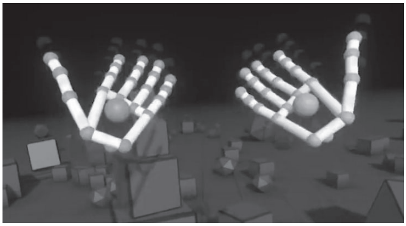
Fig. 2-8. 6DoF vs 3DoF

User movements in the VW are tracked by these technologies, allowing users to walk around or investigate the VR environment after a map localisation process has been carried out.

The other usage of these sensor systems is the tracking of head movements to engender 3DoF or 6DoF. Head orientation is one of the essential factors to increase total presence, and it is related to the FoV. If the FoV is lower than expected, 6DoF will not be effective enough to enable 360-degree vision in the VW. Some of the HMDs employ eye-tracking systems to differentiate tiny movements and to calibrate head and eye motions, though eye-tracking systems are not yet adequate to give good user experiences. VR developers know that head movements are usually coded as gaze functions that use head-tracking instead of eye-tracking.

The complexity and functionality of the integrated sensors in physical controllers are incredible, but, ideally, a high-level IVR experience should be independent of any physical controllers. This independency can be made possible by using sensors. The body or particular parts of the body are recognised via depth cameras and sensors thanks to SLAM algorithms and spatial scanning. Users' physical motions are recognised and transferred to the VW to provide interaction. Image and motion recognition systems have not yet been perfected for the reflecting of sensitive movements, but this can be actualised with additional hardware components such as optical tracking cameras or controllers. Leap motion and Fingo are the most popular optical tracking systems for the recognition of hand and finger gestures with high sensitivity and low latency. These systems require little camera integration, and they can be merged with HMDs or directly integrated with the physical implementation fields following users' locations. These systems can be integrated since they have software development kits (SDKs) to support compatibility with other hardware components.

Leap Motion



Leap Motion output

Kinect output

Kinect

Fig. 2-9. Hand and body tracking devices and outputs

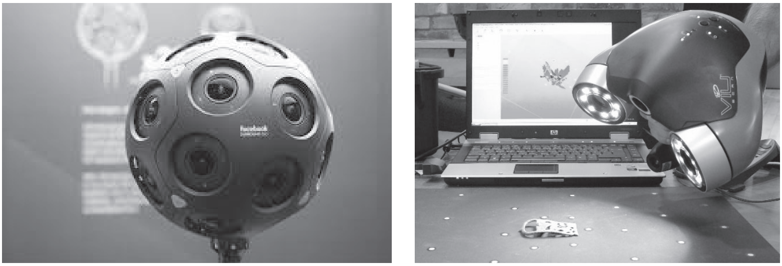
MS Kinect and Optitrack are the most popular body tracking devices, and they use similar optical tracking sensors to scan users' physical bodies for the creation of virtual reflections all at once.

Fig. 2-10. Haptic glove integration with HMD

Intuitively controlling the VR environment is possible via these technologies (Kinect, Santa Cruz, Leap Motion, and more), and this provokes another instinct in us: touching. Haptic feedback is a necessity with fatal implications for several skill-based applications such as surgery simulations. The integration of tactile motors into the gloves can be the optimum way to make such applications a reality with today's technologies. Wearable glove technologies (e.g. SensorYX VRFree, Hi5 VR Glove) usually use IMU sensors (e.g. accelerometer, magnetometer, gyroscope), flex sensors (e.g. Manus VR, Capto Glove), or other mechanical or nanotechnology products. However, the sense of touch includes several parameters for interacting with virtual objects, such as heat, density, and texture. There are also the users' interaction angle, speed, method, and other unique variables to consider. Nano textile products offer a solution to increase the flexibility and portability of glove technologies in the following years. The increasing of immersion and perceptions of surrounded-ness is possible, but there is a whole lot more work to be done.

Among other VR devices, 360° panoramic video is the current shining star of VR applications. Producing panoramic videos requires a 360° camera to make the recording and appropriate video editing software to render it. There are various 360° cameras for every budget, and the most popular ones are GoPro, Insta360, and iZugar. The main factor in choosing a 360° camera is whether one wants to make videos or take pictures. Video recordings require professional devices for higher fidelity imagery and stereoscopy.

After recording 360° videos or pictures, users can combine the pieces of the image and then share them on streaming platforms like YouTube.



360° camera Laser scanner

Fig. 2-11. Other devices

Laser scanners (e.g. Leica, Faro) are becoming more common in handling the difficulties of modelling 3D objects and VR environments realistically. These products scan the real world in 3D and transfer the scanned data as a 3D model using software components. Thanks to this technology, the environment or particular objects in the structured space can be modelled without much effort, but the rendering process is highly time-consuming.

2.3.2 Software

There are various kinds of software for developing incredible IVR applications, going from beginner to advanced levels. The tool selection is highly significant, and it varies by the functionality and concept of the particular VR application.

Novice developers can find free tools and thousands of tutorials to develop their unique VR environment without needing to do any coding. Some of these free tools are suitable for every level of developer, and their usability is increasing day by day, augmenting the diversity of VR applications out there.

The VR environment consists of (1) 3D virtual objects, (2) the 3D environment (merging of the 3D objects), and (3) interactivity. Developers can either use pre-prepared 3D objects, and assets or they can model their own objects using 3D modelling tools. These models are combined in game engines, and interactivity is added by writing code. The enhanced usability of game engines or alternative solutions like blog programming (creating relationships via drag and drop tools) offers an opportunity to develop VR environments without coding. The arduous and multi-disciplinary development process of VR applications has incentivised developers to work more with 360° panoramic VR environments. These environments can be created by recording 360° videos, combining and editing these videos with video production tools, and adding interactivity (pop-ups, buttons, markers, or audio).

Each of the VR application development tool has a particular structure and many functionalities. It would be too time-consuming to learn every detail, so I suggest learning the general structure and mechanisms of these tools. Then, you can focus on the particular functionalities required to develop an application. Developers should examine which features are commonly used to find out what they like and do not like about these tools (Sherman and Craig 2018). Being familiar with these platforms requires a self-learning process that can be aided by the tutorials that some companies and developers make for specific examples. In the following section, some of the most popular and easy to use tools are explained. Not many details are provided since a whole book could be written for each one of them.

2.3.2.1 Game Engines

The production goal of game engines is not only the developing of VR environments but also the developing of 2D or 3D games for computers or mobile platforms, video production, animation, simulation, 3D modelling, AR application development, and other things. Game engines present an opportunity to develop different kinds of applications for users.

The increased desire for VR applications has caused the most prominent game engine companies to produce VR plugins for all levels of players. This competition enhances the variety of tools –

with or without coding – and the functionalities have started to increase day by day. The two major game engine companies are Unity and Unreal Engine.

Unity: Unity is a free game engine platform that also offers a professional edition (commercial) for advanced developers. The power of Unity comes from its easy to use interface, primary structure, free usage, large-scale assets, tutorials, and high-quality visual output. Unity presents compatible functions for the majority of VR hardware, and hence companies are releasing SDKs for integration with Unity. Unity supports many OSs (Windows, Android, and Linux) for VR projects and enabling XR (Extended Reality) function of Unity is enough for someone to create their own VR application. C# and JavaScript knowledge offers advanced developers the chance to develop large-scale VR projects.

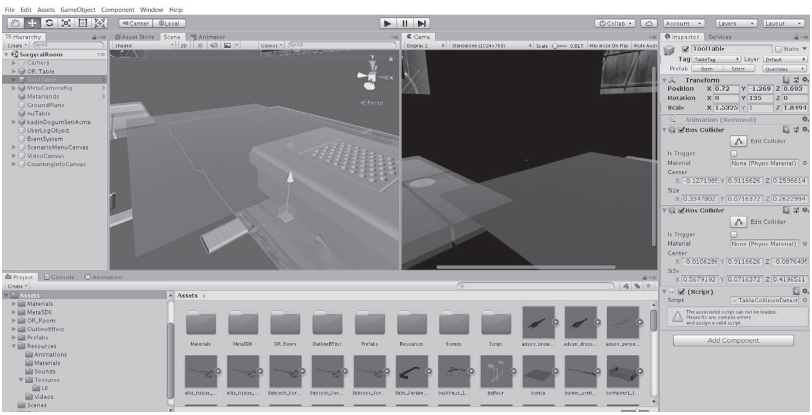


Fig. 2-12. Unity interface

Unreal Engine: Unreal engine is the main competitor of Unity, and you can easily find several comparisons for these two game engines, which emphasise the strength of Unreal Engine concerning visual fidelity. Right along with the cost-free download, the variety of free assets, and the compatibility of its hardware, the functionalities of Unreal Engine are amazingly extensive, including 2D/3D modelling, blueprints, realistic photo rendering, 360° video production, cinematic applications, animation toolset, VR editor, simulation, audio engine, content browser, and more. The interface and usability of Unreal Engine are more suitable for advanced users, but there are still several tools for novice users. One of the fantastic features of the Unreal Engine for VR development is its providing of multi-user VR environment development. This function offers a collaborative VR development process wherein users can work on the same project at the same time. Unreal Engine presents an opportunity to develop 3D virtual objects in the VR environment. In other words, developers can model their 3D objects while using HMDs and controllers and then enhance their setting by writing C++ code.

Fig. 2-13. Unreal Engine interface

Unity and Unreal Engine are the two most significant game engines in getting game and VR development to take off.

Additionally, CryEngine and Lumberyard are two other companies to mention. CryEngine is an open-source game engine and provides a programming repository for expert developers. It has a similar interface to that of Unity, but it is a bit restrictive for VR application development. Lumberyard is constructed on CryEngine, and it is structured by Amazon to be an entirely free and easy to use platform for VR developers.

These desktop-based game engines are the main ones being used for VR development, and they require a bit of coding knowledge to achieve the spectacular results that they promise. There are other tools to create VR applications that do not require coding, but they work best for the creation of 360° panoramic video rather than complex IVR projects.

Some web-based platforms (e.g. Three.js, A-frame, ReactVR, Vizor.io, JanusVR) present HTML5, WebGL, or WebVR APIs for free usage. Browsers render the outputs of these platforms, and they do not have perfect compatibility yet. Other tools that do not require any programming are:

IrisVR: With the drag and drop user interface of IrisVR, one can create 3D VR environments for architecture and engineering projects on Windows and Mac platforms. It supports many 3D visual object file formats (fbx, obj, 3dx, ifc) to allow integration and collaboration. It supports the majority of VR hardware, but it is not free.

Modbox: Modbox presents a free open source SDK to create a sandbox for VR, and it is compatible with HTC Vive and Oculus Rift.

2.3.2.2 3D modelling tools

3D modelling from scratch is similar to what an artist does to create a sculpture. Designers should start by choosing a main solid shape that they then reshape and transform to make the object they have in mind. It is possible to design 3D models using game engines, but 3D design software is preferred to reach optimum results.

There are limitless opportunities for novice to advanced designers for modelling the main components of a VW as a set of virtual objects. The most popular 3D software for professional designers is hard to use and learn; however, the results are amazingly realistic, and the high amount of detail can facilitate a high degree of visual fidelity. Some of this software is described below:

3ds Max: 3ds Max is a piece of AutoDesk software for modelling and rendering 3D objects and animations. While users must pay to use 3ds Max, it has several free assets, textures, effects, filters, lighting effects, and necessary tools for designing. There are even VR integration tools. 3ds Max is not the only VR design software of AutoDesk; Fusion 360 has spectacular results and is another easy to use application for users.

Maya: Maya is another 3D modelling, animation, simulation, and rendering product of AutoDesk that offers realistic and interactive designs. Maya is suitable for VR, character design, and motion graphics, but it has a highly complex interface and design; hence, it is proper only for professional usage.

Blender: Blender is the rising star of 3D modelling brands thanks to the cross-platform support and open-source free usage strategy. It also has support for the 3D pipeline, animation, simulation, rendering, and motion-tracking video editing. It includes a built-in game engine, but it is more appropriate for 3D modelling.

SketchUp: Google's product SketchUp is appropriate for novice designers who want to learn the fundamentals of 3D designing. The 30-day trial version and limited free personal license are suitable to begin learning 3D modelling. It can be used on a browser with supporting Cloud space of up to 10 GB.

The alternative way to do 3D modelling is to work within the 3D environment directly to make the process much faster. The leading companies working with VR have released new applications of this kind that allow designing with controllers during the VR experience.

Tilt Brush: One of Google's low-cost products, Tilt Brush, gives a 3D painting experience in the VR environment for 3D modelling. It can be used with HTC Vive, Oculus Rift, Windows MR, and Daydream HMDs.

Oculus Medium: Oculus Rift users can model, sculpt, paint, or edit 3D objects via Oculus Medium, which is an easy to use and low-cost application that includes hundreds of models in several professional fields.

Facebook Quill: Free and high-resolution animations or models can be designed and reused in Quill. The tools and interface have a layer structure like Photoshop and are easy to use.

PaintLab: PaintLab is a free 3D graffiti tool for HTC Vive users.

Gravity Sketch: Gravity Sketch is a low-cost 3D modelling tool compatible with HTC Vive, Oculus Rift, and Windows MR headsets.

2.3.2.3 360° Video editing

Interactive 360° panoramic video is the most popular VR application form because of the easy content creation, sharing, and accessibility. Unity (Skybox Panorama Shader) and Unreal Engine have their plugins to create free 360° videos without any coding. Besides, some of the video editing tools support 360° video production, and several web-based authoring tools have been released for end-users.

Adobe Premiere and After Effects: Impressive compatibility file format, easy to use interface, collaborative usage opportunity, and video editing are possible with these paid Abode products.

Mocha VR: This is high cost professional 360° video editing software that includes exclusive functionalities for immersive production. Mocha provides an easy to use interface and Windows and Mac OS compatibility. It can be used as stand-alone software or as a plugin for Adobe Premiere and After Effects.

Skybox 360: It is suitable for commercial use to produce high quality 360° videos. This easy-to-use tool also works as a plugin in Adobe Premiere.

Vizor: Vizor is a web-based 360° video editing WebVR platform to create interactive VR experiences. It supports 3D objects and audio integration into the immersive experience.

Veer: Veer Editor is a free 360° video editor without coding. Android- and iOS-supported interactive 360° videos can be created using hotspots or labels, and there is audio and button integration.

InstaVR: InstaVR is a web-based tool that requires payment to be able to use all the applications. The majority of its hardware supports the creation of 360° videos, panoramas, and the adding of 3D objects and interactivity to create high-quality outputs. This drag and drop platform does not require coding knowledge.

2.4 Benefits

VR systems can engender safe environments due to the monitoring (2D to 3D), controlling, and observing of tangible or intangible situations from different perspectives (Alqahtani, Daghestani, and Ibrahim 2017, Aguinas, Henle, and Beaty Jr 2001). Ideas and imagined scenarios can be tested in real time in these 3D environments. The presence of IVR allows users to regulate their psychological status in a particular situation (Alqahtani, Daghestani, and Ibrahim 2017).

VR systems offer individual and collaborative LEs (learning environments) according to the type of learning presented, such as experiential, discovery, heuristic, or inquiry. VRLEs (virtual reality learning environments) enhance distance learning without location dependency (Alqahtani, Daghestani, and Ibrahim 2017). VR increases the motivation and engagement of learners and offers active participation in designing constructivist LEs (Martín-

Gutiérrez et al. 2017, Hussein and Nätterdal 2015). Training with VR provides a level of realism and flexibility and reduces costs when compared to real-world exercises (Bowman and McMahan 2007).

Table 2-4. Advantages of VR

Advantage	Practitioner
Supporting the comprehension process by assisting with communication, decision making, and evaluating the scenario	Ramasundaram et al. (2005)
Logging and re-observing the data	Ramasundaram et al. (2005), Rose (1995), Mills and Noyes (1999b)
Breaking the barriers of individual differences	Mills and Noyes (1999b)
A safe environment to experience	Mills and Noyes (1999b)
Supporting imagination	Mills and Noyes (1999b)
Presenting scientific methods to analyse data	Ramasundaram et al. (2005)
Providing constructive evaluation	Rose (1995)
Providing experiential learning	Mills and Noyes (1999b)

According to Bowman and McMahan (2007), the main characteristic of successful VR environments is a high level of sensory fidelity, which is provided via visual, aural, and other types of stimulus in order to affect users' perceptions in a way that is proper to the functioning of the human brain.

2.5 Disadvantages

The major disadvantage of current IVR systems is the high-cost hardware requirement (Alqahtani, Daghestani, and Ibrahim 2017, Gartner 2018) that subsequently leads to accessibility issues. Low-cost HMDs can solve this problem, but the components of these HMDs pose various side effects such as (Mills and Noyes 1999b, Aguinas, Henle, and Beaty Jr 2001, Moro et al. 2017):

- **Sight**: Eye fatigue, headache, vertigo, blurred vision, double vision, difficulty focusing
- **Audio**: Hearing loss
- **Iterative movements**: Tenosynovitis, disorientation, balance disturbance
- **Phobias**: Claustrophobia, anxiety
- **Others**: Dizziness, drowsiness, loss of appetite, nausea, vomiting

2.6 Examples of VR applications

2.6.1 VR in Education

Individuals need expanded sense perception to learn autonomously and naturally. VR technologies have enormous and unique capabilities as teaching and learning tools (Chen 2006a, Rose 1995, Jen 2007) due to the development of low-cost computer graphics technology (Chuah, Chen, and Teh 2011). From design and manufacturing points of view, VR reduces learning time and decreases costs (Osuagwu, Ihedigbo, and Ndigwe 2015). VR provides dynamic experiences to users whose instructional outcomes can be influenced positively (Goodwin, Wiltshire, and Fiore 2015). According to Dalgarno and Lee (2010), the increased (1) immersion, (2) fidelity, and (3) active learner participation are the main components of these systems that affect learning.

Learners cannot always explore and experience events due to factors like distance, time, cost, and safety (Jen 2007). The educational benefits offered by VR technologies are that they enable learners to visualise abstract concepts, illustrate phenomena to aid understanding of their meanings, visualise the dynamic relationships between variables in systems, and present multiple viewpoints to users.

Fig. 2-14. VR in a classroom

VR users can look up, move around, and interact with VWs as if they were real. For this reason, the primary concept behind VR of illusion (Osuagwu, Ihedigbo, and Ndigwe 2015) might be used to activate the psychomotor skills of learners according to a designed discovery experience in a LE.

VR systems are used for learning and teaching in several fields, such as history, geography, biology, medicine, and vehicle driving. They are used for K-12-level children, teenagers, and adults.

The majority of VR studies in education are focused on the emotional and cognitive abilities of learners (Chuah, Chen, and Teh 2011), which are highly correlated with each other and can be affected by the interface design (Chuah, Chen, and Teh 2011, Osuagwu, Ihedigbo, and Ndigwe 2015). The learning success of VRLEs is related to the constructed information available as well as personally observing the results of learning activities (Hanson and Shelton 2008a).

Fig. 2-15. IVR example using tethered HMD, sensor, robotics

The visions of instructional designers have a significant role in the designing and developing of useful VR applications supporting the cognitive and behavioural development of learners. Instructional design for VR is falling well short because of the lack of experts in this field (Taçgın and Arslan 2016). Lack of expertise is not a mere deficiency of human resources: there are no specific models or methods by which to design VEs, either (Mills and Noyes 1999b, Goodwin, Wiltshire, and Fiore 2015, Rose 1995, Appelman 2005, Jen 2007, Hanson and Shelton 2008a, Ramasundaram et al. 2005). For this reason, each VRLE has its unique design and development process that is shaped by the nature of the material. These detailed educational VR applications and material development processes are explained in chapter 4.

2.6.2 VR in Medicine

Technology has been increasing in the medical field and VR technologies have become a requirement for several health areas (Ikeda et al. 2013, Sato et al. 2014, Wolfram et al. 2014, Hagiwara et al. 2014, Edwards et al. 2014). A diverse range of VR systems has been developed to facilitate learning and evaluation processes within fields (Scalese, Obeso, and Issenberg 2008, Spanager et al. 2013) including computational neuroscience, molecular modelling, the treating of phobias, and ultrasound echography (Alqahtani, Daghestani, and Ibrahim 2017).

Becoming a master surgeon or another highly skilled medical practitioner can be cumbersome for beginners, even if their training is based on VR (Andersen, Mikkelsen, et al. 2016). VR-based learning can be beneficial, especially for intermediate learners, as it provides an experiential, repetitive practice environment. After doctors learn to use VR systems, the complications of surgical operations can be reduced (Halarnkar et al. 2012). VR can also be beneficial for the optimising of the cognitive load of learners during training for complex surgical procedures (Andersen, Mikkelsen, et al. 2016).

Fig. 2-16. An example of VR for medical education

Reviewing the literature, there have been numerous well-executed VR studies concerning medical training. For instance, there is the video-based learning material developed by Hayden, Seagull, and Reddy (2015) to teach lung cancer surgery, and a video-based simulation emerged to increase the practical application skills of doctors (Spanager et al. 2013). Surgeons have the possibility of seeing and manipulating a virtual body before proceeding to the real thing, thus ensuring safer operations (Halarnkar et al. 2012).

VR systems are used for 3D scanning, visualisation, and orientation during the diagnosis process. VATS (video-assisted thoracoscopic surgery) scanning has reduced the complications of operations (Ikeda et al. 2013, Sato et al. 2014, Wolfram et al. 2014, Hagiwara et al. 2014). The logging aspect of VR systems presents databases in which patient information can be compared, potentially reducing diagnosis time (Puri et al. 2012). Another study indicated that failures of preoperative processes were reduced by 75% using the simulation control list (Watkins 2013). Solomon et al. (2011) developed a 3D computer-based non-immersive VR to teach surgical skills, spatial relations, anatomic approaches, and cognitive knowledge.

The improvement of psychomotor skills cannot be totally provided through computer-based non-immersive VR. Skill training requires hands-on activities, and non-IVR environments have an essential restriction on achieving the desired learning affordances. The experiential study of Jensen et al. (2014), executed using VR and a dummy body for four weeks, showed no significant differences between experimental and control groups. The reason for these results could be that the VR technology did not consider the kinaesthetic skills of learners. The success and expertise of medical learners depend on both psychomotor skills and cognitive knowledge (Kahol, Vankipuram, and Smith 2009). The essential point is to develop cheaper and reusable VRLEs that consider 3D visualisation, the individual practice environment, and haptic feedback (Solomon et al. 2011).

Fig. 2-17. VR for diagnosis

IVR has also been used to reduce the anxiety of patients in the hospital. The results of one study (Burdea 2003) showed the effectiveness of a VR rehabilitation process for fear of flying, Vietnam syndrome, fear of heights, and chronic stroke patients. VR therapy offers a less expensive, time-consuming, risky, and embarrassing (Bowman and McMahan 2007, Chen et al. 2009) treatment environment.

VR can help to reduce the feeling of pain of users by as much as 40% (Tashjian et al. 2017). Connelly et al. (2010) combined IVR and pneumatic glove technologies to rehabilitate the hand motions of post-stroke patients. The experiential study results indicated the effectiveness of their PneuGlove for the hand or wrist portion for executing box and block and also pinch movements.

VR helps to increase relaxation (Taçgın 2017a) of novice medical employees as well (Plante et al. 2006). VR enhances enjoyment and energy and reduces tiredness, psychological benefits that can be paired with related exercises (Plante et al. 2003).

2.6.3 VR in the Military

The first VR systems were developed for pilot training in the military, and VR is still being used today for the same purpose. HMD-supported VR systems are used for driving training for vehicles like aeroplanes (including jets), ships, and tanks (Aguinas, Henle, and Beaty Jr 2001).

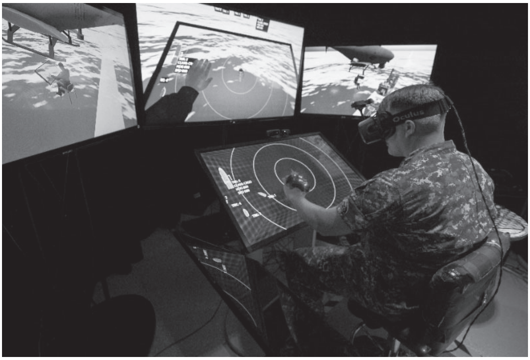


Fig. 2-18. VR being used for military vehicle training

The reasons for the increasing interest of the military in VR are cost and safety issues. Battlefield visualisation not only improves army systems but also helps in determining combat strategies (Lele 2013). Vehicle-based combat simulations have been used by the military for many years to increase personnel skills in realistic conditions (e.g. AVCATT-A). VR systems (HMDs) are used to train soldiers or police officers as they shoot guns or manage critical cases at the right moment. Battlefield simulations are used to evaluate alternative strategies and support moral decision-making. These VR systems help in assessing and reshaping significant tactics by taking in data about the battlefield via visual systems (ter Haar 2005).

Fig. 2-19. VR for military training

Other research has used 3D VR to train soldiers in live firing as a cost-effective learning tool. The results of studies have indicated better learning motivation and learning outcomes, and positive impacts on users' actual live firing achievement scores (Bhagat, Liou, and Chang 2016). The military also uses VR for stress management (Pallavicini et al. 2015) and for the treatment of posttraumatic stress disorder of soldiers after conflict (Rizzo et al. 2015), which can also be considered a kind of medical therapy.

2.6.4 VR in Engineering

Engineering work depends on various kinds of drawings, perspective projections, and prototypes of 3D designs. VR systems in the form of software that is specialised for the needs of different subfields are used significantly in engineering to save money and to examine and test prototypes (Alqahtani, Daghestani, and Ibrahim 2017, Cecil and Kanchanapiboon 2007). Several high-fidelity engineering design applications can create realistic virtual prototypes, such as Autodesk Showcase.

In this field, VR systems are usually used before the design process to see how things will fit together (Aguinas, Henle, and Beaty Jr 2001). Virtual prototyping increases the flexibility of design components, textures, and materials. The actual behaviour of objects can be observed in real time via their virtual presentation, clarifying the structure of both dynamic and complex systems (Sastry and Boyd 1998).

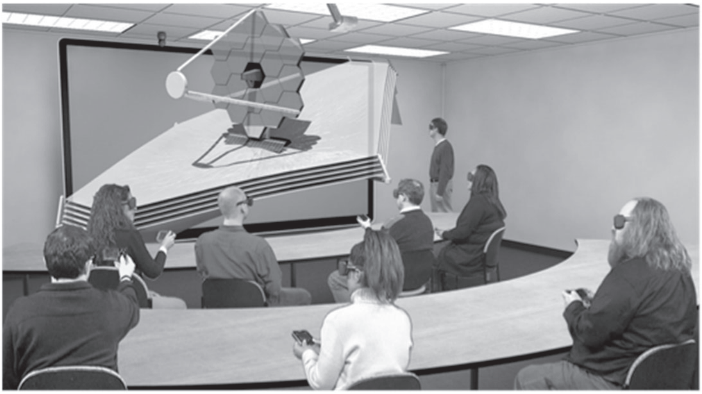


Fig. 2-20. VR in an engineering class

VR also plays a role in engineering education to improve the construction and design abilities of students (Messner et al. 2003). It increases motivation, illustrates features and processes, and allows the examination of systems or environments from different perspectives (Pantelidis 1997). Learners can be prepared for real problems, and their autonomous problem-solving and creativity skills increase. They are confronted with varied engineering problems, and they gain knowledge in business fields (Abulrub, Attridge, and Williams 2011).

2.6.5 VR in Architecture

VR has become one of the essential tools for the architecture and construction industries, thanks to providing more accessible and cheaper prototype design and environment discovering processes. There is specific software for designing indoor or outdoor components of buildings, and the modular structure of these software systems offers the opportunity to redesign a prototype before actual construction, saving companies both money and effort (Halarnkar et al. 2012).

Fig. 2-21. VR office design

Architects can arrange furnishing, lighting, and home design before the production process (Aguinas, Henle, and Beaty Jr 2001). Research results also indicate that building requirements could be reduced by telecommunication capability and real-time 3D prototype design (El Araby 2002).

2.6.6 VR in Entertainment

Like the majority of popular technologies, VR has gained incredible extension as it has been employed in entertainment. In particular, the gaming industry has integrated VR technologies (HMDs, wands, sensors) into devices such as the PlayStation, Nintendo, and Xbox to provide immersive 3D game experiences to their users. Kinect integration of game consoles presents active participation for VR games, and sensor-based moving wands and joysticks have reinforced the gaming experience.

Fig. 2-22. VR game in PlayStation

Besides the gaming industry, companies like airlines, shopping malls, maintenance companies, and textile producers have started to use VR systems to increase their potential customers and the quality of the products they offer. VR museums are even being developed within the tourism and education sectors so that historical and current events can be experienced authentically.

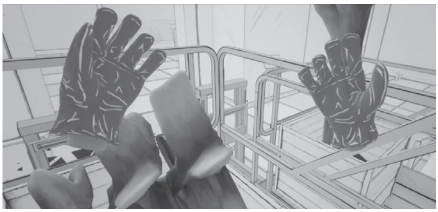



Fig. 2-23. Art and museum examples

What is more, De la Peña et al. (2010) offered an idea of immersive journalism that aimed to reflect the experiences of stories to the readers from the first-person perspective. Supporting presence helps readers to understand real circumstances and increases awareness concerning news, places, and events.

2.7 Summary of Chapter 2

- Terminologically, VR environments have main two categories: (1) immersive and (2) non-immersive.
- VR has to be immersive to surround the perceptions of users like a cocoon. This phenomenon explains the term 'presence', which is related to the perceiving and feeling of a VE as real.
- High fidelity, presence, and interaction are the three essential components of the IVR. These components can be provided in different dimensions, and they all serve the total psychological presence.
- IVR includes VW and virtual objects that use both hardware and software components.

- HMDs are used as hardware outputs by IVR. HMDs can be tethered, mobile-phone integrated, or stand-alone. Each type of HMD has its particular advantages and disadvantages. The interaction needed for IVR is provided by inputs such as joysticks, controllers, or gloves.
- IVR environments are usually developed using game engines and 3D modelling software, and there are basic development environments for novice developers.
- IVR has several advantages whenever tangible content needs to be presented in a low-risk environment, and it can provide experiences for both individual and collaborative users.
- IVR can cause cybersickness because of latency and resolution issues of HMDs.
- IVR environments have large-scale usage in education, medicine, the military, engineering, architecture, entertainment, and other fields.

CHAPTER THREE

WHAT IS AR?

AR (augmented reality) is another term under the MR umbrella that combines physical and virtual components in the physical environment. AR has a larger scale of usage than VR thanks to its compatibility with mobile technologies. Mobile technologies are not the only hardware components to provide AR as it can also be experienced using HMDs and projection displays. AR presents computer-generated digital content for users in a way similar to VR.

It has to be highlighted that both AR and AV (augmented virtuality) include physical and virtual components under Milgram's Virtuality Continuum, and today's terminology usually collapses both of these terms into the concept of AR. It is hard to say this assumption is correct because of the different natures of the environment encompassed. AR enhances the physical environment and is constructed on top of reality rather than consisting of purely virtual scenes (Azuma et al. 2001). If the surrounding environment is virtual and the artificial environment enhances this with physical objects, that is known as AV.

According to its practitioners, the necessity of achieving more comfortable and more affordable living standards makes the integration of AR into our lives inevitable. AR constitutes an enhanced physical world using virtual components to provide additional digital knowledge and functionalities to users. AR would present the most relevant digital content at the appropriate time and physical place. The content could be added onto the physical environment, and AR allows the modification of existing objects in a way that makes them indistinguishable from an authentic object for users (Orlosky, Kiyokawa, and Takemura 2017, Carmigniani et al. 2011). Thanks to the task-oriented structure of AR, users become able to interact with and manipulate visual or physical components and observe the consequences of their interaction at the same time. AR users can participate physically in applications from a particular location and definitely be there. The proximity between the physical and virtual environment has significance for AR (Sherman and Craig 2018).

AR visually enhances the physical environment using virtual components. AR devices should be able to scan or/and recognise the physical world to arrange virtual and physical components in harmony with it. AR users should never lose their sense of presence through the proximity of physical reality (Ma and Choi 2007).

Providing active participation at the current moment and accurate location is the most robust feature of AR, allowing it to activate all five senses through basic or complex display systems. The other reason to use AR is that it is generally thought to have a more straightforward content development process as compared to that for VR, as with AR, developers do not have an obligation to design and develop a wholly virtual environment. Designing additional virtual components and embedding them into the physical world can be enough to create AR applications.

3.1 Definitions

The term 'augment' is defined as 'to make something greater by adding to it' by the *Oxford Dictionary*. Making greater can be interpreted as to enlarge, to extend, or to increase the features of physical components. AR uses digital components to enhance physical reality. AR represents an extended reality using various kinds of digital components in the domains of hearing, sight, touch, and smell to enhance individuals' perception. Observing the results of an enhanced physical environment requires someone to be there at the precise moment in time. Bringing all these requirements together, Azuma defined the three main components of AR (Azuma 1997, Azuma et al. 2001) as (1) the combining of the real and the virtual, (2) real-time interactivity, and (3) the alignment of both real and virtual objects with each other.

Conducive to these general characteristics of AR, some of the existing AR definitions are:

> AR is a technology that overlays computer-generated information onto the real world. Our environment is 'augmented' so that the user can perform the task at hand with less effort. (Orlosky, Kiyokawa, and Takemura 2017)

> In AR, the environment is real but extended with information and imagery from the system. (Lee 2012)

3.1.1 Terminology associated with AR

Inside-out tracking (Bimber and Raskar 2005, Furht 2011): Inside out tracking systems refer to integrating sensors on moving targets. These systems can be used either indoors or outdoors and in mobile or fixed applications.

Outside-in tracking (Bimber and Raskar 2005, Furht 2011): This tracking is provided using fixed sensors within the environment to track moving targets. Outside-in systems are more appropriate for fixed AR systems.

Marker-based: Marker-based AR systems require a printout of fiducial markers that should be recognised by cameras to present digital content.

Markerless-based: These systems usually include mechanical or optic tracking systems such as GPS or image recognition because they do not require artificial markers. They function well in either mobile indoor or outdoor environments.

3.2 Types of AR

Differentiating the types of AR is hard because of the sophisticated technological components and structures used. The literature classifies AR types according to the technology employed, interaction type, and the recognition features provided. These classifications are systematically combined for greater clarity in figure 3-1.

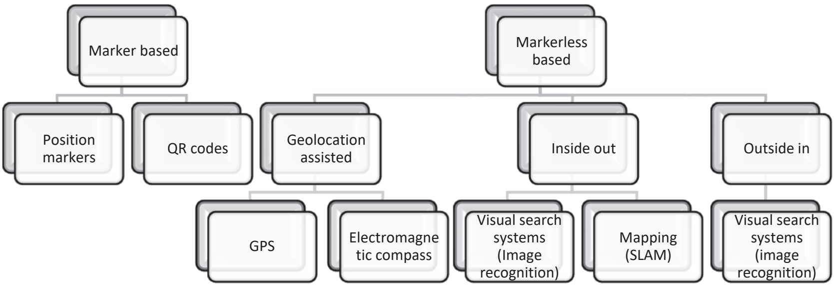


Fig. 3-1. Types of AR, adapted from Patkar, Singh, and Birje (2013), Katiyar, Kalra, and Garg (2015), Johnson et al. (2010), Cabero Almenara and Barroso (2016), Furht (2011), Bimber and Raskar (2005), Yuen, Yaoyuneyong, and Johnson (2011)

There is no consensus about the categories, classifications, or types of AR systems, but it can be said as a general rule that we see them mainly being classified as marker-based or markerless-based. Some of the resources separate the geolocation-assisted systems as another AR type; they can be considered a subtype of markerless-based.

3.2.1 Marker-based AR

Marker-based AR systems require physical (or rarely, virtual) printed-out fiducial markers or visuals to trigger digital output and present the related virtual content of the marker. The digital output can be a 2D or 3D image, video, animation, or sound signal that is associated with the marker after scanning it with a camera. The basic working principles of marker-based systems require three main components: (1) a printed marker or visual information, (2) a gripper for calling up digital content (e.g. camera), and (3) augmented digital content that displays on a screen (Lee 2012).

Fig. 3-2. Marker-based AR

Position markers for marker-based AR use a camera and visual markers, which determine the centre, orientation, and range according to the spherical coordinate system (Patkar, Singh, and Birje 2013, Katiyar, Kalra, and Garg 2015, Yuen, Yaoyuneyong, and Johnson 2011). The virtual output is orientated at the centre of the marker and users can observe the 3D digital output from different perspectives by reorienting or rotating the physical marker. The first stage in creating a position marker-based AR is to make the system recognise the physical object. Then, a virtual layer is added onto this physical object (marker) to connect the digital output and the marker. The digital output is represented on the virtual layer. Finally, the selected digital content is embedded in the virtual layer to create the completed application. After merging and defining all of these objects in the AR system, scanning the marker with a camera activates the virtual layer, which can be viewed on mobile or fixed display systems.

Marker-based tracking offers a low-cost option thanks to the conventional cameras that it uses (Bimber and Raskar 2005), and for this reason, it is the most common type of AR system. The easy content development process of marker-based AR basically recognises the particular 2D printout and projects the augmented content onto its outline. These systems are suitable for novice developers and have a wide range of users, thanks to the compatibility of mobile technologies. Novice users can easily create these applications without knowing how to code (Cabero Almenara and Barroso 2016).

The working principles of QR-code AR systems are similar, although the digital content is linked to and recalled via the QR code directly. QR-code AR users can reach the digital content even though the content cannot be rendered onto the virtual layer. Hence, rotation and orientation are not required for QR-code AR.

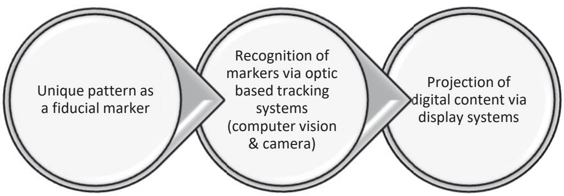


Fig. 3-3. The marker-based AR development process

As a summary, the functionalities and working principles of marker-based AR systems are presented in figure 3-3 (Craig 2013).

3.2.2 Markerless-based AR

Markerless-based AR systems have a more complex structure than marker-based systems, and they have broader applicability due to their fiducial independency (Lee 2012, Craig 2013). These systems usually consist of optical-mechanical, ultrasonic, magnetic, inertial, or GPS tracking systems (Van Krevelen and Poelman 2007) that recognise location, movement, patterns, shapes, or objects. They then project them into the physical world and present the digital content via display systems.

Fig. 3-4. Markerless-based AR example

The mechanical tracking systems used for AR are similar to those of VR systems, using sensors like gyroscopes, accelerometers, or magnetometers that help recognise the movement of the users. These sensors are usually integrated into smartphones or HMDs. 6DoF is ideal for the achieving of better outcomes. Early examples of these mechanical tracking systems were restricted to fixed indoor use because of their bulky component devices. Nowadays, mechanical sensors have become more suitable for mobile devices in the form of inertial sensors. These sensors are usually used as part of hybrid tracking systems (Van Krevelen and Poelman 2007). The accelerometer and magnetometer are not the only embedded sensors of mobile devices to permit AR applications, with GPS systems now having extensive usage for hybrid tracking for AR systems.

GPS systems are usually used by outdoor AR applications that track and transfer the location information of devices at the same time. However, overcast weather can still be a problem for GPS tracking, as it can cause the loss of signal (Azuma et al. 2001).

As mentioned above, current markerless AR systems usually include portable hybrid tracking systems (e.g. optical, mechanical, ultrasonic, GPS) via built-in devices. The goggles and mobile technologies that have been developed make it possible to experience AR applications in indoor or outdoor areas with functional mobility. The hybrid tracking systems of inside and outside systems enhance the effectiveness of the AR experience. These particular AR technologies use sensors for visual searching, recognition, and mapping. For instance, a device may use GPS to track the current location, use a compass to inform of the direction, and read an accelerometer to calculate orientation using gravity (Amin and Govilkar 2015).

Visual search systems mainly use optical sensors with appropriate image recognition algorithms. Visual searches can be executed using (1) model-based tracking or (2) natural feature tracking. Model-based tracking AR uses the edges of 3D objects to detect and compare the particular defined object. These systems need prior information to use as a comparison, although some of them can recognise objects that resemble previous data to a certain extent. The licence plates of cars are a suitable example by which to imagine model-based tracking systems. Some image recognition systems use machine-learning algorithms to help define physical objects. Machine learning algorithms execute this natural feature tracking (Amin and Govilkar 2015); thus, the recognised visuals can be compared with the input of the system's entire database. After the visual search system finds a suitably comparable object in the database, the proper outputs are offered to end-users. For instance, an AR dictionary might provide the `house' shape as an output after scanning specific house visuals, although these systems still cannot recognise unconventional house designs. Today, the developing machine learning-based visual search AR systems can learn different house designs and define similar or familiar visual outputs to present useful comparisons.

The other type of markerless AR system uses SLAM algorithms to localise the users or objects in an unknown environment through simultaneous mapping (Van Rossum et al. 2015). SLAM algorithms can be integrated into natural feature tracking AR systems, and, therefore, can work without predefined trackable points (Andre 2013). SLAM systems create mapping points on the trackable surface to estimate closed geometry using depth prediction and occlusion reasoning. Objects can be recognised at different orientations, distances, and illumination levels (Amin and Govilkar 2015, Salas-Moreno et al. 2014).

Both model-based tracking and natural feature tracking is suitable for inside-out AR systems that make an overview of the physical world and augment it with virtual components.

3.3 Current AR Technologies

AR applications render the digital visual output using different kinds of display systems that consist of embedded processors and tracking systems (Craig 2013). AR display systems not only provide output for users but also support interactivity by using other input technologies. The displays used for AR offer the opportunity for different human sensory inputs such as sight, sound, and touch (Van Krevelen and Poelman 2007).

3.3.1 Hardware

3.3.1.1 Tracking systems for AR

AR systems must track and recognise the physical environment to enhance real objects with digital content, and because of this, sensors are essential components of AR devices. Sensor technologies have extensive usage in various fields of our lives. Sensors did not originate with AR; however, their size and integration in AR have optimised their usage and increased their efficiency within all MR technologies. AR sensors and their functionalities are generally similar to VR sensors but often include extra instruments and preferences.

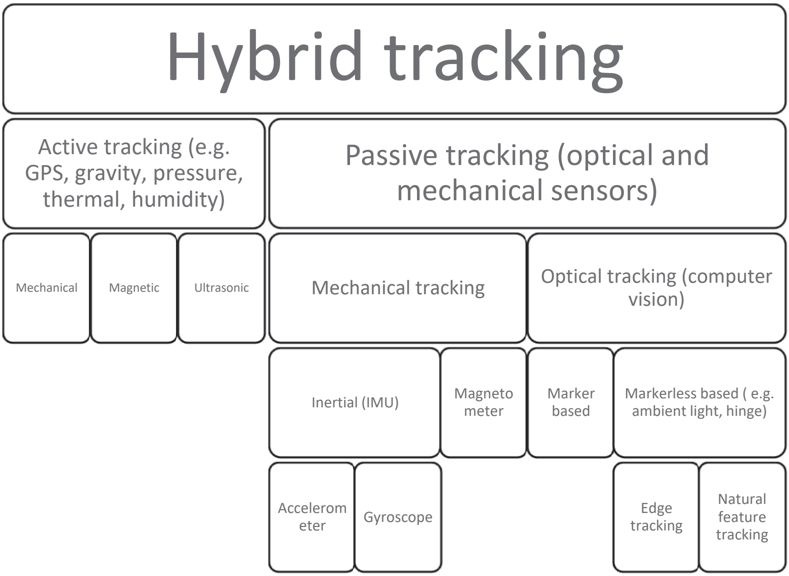


Fig. 3-5. Tracking systems and sensors in AR devices

AR hardware consists of processors, sensors, and displays that work together to enhance perceived reality. Innovative hybrid AR devices include micromechanical, optical, thermal, electric, or magnetic sensors for tracking. Active tracking is used to receive physical information concerning the location, heat, or speed of devices. This tracking enhances the outdoor AR experiences of users.

Embedded mechanical tracking systems provide passive tracking for the gathering of information on the 3DoF or 6DoF movements of users. AR systems represent the digital output via optical tracking systems. After triggering the optical tracking of users, the information is sent through active or passive (hybrid) tracking and then represented in display systems to give a final, digitally enhanced view.

3.3.1.2 AR Displays

AR display systems are the main components to convey the digital visual output to users' eyes after generating content via optical, mechanical, and electronic sensors. AR display systems have three main classifications: (1) head attached displays, (2) handheld displays, and (3) spatial displays.

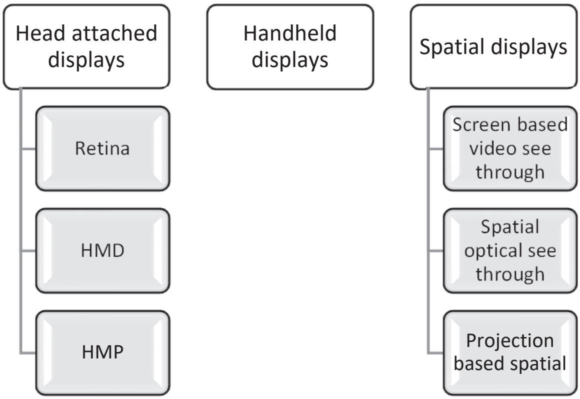


Fig. 3-6. AR display classification, adapted from Bimber and Raskar (2005), Kesim and Ozarslan (2012), Azuma et al. (2001), Carmigniani et al. (2011), Craig (2013)

These classifications depend on the nature of the visual representation of the generated images and how it relates to the users' eyes. The image generation techniques and environments of AR display systems are offered in figure 3-7.

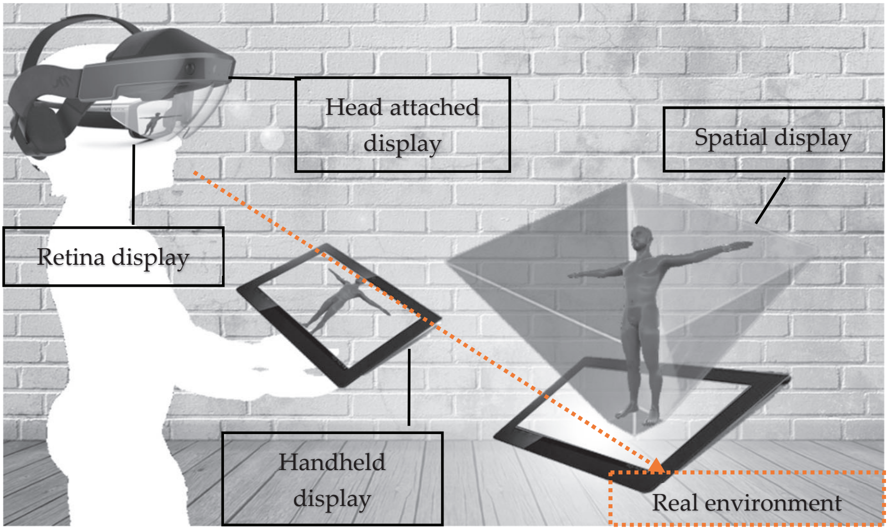


Fig. 3-7. Image generation for AR displays

Both retina displays and HADs offer the best visuals for the users' eyes in proximity and clarity and can be experienced by a single user. Handheld display systems represent 3D models on 2D screens, and single or multiple users can observe the digital output. Single or multiple users can see the represented 3D outputs of spatial displays, like a hologram.

3.3.1.2.1 Head attached displays (HADs)

HADs require users to wear head-mounted goggles to provide augmented digital visual components. The built-in camera and sensors of these displays offer object recognition in the physical world and computational visualisation of both real and virtual content. HADs use two different technologies for visualisation: (1) video see-through and (2) optical see-through technologies.

Video see-through technology consists of a semi-transparent mirror that reflects physical reality to the users' eyes. This kind of goggle records the physical environment at the precise moment the virtual components are to be visualised and transfers them to the semi-transparent mirror as a streaming video. The recorded physical environment is represented after digitalising because the added digital data can make the physical reality perception of users feel unnatural. However, the combination of merged physical and virtual components can still be synchronised for viewing.

Optical see-through uses transparent silver mirrors instead of semi-transparent ones. The physical environment is directly reflected to the users to support more realistic and natural visuals.

The HADs used for AR are of three types, based on the image generation technologies used:

Retina displays: The physical and virtual components are directly reflected onto the retinas of the eyes. Low power lasers are used to assemble the light scanned by micro-electromechanical mirrors. High brightness and low power consumption are the main advantages of retina AR displays. These systems are suitable for mobile outdoor usage thanks to their highly portable structures.

HMDs: These goggles are used in a way similar to VR goggles; however, they include two embedded cameras to scan and reflect the physical environment. These HMDs can be either video see-through or optical see-through. Both of these technologies have their advantages and disadvantages. The primary constraints of these HMDs are discomfort during usage, high expense, and low FoV. Optical see-through HMDs have latency issues when reflecting the physical environment, and the calibration process is often hard to manage. On the other hand, see-through video HMDs struggle to offer high fidelity visuals of the physical environment (Bimber and

Raskar 2005, Kesim and Ozarslan 2012, Azuma et al. 2001, Carmigniani et al. 2011, Craig 2013). These devices are more suitable for indoor usage.

HPV: Technically, HPVs use laser beams like retina displays, but their visual reflection is provided on half-silvered mirrors (Bimber and Raskar 2005).

The most common AR goggles are presented in table 3-1.

As seen in table 3-1, several kinds of HMDs can be used in AR technologies. The AR HMD selection should be suitable for the desired outcomes and functions of a particular application. For instance, cyclists have developed the Solo and Everysight Raptor goggles for sports activities. These products support outdoor usage and consist of embedded ANT sensors that measure heart rate, blood pressure, and body heat. The goggles' embedded GPS sensors and Bluetooth connection to mobile devices follow the user's status in real-time by receiving continuous data such as heart rate and blood pressure.

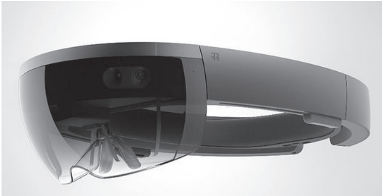
Table 3-1. Types of AR goggles

HMDs	Type	DoF	FoV (degree)	Comfortable	Heavy	Sensors	Spatial mapping	Interaction	Cable	Battery time	Sound	Release Year	Price ($)	Website
Hololens 2	Optical see through	6DoF	43	Yes	579g	IMU Depth & Ambient light	Real time	Natural	Untethered	3	built-in	2019	3500	https://www.microsoft.com/en-us/hololens/hardware
Magic Leap	Optical see through (retina)	6DoF	40	Yes	325g	IMU, Compass, Eye tracking, & Controller tracking	Real time	Natural & Wands	Tethered (belt)	3	Built-in & Plug-in	2018	2295	https://www.magicleap.com/magic-leap-one
Epson Moverio BT 300	Optical see through	3DoF	23	Yes	69g	GPS, Compass, Gyroscope, &	No	Touchpad & Button	Tethered (belt)	6	built-in	2016	999	https://www.epson.com.au/products/ProjectorAc

						Accelerometer								cessories/Moverio_BT-300.asp
Vuzix Blade	Waveguide based see through optics (retina)	3DoF	28	Yes	90g	Motion, IMU, Ambient light, & Pressure	No	Touchpad, Button, Haptic vibration, & remote control	Tethered (Bluetooth)	8	Plug-in	2018	1000	https://www.vuzix.com/products/blade-smart-glasses
Google Glass	Optical see through (retina)	3DoF	13	Yes	36g	Barometer, Proximity, Hinge, GPS, & GLONASS	No	Touchpad, audio command, & remote control	Tethered (Bluetooth)	8		2017	1500	https://x.company/glass/
Solos	Optical see through	-	10.68	Yes	65g	ANT & GPS	No	Tactile button	Untethered		+5 hours	2016	499	https://www.solos-wearables.com/product/solos-smart-glasses/
Meta 2	Optical see through	6DoF	90	No		IMU, Gesture, Hand tracking,	Yes	Natural	Tethered (pc)	-in	Non	2017	Non	https://www.metavision.com/optimi

						Compass, & Head								ze-your-workspace/
ODG R-9	Optical see through (retina)	6DoF	50	Yes	125g	IMU, Altitude, & Humidity	No	Trackpad, Button, & Voice control	Untethered	8 +	built-in	2017	1800	-
Everysight Raptor	optical see through	3DoF	-	No	98g	IMU, Barometer, Proximity, GPS, & GLONASS	No	Touchpad, audio command, & remote control	Untethered	8 +	built-in	2018	599	https://everysight.com/all-products/
ThirdEye GenX2	Optical see through	6DoF	42	No	170g	IMU, Ambient light, Compass, Thermal, & Flashlight	Yes	Audio command, Head motion control, Gesture control, & Bluetooth device remote control	Untethered	4 +	built-in	2019	1950	https://www.thirdeyegen.com/x2-smart-glasses/

*IMU: Accelerometer, Gyroscope, & Magnetometer



HoloLens 2

Magic Leap

Meta 2

ThirdEye GenX2

Fig. 3-8. AR HMDs

MS HoloLens 2 and Magic Leap are the most popular AR HMDs that include SLAM algorithms for real-time environmental mapping. The HoloLens is a device that works well for indoor and outdoor usage, thanks to the wholly untethered and cable-less design. The HoloLens is a bit heavier than Magic Leap. The makers of Magic Leap have stated that it was designed for indoor and not outdoor usage, and for this reason, lighting or other environmental variables can affect its performance. Magic Leap is not completely untethered and requires a small computer that can be worn on a belt. These two AR HMDs are mainly being employed in the education, professional training, and game industries. Meta2 was once a worthy competitor to these two giants, being suitable for indoor usage with its tethered design, but the company closed in 2019. The spectacular ability of these devices comes from their natural gesture interaction via embedded sensors. These devices do not require additional devices like Leap Motion for gesture recognition.

The ThirdEye and ODG HMDs are appropriate for either personal or professional usage. The titanium frame of ODG makes it durable, and both of these fully untethered devices can be connected to mobile devices. Engineers, architects, medical employees, and other specialised workers require this high-end AR goggle technology to augment their professional experiences. ThirdEye has further customisation options whereby users can request additional sensors to enhance their practices, and it also offers SLAM SDK for developers who work with it. The expense of these systems is still a challenge to their wide-scale adoption.

3.2.1.2.2 Handheld displays

Accessibility and portability increase the popularity of AR applications that support handheld displays. Handheld displays provide an opportunity to access AR applications using individual mobile devices, and different pocket-sized handheld devices have been released to enhance the quality of AR experiences.

Smartphone Tablet

Fig. 3-9. Handheld displays

Handheld displays usually use see-through video techniques, except for handheld projectors that use the optical see-through method. Video see-through handheld displays contain various sensors, such as GPS, electromagnetic compasses, accelerometers, magnetometers, gyroscopes, fiducial marker systems, and free tracking systems (Carmigniani et al. 2011). Smartphones, tablet PCs, and PDAs are popular handheld devices for AR experiences, especially since their users typically do not require extra equipment. The integrated cameras capture the physical environment upon which to overlay the digital content on the screen.

For this reason, the integrated cameras and sensors of the ever-developing smartphone sector are being adapted to work in AR applications. The widespread usage of mobile technologies is driving the acceleration of AR usage faster than the development of VR technology. Despite these strengths, the small screen size, limited FoV, and need for active hand usage are the main disadvantages of these mobile devices' display systems (Bimber and Raskar 2005).

Handheld projectors are bulkier than HMDs, and they tend not to be preferred. The entertainment and marketing sectors tend to use these systems thanks to their cost-effectiveness and ease of usage (Van Krevelen and Poelman 2007).

3.2.1.2.3 Spatial Displays

Spatial AR displays use certain technologies to integrate digital content into the physical world. SAR does not require wearable or portable technologies (e.g. HMDs or handheld displays) and directly projects digital content onto the physical environment via video projectors, optical elements, or holograms (Carmigniani et al. 2011). They mainly use three different techniques to render digital content (Carmigniani et al. 2011, Bimber and Raskar 2005, Kesim and Ozarslan 2012): (1) screen-based video see-through, (2) spatial optical see-through, and (3) projection-based spatial or direct augmentation.

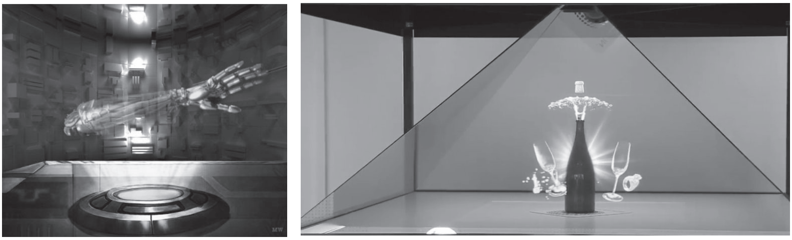


Fig. 3-10. Spatial display output

AR applications of the spatial optical see-through type use PC systems and monitors to achieve the visualisation. The widespread usage of PCs makes these systems cost-efficient, easy to use, and accessible. The augmented content can be observed simply with monitors, although screen specifications like FoV, resolution, and quality restrict the representation of the digital content. These displays are suitable for indoor rather than outdoor applications (Carmigniani et al. 2011, Bimber and Raskar 2005, Azuma et al. 2001, Van Krevelen and Poelman 2007).

The second type of spatial display uses optical see-through techniques via integrated planar or curved mirror beam splitters, transparent screens, or optical holograms. These systems present the AR experience via bulky visualisation devices to a single user and are often only suitable for indoor usage. These devices are developed for a particular purpose, and their implementation in other applications is cumbersome. They offer high-resolution visual output, large FoV, and precise calibration thanks to their visually-based development. A more natural perception of the physical world is achievable by these systems (Carmigniani et al. 2011, Bimber and Raskar 2005, Azuma et al. 2001, Van Krevelen and Poelman 2007).

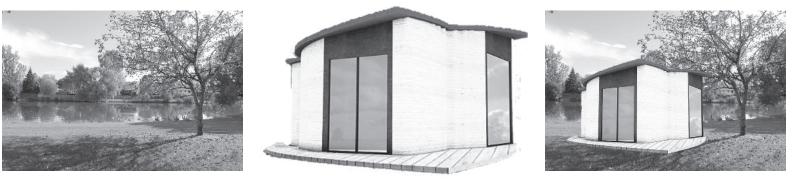
Lastly, projection-based spatial displays directly project digital content onto the surface of physical objects using front projections. This allows the observation of digital content by multiple users at once and also limitless FoV, but the physical surface's specifications (e.g. colour, light, size) are relevant and can affect the augmented content (Carmigniani et al. 2011, Bimber and Raskar 2005, Azuma et al. 2001, Van Krevelen and Poelman 2007).

Table 3-2. Characteristics of AR displays

Criterion	HWD		Handheld Display	Spatial Display		
	Retina	HAD		Video	Optical	Projective
Indoor	+	+	+	+	+	+
Outdoor	+	-	+	-	-	-
Multi user	-	-	+	-	+	+
Interaction	+	+	+	-	-	-
FoV	Developing	Developing	limited	limited	+	+
Display Quality	Developing	+	+	limited	+	+

3.2.2 Software

AR applications are developed using some of the same tools as for VR development such as game engines or 3D modelling tools. The popular game engines, like Unity and Unreal Engine, have released plugins for the creation of AR applications in the hands of novice to advanced developers.



Physical Virtual Combination

Fig. 3-11. Physical, virtual, and their combination

This section explains the fundamentals of an AR application development process from different perspectives and introduces essential tools and functionalities. AR application development requires more complex processes that require hardware with multiple components. The designing of VR applications requires the structuring of the whole environment in a single scene (including 3D objects and interactions). It does not require recognition or the merging of components.

For this reason, the virtual output is more comfortable to design. AR environments require the design of both virtual and physical components, their interaction, and a coherent presentation of all these components combined. For this reason, the AR interface and available interaction types should be considered before using development tools.

3.2.2.1 Interaction in AR interfaces

AR applications have four core categories, which can be defined by their interaction types and rendering interfaces.

3.2.2.1.1 Tangible AR interfaces

Tangible interfaces require physical objects to manipulate the virtual illusion of a related physical object in the real world (Azuma et al. 2001, Carmigniani et al. 2011). The dependency on physical objects of tangible AR interfaces provides opportunities for active participation and the experiencing of AR collaboratively. Users can observe the same digital visuals to understand the relationships or systematic structure present in the content. A tangible AR environment allows either individual or collaborative experience using multiple physical triggers, but 3D visualisation is usually presented on the 2D screens of handheld displays.

Fig. 3-12. Tangible AR interface sample

Marker-based applications (e.g. cubes, cards) are a typical example of tangible AR experiences. The users can rotate or orientate the virtual content in 6DoF on display devices. These systems are made to recognise a fiducial image or marker, but that creates difficulty in changing tangible triggers because the markers need to stay at the same points in space. Tangible AR applications are usually preferred by interior decorators and furniture designers and for educational purposes, since they are easy to develop. In the education field, tangible AR interfaces are highly useful in teaching astronomy, physics, chemistry, biology, and other science-related topics thanks to the multi-user interaction between learners and the facilitation of active participation. For example, the marker card-based application Kartoon3D (Tacgin and Ozuag 2018) supports the learning of letters, words, and mathematical equations in three different languages. As another example, HELIOS is an affordable way to teach astronomy (Fleck, Hachet, and Bastien 2015).

Fig. 3-13. Kartoon3D interface

Contemporary tangible AR applications present more functionality because they support the integration of different devices and techniques. For instance, the optical movements of scattered points were simulated using multi tablets in one example of tangible AR. Each of the tablet PCs had a single scatter plot and the plots interacted with each other through the tablets' technology. The users could observe the variation of the points' interaction from different distances and angles (Hubenschmid et al. 2018). Another interesting example of tangible AR interface uses wearable technology such as a ring that provides haptic feedback to users (De Tinguy et al. 2018).

3.2.2.1.2 Collaborative AR interfaces

Collaboration can be localised or remote (Dong et al. 2013). The majority of AR display systems (handheld or monitor-based) already allow localised cooperation. When we talk about collaborative AR, we are usually referring to high tech remote collaboration AR systems. These AR interfaces allow for the multiuser manipulation of virtual content from multiple locations

(Carmigniani et al. 2011). These systems direct digital content remotely for co-located users.

Let us turn back to the futuristic vision described in chapter 1, where you have a remarkably evolved smart house. There, you could join meetings using goggles, observing and working on the same objects in collaboration with co-workers. This example illustrates the collaborative potential of AR interfaces, as they can permit multiple users to view and control 3D objects remotely. Currently, visualisation-based collaborative AR interfaces are being used in some areas such as engineering (Dong et al. 2013).

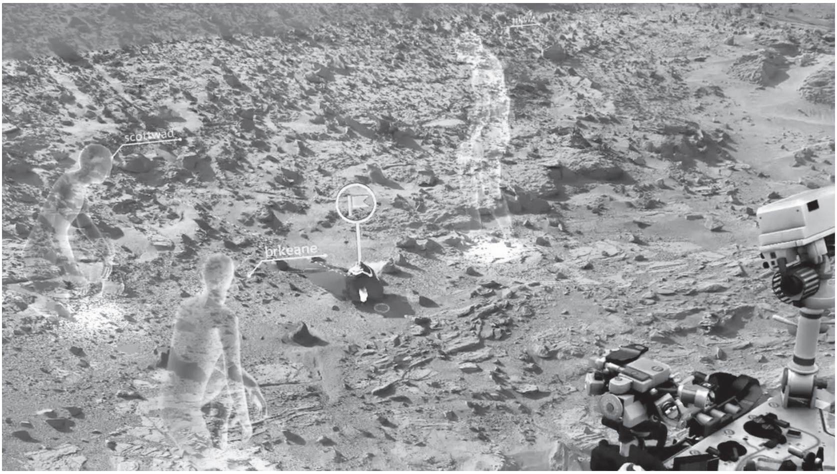


Fig. 3-14. A co-located collaborative AR interface of NASA

These markerless-based systems require visual search systems, SLAM algorithms, and various embedded sensors or multi-displays to execute. In terms of today's technologies, collaborative AR interfaces are generally limited to visualisation or indoor usage because of the required fast internet connection speed and high-quality displays. Electronic devices have been developed for collaborative AR. 'A first electronic device receives information relating to the modification made to an AR presentation at a second electronic device, and the first electronic device modifies the first AR presentation in response to the information' (Blanchflower and Halbert 2017). It is expected that AR technologies will eventually be developed that allow for remote surgery and mechanical detection, virtual meetings, and the wearing of smart clothes and contact lenses that can overlay content onto the physical environment using computer graphics (Lukosch et al. 2015).

3.2.2.1.3 Hybrid AR interfaces

Hybrid AR interfaces require integration and communication among different hardware components, such as HMDs, gloves, wrists, robots, or various sensors, for the rendering of complementary interfaces. They require multi-disciplinary expertise to make.

Fig. 3-15. Hybrid AR interface

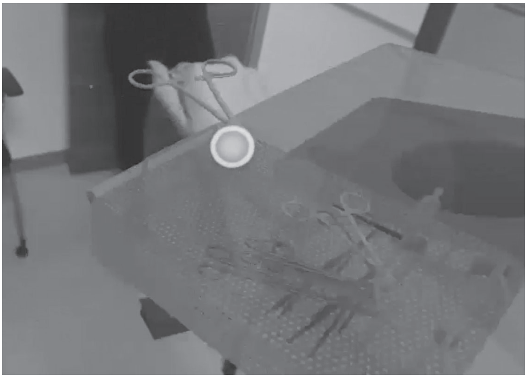
There are several futuristic and innovative hybrid AR interfaces available now. A spatial hybrid AR using an HMD and a wand has been developed to manipulate virtual objects collaboratively (Roo and Hachet 2017). What is more, there are incredible hybrid AR systems like that in the study of Wang, Zeng, et al. (2017) and Zeng et al. (2017) who developed an application that allowed a paralysed person to control the movements of a robotic arm with their brain through visualisations. This unique example provides telepresence for users through AR visualisation. Seo et al. (2016) used physical systems, sensors, and human-object interaction to create egocentric VR and an exocentric AR-based smart house prototype. The smart house's owners can experience the virtual house's life from their perspective. The context-aware smart home recognises the users' movements, and they can interact and manipulate the house through AR. Furthermore, a hybrid AR system developed by Majewski and Kacalak (2016) employed machine learning algorithms and speech recognition technology to enhance intelligent human-machine communication. Altosaar, Tindale, and Doyle (2019) developed a hybrid AR application using wands and HMDs to control music via body movements.

3.2.2.1.4 Multimodal AR interfaces

Multimodal AR interfaces have emerged out of increasingly popular AR technologies that combine natural interaction with virtual objects. Natural interaction can be provided by physical hand movements, gestures, speech recognition audio-based commands, gaze/eye tracking, and head movements. Such AR interfaces became possible after the development of micro-sensors and related tracking systems. Extensive interaction capability is not only the result of the hardware components but also the integration of machine learning algorithms and neural network systems that provide a high degree of human-computer interaction for users.

Let us look at a recent example that demonstrates an imaginative use of emerging multimodal AR interfaces. The simplest components of the system used hand-tracking devices like Leap Motion to provide gesture recognition with a depth camera for interacting with virtual objects. Gesture and speech inputs were used for virtual object manipulation by Ismail et al. (2018) to provide intuitive control in the multimodal AR interface.

Chen et al. (2017) developed a mobile AR application for dog training using a multimodal interface design that included gesture and speech interaction. The users of this application could interact with and command a virtual dog thanks to the integrated Leap Motion and microphone systems.



AR interaction with physical hand movement

User

Fig. 3-16. Multimodal AR interface example with physical hand interaction

As mentioned in the hybrid interface AR examples, machine learning and human brain interfaces are being increasingly applied to AR systems (Wang, Zeng, et al. 2017, Zeng et al. 2017). Gang et al. (2018) and Stirenko et al. (2017) made a multimodal interface that combined machine learning, visual recognition, tactile sensors, and a speech control-based multimodal interface in a brain human interface in order to help disabled people to better function. This system was able to transform the neurophysical reaction data of the brain into accurate constant feedback for individual users by using machine learning. The system they suggested has potential for other fields such as home care, healthcare, eHealth, and education. Another application was developed by Pereira et al. (2017) for teleoperation. This robotic and HMD-based AR could be controlled with verbal and nonverbal behaviours by one or two users.

Wang, Zheng, and Mao (2019) combined ergonomic HMDs and robotic systems to interact with telepresence robots to manipulate smart home objects. The interaction was achieved by having the computer use image recognition to scan eyes and facial gestures to measure physiological signals. The users could interact with smart home objects completely hands-free with their facial gestures. Similarly, Karambakhsh et al. (2019) used a neural network for machine learning to create 3D models for the recognising of gestures. This system was designed to teach anatomy with the use of HoloLens goggles.

Developing technologies and techniques provide incredible opportunities to enhance human-computer interaction with smart systems. The integration of these systems into every field is inevitable. However, the development of this kind of AR applications is highly cumbersome and requires teams that bring together skills from many different disciplines.

3.2.2.2 AR development tools

The multi-interface and device-based structure of AR applications may sound highly complex, but the challenges of the development process are directly related to the application's objectives. After planning the application requirements and making the hardware selection, the digital output should be prepared, and the related physical objects should be determined to create proper interaction between them. The main components of an AR application can be prepared separately via 3D modelling or audio/video production software – all also standard VR tools. The main issue is the combination and interaction of all these components.

This section introduces the main AR development tools to understand the systematics of the development process. After learning the structure of tangible, basic collaborative, or hybrid AR interfaces, AR applications can be developed without coding in most cases. The emerging machine learning, intuitive interaction, and visual-search-recognition-based AR applications require programmers, 3D designers, and engineers. In other words, AR applications that are marker-based or GPS-based, and many mobile AR applications as well, can be created by novice developers.

There is no single AR development tool, and many novice-friendly mobile-based drag and drop apps exist. AR functionality can be added to game engines (e.g. Unity, Unreal Engine) by using the appropriate Software Developer Kit (SDK). An SDK works as a set of plugins for the game engine and must be compatible with the version chosen for development.

There are numerous AR SDKs that facilitate application development by providing specialised capabilities. Some AR SDKs are more popular than others because of their comprehensive functionality, free cost, or professional-grade options. The functionalities of AR SDKs mainly provide object recognition, tracking, and rendering. Object recognition is the main requirement of AR applications, and most SDKs can recognise 2D and 3D objects from different distances and angles. The motion of the recognised physical objects can be tracked with AR SDKs, and the required digital content can be rendered on them continuously as they move.

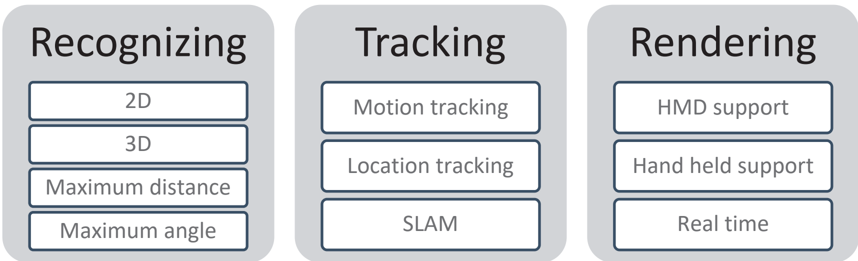


Fig. 3-17. Main specifications of AR SDKs

The main functionalities used in classifying the features of AR SDKs are presented in figure 3-17. There are several finer points, such as cloud recognition support, price, and compatibility, that can also be considered. Some of the famous and easy to use AR SDKs are described below.

3.2.2.2.1 Vuforia

One of the most popular and easy to use AR SDKs, Vuforia, is suitable for novice and advanced developers thanks to the array of functions and the free and professional versions. Vuforia generates iOS-, Android- and Windows-compatible AR applications by providing Unity game engine support.

2D/3D objects, texts (up to 100,000 different English words), barcodes, or QR codes can be recognised and tracked from a distance of between 1 and 4 metres with the Computer Vision technology of Vuforia. Vuforia offers the Vuforia Object Scanner in a private cloud to which can be uploaded and stored 3D or 2D images. The scanned versions of the physical objects are logged in a private space, and a unique activation code is generated to embed in Unity. Unity can reach the visual components using this code and then add digital content onto a virtual layer. After this process, digital content is rendered in real time while scanning 2D/3D objects via camera. Vuforia can detect up to 6 separate objects at the same time, thereby providing multiple digital outputs. Motion tracking and advanced orientation capability allow users to view 3D content from different angles. Virtual buttons can also be added into the virtual layer to interact with and manipulate the objects on touchscreens. Vuforia can be used to develop handheld-display- or HMD-based AR applications, but its SDK does not support GPS-based systems.

3.2.2.2.2 EasyAR

EasyAR is a free and easy to use AR SDK that is an excellent alternative to Vuforia. EasyAR is compatible with Android, iOS, and Windows and offers a Unity plugin. Mobile device and smart glass AR applications can be developed using EasyAR SDK, but planar objects (exact 2D objects placed into the 3D space) and GPS location are not possible. EasyAR applications can recognise and track a maximum of three defined 2D objects between 1 and 3 metres away to calculate 3D digital outputs.

3.2.2.2.3 Wikitude

Wikitude is one of the most powerful and multi-functional AR SDKs for multi-platforms like iOS, Android, Windows, Unity, and smart glasses. Wikitude offers free limited usage with watermarks, but the full version requires payment.

The powerful features of Wikitude are not only SLAM and GPS tracking support but also the recognising of six 2D/3D multiple objects from up to 5 metres distance. Indoor and outdoor AR applications can be developed with markerless tracking thanks to the SLAM support. Wikitude users can log their data in a secure cloud space. Wikitude is suitable for professional developers, with its JavaScript API, Native API, Xamarin, Unity3D, Cordova, and Titanium supported extensions.

3.2.2.2.4 Kudan

Kudan SDK is suitable for advanced iOS and Android AR developers, providing SLAM, AI, and robotic integration functionality. Kudan SDK can be used with its KudanCV engine or a Unity plugin. Mobile devices' cameras use SLAM for simultaneous mapping and localisation of an outdoor or indoor environment, and a markerless AR can be created for them with integrated AI algorithms. Robotic equipment, drones, or smart systems can be integrated to achieve emergent, collaborative, hybrid, or multimodal AR interfaces. Limitless 2D/3D object recognition and tracking are also provided for marker-based applications.

3.2.2.2.5 ARToolKit

The most used AR SDK, ARToolKit, is free and open-source. Applications based in Android, iOS, Linux, Windows, Mac OS, and smart glasses can be developed using its extended functionalities. ARToolKit can estimate a user's viewpoint with intelligent computer vision algorithms before rendering digital content. This unique function presents the calibrated digital output from a perfect angle to users. ARToolKit can recognise six multiple objects from 3 metres away and provide real-time calibration. SLAM is supported for the tracking of the position and orientation of 2D and 3D objects, or even black squares, via single or stereo cameras. ARToolKit contains plugins that allow it to be used with Unity and OpenSceneGraph.

3.2.2.2.6 ARCore

Google's open-source AR solution, ARCore, provides motion tracking, environment tracking, and light estimation functionality for developers. iOS- and Android-based applications can be developed using the ARCore SDK within Unity, Unreal Engine, or OpenGL. ARCore is a mature SDK for developing mobile AR applications. GPS-based and tangible AR interfaces can be developed thanks to the recognition of 2D and 3D images or text and the tracking of the location and motion of mobile devices. The environmental tracking also tracks the size and location of surfaces in 3DoF. The light estimation ability renders digital content with correct lighting to provide better interfaces for outdoor AR applications. TiltBrush and Block VR building tools from Google are also supported for the modelling of 3D objects.

3.2.2.2.7 ARKit

Apple's AR development SDK ARKit only supports iOS mobile devices. ARKit SDK is free and can be used with Unity, Unreal Engine, and Vuforia. 2D/3D object recognition and interaction, environmental detection of surfaces, and motion tracking of mobile devices via GPS permit multiplayer AR experiences, light estimation, and facial tracking.

Less mainstream AR SDKs, like DeepAR, offer cross-platform support for the creation of hybrid and multimodal AR interfaces using machine learning techniques. DeepAR can support face and gesture recognition with AI algorithms for the creation of AR applications based in Android, iOS, Windows, and WebGL.

Table 3-3. AR SDK comparison

	Vuforia	EasyAR	Wikitude	Kudan	ARToolKit	ARCore	ARKit
Price	Free (with Watermark) Commercial	Free (with Watermark) Commercial	Commercial	Free Commercial	Free Open-source	Free (open source)	Free
Platform	iOS Android Windows	iOS Android Windows	iOS Android Windows	iOS Android	iOS Android Windows Linux	iOS Android	iOS
Smart glasses support	Yes	No	Yes	No	Yes	Yes	Yes
Unity support	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cloud storage	Yes	Yes	Yes	No	No	Yes	Yes
2D recognition	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3D recognition	Yes	No	Yes	Yes	Yes	Yes	Yes
Geolocation	No	No	Yes	No	Yes	Yes	Yes

SLAM	No	No	Yes	Yes	Yes	Yes	No
Marker-based AR	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of moveable markers	6	3	4	6	6	6	7
Number of stable markers	10	7	6	10	8	9	9
Markerless based AR	No	No	Yes	Yes	Yes	Yes	Yes

Alternative AR SDKs, like ARLab and Droid AR, provide easy to use and free tools for location-based mobile AR application development.

The specifications for an AR project lead the creator to choose a suitable SDK for the application. Game engines are essential components of MR material development.

3.3 Benefits of AR

The fundamental working principles and requirements of AR utilise recognition, tracking, and interaction techniques to combine physical and virtual environments and thereby present real-time, digitally enhanced content. The exceptional features of AR allow it to integrate various fields, producing excellent outcomes by transforming traditional techniques, also supporting and enhancing user experiences in multiple perceptual domains, especially sight, hearing, and touch. The expanded device integration of AR systems enhances multiple perceptions of users. Providing location-based applications, collaborative usage, and active participation are only a few examples of the possibilities of AR.

The multi-interface and multiple device structure of the AR field can be broken down into a taxonomy, wherein different beneficial outcomes are related to the functionality of specific hardware and applications. Such knowledge can be useful, as proper technology and tool selection yield particular outcomes.

AR technologies have great potential for integration into many fields, such as education, engineering, architecture, medicine, the military, entertainment, and a whole lot more. The real-time information adaptation and integration of AR are the fundamental efficiencies gained in both schools and business settings (Lee 2012). A majority of studies that determine the benefits of AR focus on such psychological outcomes for users as motivation, attention, confidence, and satisfaction. An experimental study of Di Serio, Ibáñez, and Kloos (2013) showed that AR was a useful teaching tool for visual art students through increases in motivational factors like attention, relevance, confidence, and satisfaction. According to Bujak et al. (2013), learning with AR technologies provides physiological outcomes from three different perspectives. First, intuitive manipulation and interaction help students to create an embodied representation. Second, visualisation supports students' cognitive processes with scaffolding, symbolization, and an understanding of intangible concepts. Finally, collaboration and active participation facilitate a contextual relationship with the experience.

The systematic literature review of Diegmann et al. (2015) classified the educational benefits of AR in six primary ways. The first is that psychological outcomes are conceptualised as a state of mind to explain the benefits of motivation, attention, concentration, and satisfaction. Secondly, they found that the presentation of digital content provides the real-time accessibility of detailed information as a result of the interaction. That second benefit leads to the third one, which is an understanding of content using spatial abilities in the AR experience; memorisation of content is easier thanks to the enhancing of the dual coding system of the human brain. The fourth category of benefits deals with faster learning curves and the promotion of different learning styles. The creativity of learners is also strongly supported by AR techniques. Fifthly, the active participation and collaboration facilitated by AR usage provide student-centred teaching concepts. Lastly, AR technologies have the potential to reduce educational costs. According to Wu et al. (2013), AR promotes engagement by emphasising roles in the environment that have a sense of immersion, presence, and immediacy. It helps the learners' contextualisation process by highlighting locations that provide collaborative and situated learning, and it bridges between formal and informal education. Conducting tasks in AR visualises digital content from different perspectives, thus providing authenticity for learners.

The educational advantages of AR can be applied to businesses and industrial fields. HMD-based AR applications have become one of the essential tools for supporting assembly and maintenance processes (Reinhart and Patron 2003, Henderson and Feiner 2011, Wang, Ong, and Nee 2016, Palmarini et al. 2018, Jetter, Eimecke, and Rese 2018). AR applications for teaching assembly tasks have been shown to reduce the cognitive effort and error rate of learners. What is more, AR reduced the knowledge transfer time of learners, and they kept their attention on the topic longer (Tang et al. 2003, Jetter, Eimecke, and Rese 2018). AR is a more effective learning tool for novice assemblers thanks to a reduction in cognitive load over monitoring techniques. AR usage not only provides a faster and more effective learning curve for both genders (Hou and Wang 2013) but also allows workers of both genders to locate items to complete tasks more quickly as compared to their respective baseline performances (Henderson and Feiner 2011). Adding a constant feedback feature into the operational job of AR applications improves task performance and users' experiences (Liu et al. 2012). AR provides a collaborative design and detection opportunity for industries. However, genuinely multimodal and collaborative AR interfaces still require the invention of innovative devices and technologies.

The benefits of AR can be summarised as:

- Providing active participation for individuals
- Providing a collaborative working environment
- Providing real-time interaction
- Providing enhanced digital content
- Providing instant feedback
- Reducing learning time
- Reducing cognitive load
- Increasing motivation and satisfaction

- Providing increased and sustainable attention
- Increasing creativity
- Catalysing memorisation
- Providing a demonstration of tangible and intangible concepts
- Reducing costs
- Offering accessible and portable digital content

3.4 Disadvantages

AR has different kinds of advantages and disadvantages depending on the particular technologies used (e.g. HMDs, handheld displays) and the target audience. The display-based challenges generally relate to the visual output quality and user observation opportunities. First of all, because wearing bulky devices is mandatory, HMDs are usually appropriate for indoor usage but not outdoor environments, (Van Krevelen and Poelman 2007). The virtual outputs of current HMDs still have calibration, visual quality, colour fidelity, and time lag issues (Carmigniani and Furht 2011, Carmigniani et al. 2011, Kruijff, Swan, and Feiner 2010). The most common interaction techniques require additional devices; however, this is not ideal because fully active participation needs hands free application. Multimodal and hybrid AR interfaces have the potential to provide intuitive interaction, but these technologies are expensive and require sophisticated software components. Visualisation on handheld displays is limited by their screen size, and 3D content can only be rendered in 2D on their screens (Carmigniani and Furht 2011, Carmigniani et al. 2011). This situation does not allow for holographic digital output. The requisite active hand usage of these displays inhibits hand free usage. Projector-based displays are deprived of mobility, making it difficult to use them outdoors, and the projectors are expensive devices (Zhou, Duh, and Billinghurst 2008).

The recognition of the physical environment necessary for AR is usually provided via depth camera technologies and sensors (Kruijff, Swan, and Feiner 2010). These systems can work correctly within indoor areas even though the light-sensing mechanism of the depth camera does not provide good outcomes in outdoor environments.

AR applications have some challenges for users as well as developers. The results of Călin's (2018) study showed that insufficient funding of the required digital infrastructure (Chavan 2014, Călin 2018) prevents schools from creating their own custom AR content. Teachers also lack knowledge of AR technologies (Călin 2018) or are resistant to using them (Garzón, Pavón, and Baldiris 2019). These points can help explain the lack of custom AR content (Călin 2018), but very simple AR content can be developed by teachers who are willing to invest the extra effort. According to Garzón, Pavón, and Baldiris' (2019) study, AR often has technical difficulties when used in the classroom. Teachers might also be resistant to AR applications because they commonly evaluate them to be complicated, but this belief can be changed. I believe that this depends on the structure of the technology and the application being used.

According to Chavan (2014), the free and easy content creation opportunities for AR can cause other challenges for users who may struggle to avoid unwanted digital content for which they have not given their permission, such as spam. Careless usage of AR for purely social purposes might be contributing to the spread of such content, which can negatively affect the processing capacity of mobile devices.

3.5 Examples of AR Applications

3.5.1 AR in Education

The most common usage of AR in all levels of education is to provide training in schools and universities or in-service training for enhanced perception. The widespread, free accessibility of AR applications based on mobile technology makes AR a great tool to reinforce learning outcomes for individual or collaborative learning. The learning process of users can be supported with real-time digital content, primarily through active participation and the possibility for learner-centred training. Active participation happens through using the device, and the interaction by which digital content is rendered facilitates the scaffolding and knowledge reconstruction process of learners.

Portable devices and GPS-supported AR applications are preferable for outdoor usage. Also, AR suits constructivist learning strategies well, supporting discovery and experiential learning by providing active participation and collaboration.

Fig. 3-18. VR magic book

There are numerous educational AR applications that have been made to teach and reinforce course content for schools and for businesses that want to capitalise on the previously mentioned benefits of AR for their workforces, such as increased long term attention, higher motivation and satisfaction, faster learning, increased creativity, and improved memorisation. For instance, Billinghurst (2002) presented the Magic book AR application to assist children learning to read by providing 3D content and interactivity. Magic books have the potential even to teach kindergarten children visually based contexts that go along with recorded stories. There are several marker-based AR applications to teach animals, colours, professions, letters, numbers, or words to young children, such as Kartoon3D (Tacgin and Ozuag 2018). These game-based applications are not only suited to individual and collaborative usage but also have the potential to offer constant feedback to students. The animated 3D digital content helps the dual coding process of the human brain, making memorisation easier.

Fig. 3-19. AR example for education

AR has a tremendous representational capability to demonstrate intangible concepts and will become a required learning tool to teach different subjects in higher education and at universities. Learners can improve their knowledge and skills, especially concerning complex theories or mechanisms, thanks to AR support (Lee 2012). In this way, the abstract concepts and relationships in biology, physics, chemistry, astronomy, mechanics, electronics, and mathematics become more understandable for students. There are thousands of AR applications within these various fields for learners. For example, Kaufmann and Schmalstieg (2002) developed Construct3D to teach mathematics and geometry, providing individual, collaborative, and teacher interfaces. Multiple AR devices, such as HMD, virtual workbench, conventional monitors, and a variety of tracking devices for input, were used to reinforce the desired outcomes and expectations. Martín-Gutiérrez et al. (2015) developed a collaborative and autonomous AR application for electric machine lessons. Their ElectARmanual presented a low-risk LE by animating connections with a theoretical explanation of electrical machines.

There are lots of educational AR applications in chemistry (Taçgin, Uluçay, And Özüağ 2016, Chen 2006b), anatomy (Blum et al. 2012, McLachlan et al. 2004), biology (Weng et al. 2016), nursing (Taçgın 2017a), and physics (Dünser et al. 2012, Wojciechowski and Cellary 2013). These applications and features are evaluated in-depth within the 'MR in education' section in chapter 4.

3.5.2 AR in Medicine

AR has enormous potential and usage in the medical field to support diagnoses, treatment, and training processes. The integration of the developing technologies of both medical displays and robotics into AR is providing innovative medical tools and notably improved health care delivery and systems. Particularly since the end of the 2000s, augmented binocular and ultrasound devices have been providing expanded biomedical visualisation opportunities for both the preoperative and intraoperative processes of specialists (Sielhorst, Feuerstein, and Navab 2008).

Intraoperative AR usage was at one time hard because of the calibration deficiency of old techniques. AR systems must recognise actions at the moment they occur to provide the right information instantaneously and in the most suitable form (Navab et al. 2007). In view of this, Birkfellner et al. (2002) created a cost-effective HMD by modifying current HMD devices and Varioscope for position and location tracking. They achieved a less than 1 mm error in support of an intraoperative process. Fuchs et al. (1998) developed a 3D visualisation prototype capable of 6DoF and tracking for laparoscopic surgery. Feuerstein et al. (2008) created an intraoperative imaging system for the planning and reconstructing of 3D positions for laparoscopic surgery. This system was tested on liver surgery by combining intraoperative imaging, tracking, and visualisation devices (e.g. c-arm) within a registration-free navigation framework.

Fig. 3-20. AR example for surgery on a dummy patient with robots

Emerging technologies have produced AR operation rooms to support different kinds of surgery, such as plastic surgery, neurosurgery, general surgery, orthopaedic surgery, maxillofacial surgery, otolaryngological surgery, cardiovascular surgery, and more (Shuhaiber 2004, Kim, Kim, and Kim 2017). For instance, Olsson et al. (2015) developed haptic-assisted surgical planning (HASP) AR technology to reconstruct the face and necks of patients before surgery. HASP visualises a 3D anatomical model of the patient on a semi-transparent mirror. The surgeon can manipulate the 3D model with an integrated robotic haptic device under the mirror and can observe the output via an infrared camera and tracker-integrated smart goggles. Fischer et al. (2004) developed a marker-based AR application using ARToolKit that provided a 3D visualisation of MRI scans that expedited the planning process before brain surgery. AR applications for surgical planning and navigation require collaborative, hybrid, or multimodal interfaces along with additional optic, mechanical, robotic and haptic devices. At present, active AR surgery during the intraoperative process is still limited and requires better tools.

Kilgus et al. (2015) offered a system that probed the capability of AR systems in forensic medicine. The image and surface recognition, as well as the digital representation potential of AR, could offer a useful tool to help pathologists avoid false conclusions. For example, internal and external wounds on cadavers could be logged to predict the reason for death with the help of a multimodal AR interface. Besides this, AR can also be used for phobia treatment, just like VR (Juan et al. 2005).

AR is one of the most popular training tools in the medical field. According to a study done by Barsom, Graafland, and Schijven (2016), visualisation in this field is usually supported by 2D screens and interaction comes from embedded controllers in the designed application. Specific examples include ProMIS, AR laparoscopic simulator, the perk station, CAE Videmix, and EchoCom. These systems provide single-user usage and require expensive devices.

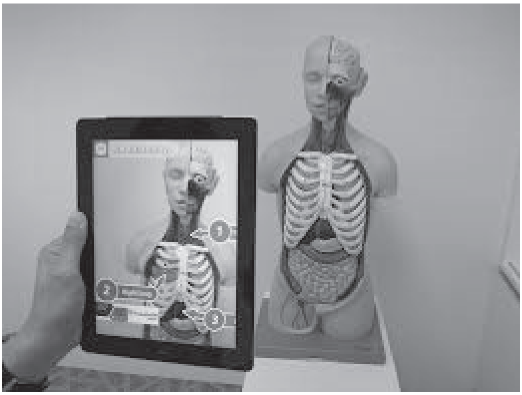


Fig. 3-21. AR for an anatomy lecture

Contemporary AR technologies (e.g. handheld devices, HMDs, and robotics) have already been integrated into medical education. For instance, Bond University developed some mobile device-based AR materials to reinforce their anatomy education (Moro et al. 2016). A tablet-based AR system was developed by Andersen, Popescu, et al. (2016) for the teaching of telementoring to novice medical students. The results of their study showed that AR-based learning reduced placement error and focus shifting time, but students were still working more slowly than those who remained in the traditional system to learn this skill. Küçük, Kapakin, and Göktaş (2016) developed a portable magic book for anatomy training that was effective in reducing the cognitive load of learners. Monitor-based NeuroSimVR was developed by Mostafa et al. (2017) for the teaching of procedures of spine surgery via a haptic interface to novice surgeons.

Hamza-Lup, Rolland, and Hughes (2018) developed an HMD-based AR training tool to help teach paramedics, pre-hospital personnel, and students to perform endotracheal intubation processes. The application consisted of optical tracking systems, a PC, and physical intubation tools. Sielhorst et al. (2004) developed an HMD-based AR birth delivery simulator that was called RAMP and that provided haptic and auditory feedback in response to the blood pressure, heart rates, pain level, and oxygen supply of the participants. I myself developed another HMD-based AR (Taçgın 2017a) to teach preoperative processes to nursing students.

The magic mirror is another popular AR technique for medical training, one which recognises and tracks the user's body through optical sensors (e.g. Kinect) and renders digital content onto it. In one example, Ma et al. (2016) created an anatomy training tool using the magic mirror technique to teach about the locations and functions of organs, bones, and muscles by using 3D visualisation and putting digital content onto the user's body.

3.5.3 AR in the Military

The military has been a source of significant technological advancement in AR. According to Livingston et al. (2011), the requirements of the military field are naturally suited to the development of AR systems. AR systems are mainly used for four issues in the military: (1) situation awareness, (2) information overload, (3) training, and (4) decreasing reaction times. Situation awareness indicates the recognition of the environment and objects that have fatal significance for soldiers on the battlefield. If information is taken into account but cannot be processed fast enough, information overload occurs. Since simple processing is not enough to execute military operations, AR systems should also include fast decision-making mechanisms for quick critical responses. The military requires functional AR systems that include depth perception, occlusion representation, information filtering, object selection, collaboration, and the evaluation of vehicles in outdoor conditions.

Fig. 3-22. AR-supported situation awareness

Technology-enhanced systems are mandatory to avoid human error in military activities (Livingston, Ai, and Decker 2018). These systems can be integrated into vehicles, although greater mobility is necessary on the battlefield and wearable technologies have great potential here (Barfield and Caudell 2001). Livingston et al. (2002) developed the wearable Battlefield AR Systems (BARS) that consisted of a tethered see-through HMD, GPS, position tracking, orientation tracking, and a Wi-Fi connection (Yohan et al. 2000).

Fig. 3-23. AR in the military

A tethered HMD was integrated into a small-sized PC and wrist controllers to provide portable indoor and outdoor usage. The system also had speech and gesture input as control inputs. BARS provided collaborative and real-time environment recognition by scanning defined objects in the physical environment using markerless-based visual search AR systems. BARS could recognise massive objects like buildings at more than five metres of distance. Also, the US Army uses 'AR Sand Table', a system that uses Kinect motion sensors to detect and visualise the features of sand to produce a realistic topographical map (Mao, Sun, and Chen 2017, Boyce et al. 2016).

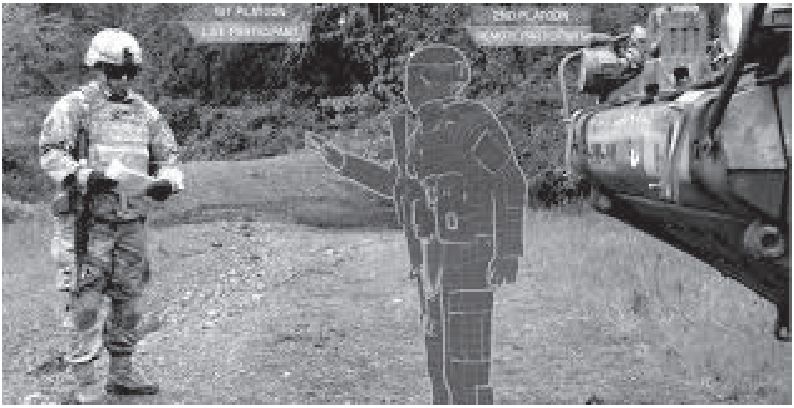


Fig. 3-24. Real-time 3D AR visualisation in the military

As mentioned in the history of MR technologies, Furness III (1986), the grandfather of MR, developed a super cockpit for pilot training. After the integration of AR systems, the military started to use helmet- and display-based AR simulators for pilot training (Silva, Oliveira, and Giraldi 2003). The C-130 weapon system and cargo trainer simulator were developed to train USAF pilots. HMD helmets that support excellent FoV are still used for this training (Mayberry et al. 2012, Livingston et al. 2011). Vehicle-based AR is also being using for specialist vehicle training, such as for the Army Stryker, which has periscopes and remote gun controls. Periscopes determine the environment and location via embedded camera, and IMU and GPS sensors are used to present the recognised environment on LCD screens. Thus, soldiers can observe the environment while in the vehicle and accurately control weapon systems (Brookshire et al. 2015).

Fig. 3-25. AR flight simulator

Henderson and Feiner (2011, 2009) developed an AR prototype to support military mechanics who conduct routine maintenance tasks from the inside of an armoured vehicle. This system merged HMD and vehicle equipment to facilitate task comprehension, location, and execution. Text instructions, 2D/3D arrows, and labels were used to visualise instructions in the tethered 6DoF-supported HMD.

AR applications for handheld displays have also been used for military training. Mao, Sun, and Chen (2017) developed and experimentally tested a marker-based ARB-MDMP system to teach troop strategies, terrain environment, and immediate battlefield intelligence. Results of the study showed that ARB-MDMP was not only a useful and easy to use tool for the supporting of learners' attention but was also sufficient in increasing their situational awareness. Similarly, Amaguaña et al. (2018) developed a marker-based AR application using the Unity game engine and Vuforia SDK for the teaching of military techniques. Jung et al. (2008) developed a marker-based virtual tactical map AR application that merged an AR sand table and markers for military training. Also, Boyce et al. (2016) integrated a 'Generalized Intelligent Framework for Tutoring' into the AR Sand Table to create a tool for the evaluation of military tactics.

3.5.4 AR in Engineering and Architecture

The abstract and modular structure of both engineering and architecture can make it difficult for students to construct knowledge about systems and mechanisms before implementing that knowledge in specific projects. For this reason, AR systems have large-scale usage in these areas. AR systems can be used for detection, visualisation of concepts or mechanisms, and training. They are also useful for the modelling of systems, environments, and mechanisms. The designed environments can be recognised or evaluated with the aid of low cost and low-risk AR applications.

Fig. 3-26. Indoor environment design with AR

AR systems are currently being used to support work in architecture, engineering, construction, and facility management for a combination of 4 purposes. First, relevant data that is currently available can serve as information for a new project. More specifically, cloud computing environments are used to store and define the features of the environment, surface, type, or other preferences. Current visual information can be compared with that in the database to determine a building model. Second, localisation technologies such as SLAM, GPS, and RFID are being used to reconstruct 3D models or to define features. Third, portable and mobile devices can transfer information from a physical environment. Fourth, NUI can be used to provide intuitive interaction through physical motions with visualisations of structures (Chi, Kang, and Wang 2013).

As an example of a project that uses AR for these purposes, Gabbard and Swan II (2008) developed an algorithm for the initial stages of a design, to allow a user to follow an iterative process to make choices. They used an optical see-through HMD, real-time video camera, and light meter sensor to recognise the environment. They defined the features of four realistic environments – brick, building, sky, and sidewalk – for recognition. Behzadan, Timm, and Kamat (2008) developed a reusable and easy to connect outdoor AR system using a tethered HMD, PC, controller, IMU, and GPS sensors and trackers. They employed both hardware and software. Engineers could thereby see the explanations and 3D visuals of the recognised places or structures in outdoor areas. A scalable algorithm was developed and integrated into this system to resolve incorrect occlusion in dynamic environments. The real objects were determined with real-time depth sensing to represent misplaced planar images in the correct way (Behzadan and Kamat 2010). This algorithm is not only useful for civil engineering but also has the potential for use in other fields such as medicine, architecture, and design. One main limitation of this system was that it used multiple tethered bulky devices.

Fig. 3-27. Outdoor mobile AR for architecture

A few years later, these AR systems were integrated into handheld displays and web technologies for general use. Bae, Golparvar-Fard, and White (2013) produced a mobile phone-based and cloud-supported context-aware application. The system did not require any extra equipment for tracking, and it was compatible with the majority of smart mobile devices. This AR application compared newly taken photos with those in a database of pictures with text descriptions, doing so quickly through the use of cloud technology. Meža, Turk, and Dolenc (2014) developed a mobile application for the editing, detecting, and converting of 3D models of buildings before making changes to them in the physical environment. The application built a model of the building and then paired it with professional 3D modelling software.

According to Erra and Capece (2019), AR systems can detect the environment by using the data gathered from geo-location tracking and comparing it to a related database. A bus stop, bridge, building feature, or tourist map can be determined and designed using AR tools according to variables such as usage frequency information or electricity requirements.

In another example, Panou et al. (2018) developed a location-based mobile AR application using gamification components for tourists. The study used HoloLens, one of the best HMDs available, but the results showed that such comprehensive AR systems still have the downside of needing bulky devices.

As is known, we use QR codes, social media, cloud computing, and other rapidly emerging technologies in our daily lives in ways that are reshaping big data day-by-day. Accordingly, engineers and architects can produce designs using the data of both AR and intelligent systems. The solutions with the best probable success can be visualised to support decision-making processes, as in the study of Rehring et al. (2019).

Several automotive companies use AR technologies to support collaborative detection. AR systems not only facilitate the visualisation of systems and mechanisms but also provide enormous potential in manufacturing such as in the tasks of assembly, maintenance, service, repair, inspection, product development, and telerobotics (Ong, Yuan, and Nee 2008). According to Berkemeier et al. (2019), AR systems have spread throughout the industrial fields for their provision of communication, documentation, process guidance, notification, data visualisation, automatic control, education, inventory management, automated ordering, resource allocation, text handling, and navigation. As can be seen, AR systems facilitate many processes for the designing of indoor or outdoor environments, systems, and mechanisms.

Fig. 3-28. AR for a mechanical inspection

AR systems can be used to reinforce education in architecture and engineering as well. Such training is usually mobile-based to reach a broad audience through easy accessibility. For instance, Martín-Gutiérrez et al. (2015) developed a mobile application to visualise the working mechanisms and features of electrical laboratory components for mechanical engineering students. The students were able to learn about electrical components in this low-risk LE, individually or collaboratively, without teachers' assistance. Their application was marker-based and worked by allowing users to observe 3D models via webcam. According to students, this AR tool was a low cost, easy to use, attractive, and useful LE (Martín-Gutiérrez et al. (2010). Similarly, Luo and Mojica Cabico (2018) produced a marker-based AR application using SketchUp, AutoDesk, Unity, and Vuforia to teach bridge engineering spatially. The result of the study indicated that the AR application enhanced students' learning experiences and knowledge acquisition processes. In another example, manuals and lab instructions were defined using a marker-based AR application that was developed using Vuforia and the Unity game engine for electronic engineering students (Baloch, Qadeer, and Memon 2018). Dong et al. (2013) developed a marker-based AR application to teach civil engineering students how to integrate 3D and 4D CAD models and to reduce the misinterpretation of spatial, temporal, and logical aspects of construction planning information. Their tabletop AR application provided collaborative LE with HMD support and students showed better learning outcomes. Chen et al. (2011) offered a marker-based AR application for engineering graphics education to represent 3D solid models of 2D drawings.

Fig. 3-29. AR for an electronics laboratory

The integration of web technologies into AR systems has the potential to present an alternative way of supporting distance education and enhancing eLearning tools. From this point of view, Borrero and Márquez (2012) developed an augmented remote lab for electronics engineering students. The students could control a remote electronics board using physical markers. Virtual switches are connected to this board, allowing students to observe 3D models on a 2D monitor.

Furthermore, if the students had access to 3D goggles and transmitters, they could observe the mechanism on the board and manipulate the components on an integrated console. This system was developed for students who had prior knowledge of robotics and industrial automation. Liarokapis et al. (2004) developed a completely web-based AR application using Web3D for the teaching of machines, vehicles, platonic solids, and tools to mechanical engineering students. This system presented realistic 3D visuals thanks to the use of ARIFLite.

Salah et al. (2019) produced and experimentally tested an AR system to enhance the manufacturing sustainability skills of engineering students. They defined each component of 3D models in the application to create a reconfigurable manufacturing system. The students gained experience with 3D virtual models instead of actual robotic systems. This system used a projector, projector screen, hand wand controller, and shutter glasses with a head tracker and controllers. The results of the study showed that the developed AR system was a useful learning tool by which to achieve desired learning outcomes which demonstrated (1) knowledge, (2) cognitive skills, (3) interpersonal skills and responsibility, and (4) communication, information technology, and numerical skills.

3.5.5 AR in Entertainment

People always want to have a good time and playing with knobs in digital games is a sure way to provide enjoyment. Digital games have the potential to be addictive through enticing visuals, animations, levelling, badges, and competition components; nevertheless, AR has quickly stepped into the game industry.

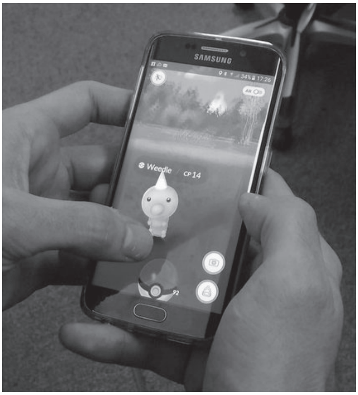


Fig. 3-30. Pokemon Go

Pokemon Go is one of the most popular AR games for outdoor usage, directing users to discover the environment to complete particular tasks collaboratively. Today, Pokemon Go has more than 5 million daily users and a total of 147 million monthly users all over the world. Promoting an outdoor and collaborative game experience instead of sitting and playing in a fixed location is the main characteristic of this location-based AR game. According to Alha et al. (2019), the pleasure of progressing in the game is the main reason why users keep playing the game and playing it frequently.

Piekarski and Thomas (2002) developed the ARQuake game for the outdoor environment. This game had the restriction of bulky devices because it was played with a tethered HMD, IMU sensors, a PC, and controllers. The enhanced 3D virtual objects presented on the visuals of the real world clarified users' understanding of certain real-life physical elements and metaphors related to them. Other popular game-oriented frameworks using AR include MicrosoftRoomAlive, MicrosoftHoloLens, and RoboRaid (Von Itzstein et al. 2017).

Fig. 3-31. AR Sandbox

AR toolbox can also provide multi-user observation of 3D models. Collaborative AR applications, like 3D sandbox storytellers, can be developed using this AR toolbox (Mine et al. 2012). Walt Disney Imagineering and Disney researched and established a projection-based AR toolkit to help with the creation of the spatial representation of augmented 3D objects, dynamics, and interactive spaces. AR can be used to reinforce museum experiences, and research results have shown that AR not only attracts tourists and provides an enjoyable time but also facilitates their learning processes (Ma and Choi 2007). Location-based AR systems have a significant role in the tourism field to enhance cultural experiences (García-Crespo et al. 2016).

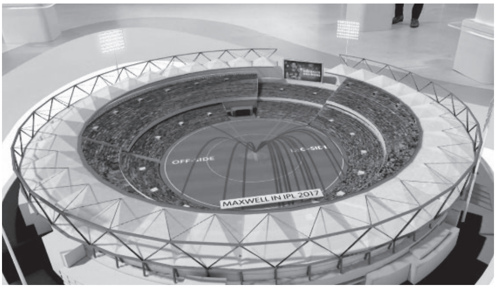


Fig. 3-32. AR sport channel

Nowadays, AR is everywhere! Sports channels use AR systems to explain game strategies, home design companies create miniature prototype designs of your house and rooms, and textile companies can dress you up in selected clothes. Such systems have a few problems in calibrating the integration of real and virtual objects, but numerous algorithms already exist to solve these issues (Lyu et al. 2005).

Emerging toy technologies are already adapting to AR systems. Drones and other integrated devices like Quadcopter are controlled or enhanced using AR technologies to experience a different environment and conditions (Bhaduri et al. 2018, Kim et al. 2018). Self-driving cars can be tested using HMD goggles via mirror cars (Haeling et al. 2018).

3.6 Summary of Chapter 3

- AR systems use various kinds of sensors and tracking technologies to capture the physical environment and movements.
- The two main types of AR are marker-based and markerless-based systems.
- Marker-based AR systems are easy to develop and use fiducial markers to represent digital content.
- Markerless-based AR systems have a more complex structure than marker-based systems and use visual search systems and SLAM algorithms. Location-based AR is a basic version of markerless-based AR.
- AR interfaces are presented via display systems such as (1) HMD, (2) handheld displays, and (3) spatial displays. Handheld displays are the most common type thanks to the accessibility of mobile technologies. Each display system has its advantages and disadvantages.
- AR interfaces are separated into four main categories according to interaction techniques: (1) tangible, (2) collaborative, (3) hybrid, and (4) multimodal.
- AR applications can be developed through the integration of AR SDKs into game engines. Each SDK provides particular functionalities.
- AR applications have several advantages, especially in educational settings, such as providing better collaboration,

experience, inquiry, and individual learning; and increasing memorisation, motivation, and learning outcomes.

- AR environments have large-scale usage in many professional fields, such as education, medicine, the military, engineering, architecture, and entertainment.

Chapter Four

MR in Education

The constructivist approach to education aims to activate analysis, synthesis, and evaluation of knowledge to provide comprehensive learning (Wang and Hannafin 2005, Macleod and Sinclair 2015), which indicates meta-cognitive abilities. Discovery-based, problem-based, inquiry-based, and experiential learning are the most common and effective constructivist learning strategies, all requiring participation in and the experiencing of the learning environment (Savery and Duffy 1995, Kim 2005, Kirschner, Sweller, and Clark 2006). You might be wondering how you can use MR systems to create constructivist learning environments. Learning scenarios, tasks, visuals, and collaboration are the most common aspects being developed to make exploratory and active LEs. Students can build upon prior knowledge and build the scaffolding of their second layer of knowledge using these active learning strategies and approaches. In addition to active participation, MR systems provide multiple perceptions and make it possible to create LEs well-structured for the constructivist learning paradigm; indeed, these systems are becoming the new trend in teaching and learning.

There is a wide range of research analysing the effectiveness of MR with respect to the motivation and learning outcomes of students (Lee 2012). The emerging educational virtual and augmented reality applications used in primary schools, secondary schools, higher education, universities, and professional training over the last few years have investigated how to reinforce users' imaginations and create new MRLEs for different disciplines.

4.1 VR in Education

Offering (1) 3D high-fidelity representation, (2) the real-time recording of movements, (3) natural navigation and communication, (4) immediacy of control, and (5) personalized and repetitive learning are the fundamental features of IVRLEs, systems which increase the presence and learning outcomes of learners (Lenz et al. 2015, Dalgarno and Lee 2010). From the perspective of Dede (2009), immersion has the potential to enhance learning in at least three ways: enabling (1) multiple perspectives, (2) situated learning, and (3) transfer.

A high-fidelity MR environment that offers active participation increases immersion, and the multiple stimuli of MR enhance perceptions. With these strengths, appropriately designed MR applications can support learners with different cognitive styles. In these environments, they can directly and instantaneously control objects in the learning scenario. They can experience, observe, discover, and synthesise the situations within the VW, activating meta-cognitional processes as knowledge transfer and acquisition processes are facilitated.

As discussed in chapter 2, VR environments have the potential to simplify the learning process by increasing student's motivation, comprehension, and imagination abilities. They provide individual, experiential, and discovery-laden LEs. Inspired by these qualities, Iidal et al. (2017) developed a brain-computer interaction game system and tested the system with naturalistic user experiences in both 2D and 3D VR environments. The results of the study showed that the 3D environment had superior impacts on operability, immersion, ease of concentration, and fun, which are all significant components of learning. The human brain uses dopamine to transfer information, and motivational factors increase dopamine levels. The vivid structure of a VW is generally sufficient for motivation but be aware that long-term usage of these technologies requires additional motivational design components for the continued facilitation of learning using dopamine.

4.1.1 VR applications for primary school

Using VR technologies to reinforce the learning process has several advantages and disadvantages. Analysing a sample of contemporary educational VR applications can be useful to help understand what they are.

Fig. 4-1. VR in primary education

K-12 education is highly significant in the shaping of the characteristic abilities and thinking styles of children because active participation in the educational environment has an enormous role to play in the reaching of desired learning outcomes.

One systematic analysis of studies on IVE usage for K-12 education children revealed that the knowledge, ability, and skill-based outcomes of the reviewed examples supported both typical and special education needs. The significant benefits of IVR were especially evident in skill-based education, and it increased motivational factors for students (Queiroz et al. 2018). On the other hand, the HMD-based structure of IVR presents difficult challenges in implementation for primary education. K-12 students have much smaller physical proportions and require more ergonomic and specially designed goggles. Younger children are likely to damage the fragile and miniature technologies included in HMDs. K-12 students can be incredibly enthusiastic, energetic, and excited to explore the virtual world, meaning that expensive HMDs will usually require teacher supervision rather than free use. Being less likely to break and cheaper to replace, mobile integrated HMDs are generally better options for young learners.

Like all HMDs, latency issues should be minimised to avoid unpleasant side effects such as cybersickness. Studies on VR applications for primary education usually centre on non-IVR rather than IVR because of these issues. There are thousands of computer-based e-Learning materials for each level of primary education, and researchers have evaluated the effectiveness of well-designed examples.

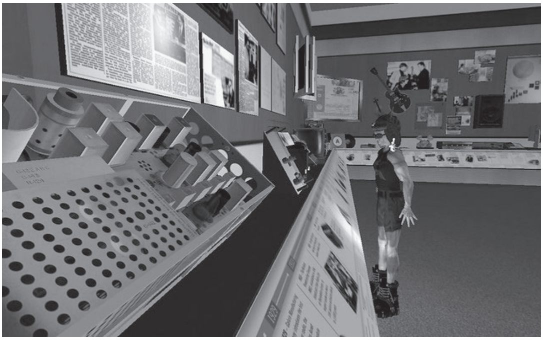


Fig. 4-2. VR museum interface

I only summarise some of this research in computer-based non-IVR environments for primary education because of the IVR focus of this book. One example is a computer- or smartphone-based VR that taught pedestrian safety skills to students (Schwebel et al. 2018, McComas, MacKay, and Pivik 2002). The empirical research showed that children learned safe street crossing procedures and transferred their knowledge to real-life (McComas, MacKay, and Pivik 2002), and the self-sufficiency of students increased (Schwebel et al. 2018) after a computer-based VR training process. Sun, Lin, and Wang (2010) developed and implemented computer-based 3D VR to teach the sun and moon systems to fourth-year students. According to the research results, the experimental group achieved better grades than the control group. A computer-based 3D digital museum for primary and secondary school students was developed by Ying et al. (2019) to get around the limitations of actual museum visits (e.g.

transportation, lack of evaluation). The results of the study showed that the average learning achievement of digital museum visitors was higher than that of actual visitors. The participants said that the digital museum's instructional resources were more efficient and convenient to access. Abdullah, Mohd-Isa, and Samsudin (2019) used problem-based learning strategies in a computer-based 3D VR environment to solve various scenarios in biodiversity. The results indicated an improvement in the collaborative working skills and self-directed learning of students. Another research project used scientific practice-based activities in a spherical video-based VR to help educate an elementary school class. Attitudes of lower performing students were higher in contrast to higher performing students, but the overall problem-solving skills and learning outcomes of all participants improved (Wu et al. 2019). According to Yeh (2010), 3D rotation can be hard for young children to understand because of the non-communicable nature of the topic. Computer-based VR can facilitate their perception of 3D manipulation and mental movement through visual presentation.

STEM education is a primary driver of early education policy in most countries. According to Parmar (2017), experiencing VR applications increases student interest in computer science and supports the STEM paradigm. Several virtual labs have been developed to support STEM education for primary schools. Herga, Čagran, and Dinevski (2016) used a virtual laboratory to visualise chemical experiments and concepts for seventh-year students. The research determined that students increased their knowledge thanks to dynamic demonstrations. In another example, a 3D computer game for the learning of geography was developed for fourth- and fifth-grade students. According to the research results, the intrinsic motivation and learning outcomes of the pupils had statistically positive significance over the traditional learners (Tüzün et al. 2009). A 3D virtual lab was developed to demonstrate the water cycle process in nature for primary school physics training (Bogusevschi et al. 2018, Bogusevschi, Muntean, and Muntean 2019). Participants found this environment useful and enjoyable. In a study by

(Migkotzidis et al. 2018), some chemistry and wind energy virtual labs were developed using game analytics, and detailed tracking detected the behavioural data of learners. The results showed that both virtual labs facilitated users' decision-making and adaptation to learning content.

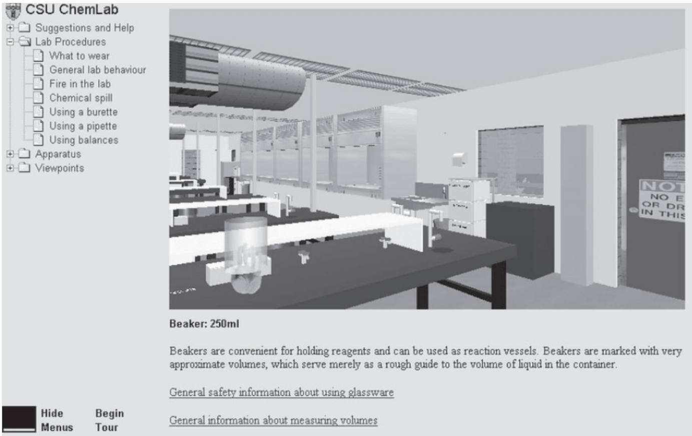


Fig. 4-3. Virtual lab interface

A VW has also been developed to teach natural science and ecology with pedagogical theories and curricular objectives in mind. The experimental analysis of these applications indicated that there were no significant differences between the test and control groups concerning learning effectiveness, but the motivational factors of the test group did increase (Wrzesien and Raya 2010).

Fig. 4-4. STEM education using Cardboard for primary education

There are a few IVR applications for primary school students. I think one of the most widespread VR projects in use is VRSchool, an app created by the University of Newcastle using Minecraft to support STEM education. However, there is less experimental data concerning the effectiveness of this project. Olmos-Raya et al. (2018) developed both immersive and non-IVRLEs for the teaching of the birth of agriculture, plagues in Europe, and the industrial revolution to secondary school students. The study explored motivational differences between the students who used HMD-based IVR and tablet-based non-IVR. The results indicated that both VR types had positive effects on motivation. IVR has a significantly positive impact on the emotional status and knowledge retention process of students compared to a non-immersive environment. Çakiroğlu and Gökoğlu (2019) designed and integrated the SecondLife 3D game environment into HMD-based

Fig. 4-5. CAVE systems

VR technologies to train young children about fire safety. The VRLE was implemented for ten children (ages 9-11) to observe their changing behavioural statuses. The results showed that the children achieved positive learning outcomes and became able to transfer their knowledge into real-life situations. According to the authors, there is a crucial relationship between the presence level of the VR environment and the transference of skills to real-life conditions. Zikas et al. (2016) developed an IVR and a multimodal AR using gamification components for the exploration of the archaeological site of Knossos, but they did not perform experiment tests.

IVR environments provide a useful tool to help support the adaptation of disadvantaged students as they learn about the physical world at an early age. This was demonstrated when Ip et al. (2016) developed an IVR environment that utilised four-sided CAVE technologies. The team created six unique learning scenarios that facilitated the transition process of autism spectrum disorder students from kindergarten to primary school. The results of the study indicated that the emotion recognition, effective expression, and social reciprocity abilities of students improved after 14 weeks of using this application in the safe and controllable IVR environment. Lorenzo et al. (2016) designed and developed an IVR environment for the improving of the emotional skills of autism spectrum disorder children whose ages ranged from 7 to 12. A semi-CAVE (L-shaped screen) was used to visualise ten different learning scenarios for social situations. A robot with an eye-in-hand camera system was used to determine the children’s current

Fig. 4-5. VR Technologies for special education

emotional status and mood through the recognition of facial expressions. This system evaluated the appropriateness of children's behaviour automatically. After the 10-months-long implementation of the IVR with 40 children, where each participant completed 40 sessions, the emotional behaviours of participants showed significant improvement.

4.1.2 VR applications for high school and university

4.1.2.1 Mathematics and geometry

A co-location collaborative IVR tool, Construct3D, was developed by Kaufmann and Schmalstieg (2006)/Kaufmann, Schmalstieg, and Wagner (2000) in order to simplify the learning processes for 3D geometry and mathematics. An HMD, handheld pen, and personal interaction panel were used as hardware components to provide 3D visualisation and interaction. They evaluated the usability of Construct3D in an experiential study with students. The results showed that Construct3D was an easy to use tool thanks to useful design components such as the menu, navigation, and language. Lai et al. (2016) developed the HMD-based IVR environment Geometry Explorer to facilitate geometry education. They used game components, such as scoring, to increase the intrinsic motivation of students.

4.1.2.2 Science

Physics: Kozhevnikov, Gurlitt, and Kozhevnikov (2013) used both immersive and non-IVR environments to teach relative motion concepts to university students. The results indicated that both immersive and desktop-based VR environments helped students to understand concepts and epistemological beliefs better. They also noted that the problem-solving skills and performance of the IVR learners were significantly better than those of other learners.

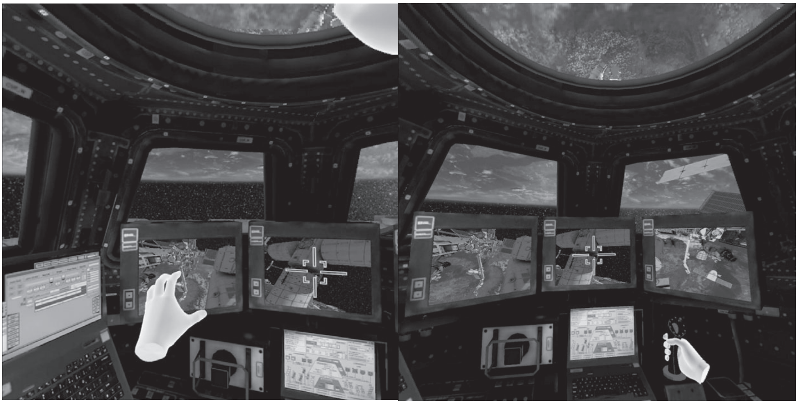


Fig. 4-7. IVR for astronaut training: Interface of ISI VR app

Kaufmann and Meyer (2009) developed PhysicsPlayground to present supplementary material for physics lessons. They used PhysX and Studierstube frameworks for calculations for the analysing of forces, masses, paths, and other properties of objects. The users wore an HMD to participate in the experiments and interacted with the virtual objects using a 3D pen on a personal interaction panel. According to educators, PhysicsPlayground was a useful tool to reinforce students' knowledge.

Biology: As previously discussed, VR studies have generally focused on the motivational effects on students or have fixated on the design and features of the VR applications. There are less empirical studies that determine the educational benefits of IVR for students. One such exciting research study (Makransky, Terkildsen, and Mayer 2017) was run with 52 university students who used a science lab simulation to learn about mammalian transient protein expression. Two multiple-choice tests were applied to measure learning outcomes and the knowledge status of the students. Test (HMD-based IVR learner) and control (computer-based learner) groups were randomly assigned in this 2 x 2 mixed design research. The level of presence, learning beliefs, and satisfaction of the students were analysed using a self-survey, and EEG was used to determine the cognitive overload status of students. The results showed that both presence and motivation were higher for IVR learners; however, they learned less and were cognitively more overloaded than computer-based learners. These findings are ambivalent because the ANOVA and ANCOVA parametric statistical analyses were used on such a small sample size.

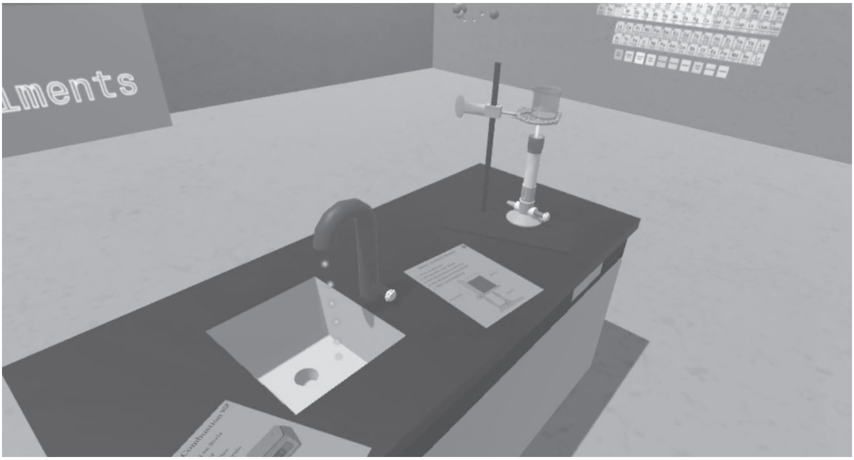


Fig. 4-8. Science lab VR

Parong and Mayer (2018) applied a similar methodology to their research to determine the impacts of PC- and HMD-based VR on students' motivation and learning outcomes. Data gathered from 55 students showed that IVR was more effective than PC-based learning for motivation, although the learning outcomes of PC-based learners were rated as higher. They then applied a second phase with added discussion and summarisation after the IVR learning process. At the end of the second phase, they observed improving learning outcomes for IVR learners.

4.1.2.3 Medicine

Medicine is the field of some of my research results (Taçgın 2017a). I applied IVR iteratively to 14 third-year nursing students to help teach them preoperative procedures and concepts. Each participant implemented IVR 4 times in a month. I observed that the students lacked knowledge of how to use IVR technologies in the initial session; however, they learned it quickly. After the third session, their technological adaptation level was acceptable, and then they started to focus on the learning scenario. I observed that simultaneously learning both the usage of IVR technologies and related lecture topics can be the reason for the cognitive overload and lower learning outcomes seen in other studies. The majority of students seemed familiar with PC and PowerPoint-based environments, but they were not familiar to the same level with IVR technologies. Understanding 3D orientation and rotation in the IVR environment can cause confusion. In my opinion, the learners' technology-usage abilities should be addressed before relating the lecture topics if better results are to be gained.

Fig. 4-9. Medical VR

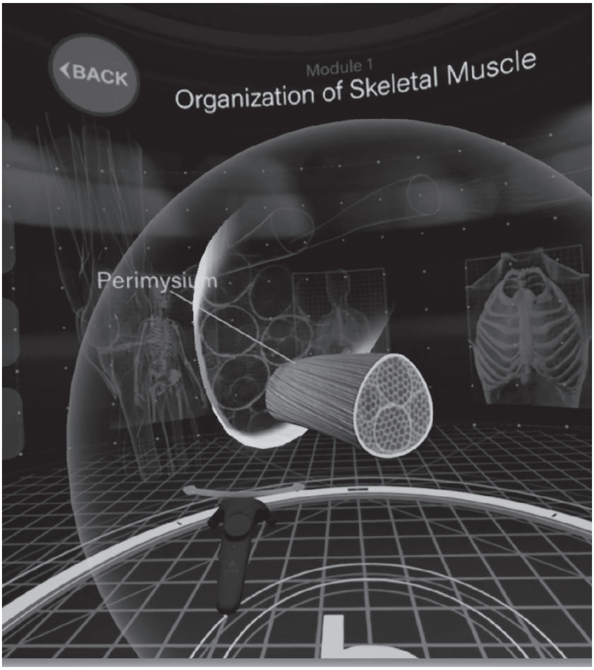


Fig. 4-10. Anatomy instruction with VR

IVR applications are highly prevalent in the medical field. For instance, an Oculus HMD was used to develop an IVR learning tool to teach the five main stages of cricothyrotomy procedures (Buń, Górski, and Turkowska 2018). Similar hardware components were used to develop the ovidVR that provides training for the surgical process of knee arthroplasty procedures (Papagiannakis et al. 2018). These applications have not been experimentally tested.

360° panoramic videos are used to achieve a high level of immersion and presence within IVRs in the teaching of laparoscopic surgery. Experiential test results showed that the motivation and attention levels of participants were higher than those of traditional learners (Huber et al. 2017).

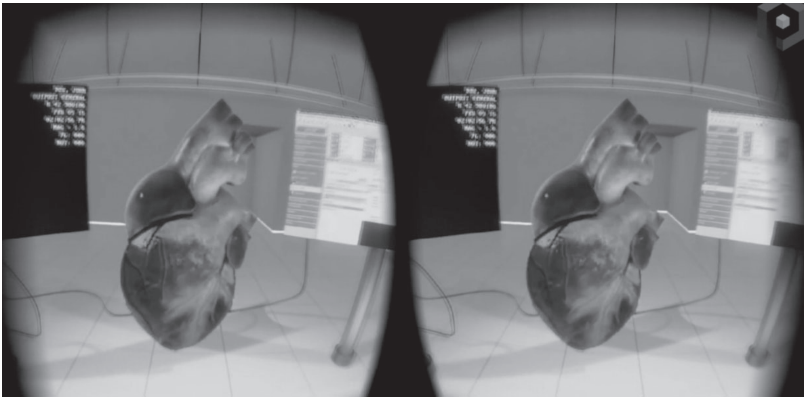


Fig. 4-11. 3D organ representation

Huang, Liaw, and Lai (2016) applied desktop and projection-based VR systems to teach the nervous, respiratory, digestive, circulatory, urinary, and skeletal systems to undergraduate biology students. The data gathered from 167 students indicated that VR offered an easy to use and useful learning tool for medical students. VR provided more immersion, imagination, and intention in comparison to a desktop-based environment. I have also recently viewed the 360° VR products of Darryl Clare of Central Queensland University for the increasing of the paramedic skills and decision-making processes of students.

4.1.2.4 Architecture and engineering

IVR environments can help with the spatial awareness of students. They improve students' real-life lighting, digital, and graphic representation skills (Navarro et al. 2019). Angulo and de Velasco (2014) implemented an interactive university-level architecture and planning application using 6DoF HMDs to teach 3D spatial geometry, design, object, colour, and light concepts to novice architecture students. The results showed that the space perceptions of the students increased with regard to the design of architectural spatial experiences, and they wanted to spend more time in the LE.

Another benefit is that the students were more confident in sharing their ideas when they were learning in the IVR.

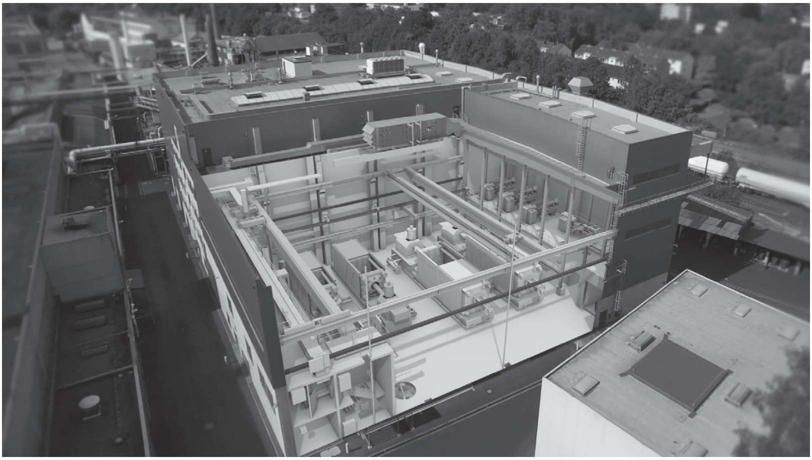


Fig. 4-12. IVR usage for environment design and architecture

Dinis et al. (2017) developed the ELBigMAC project for civil engineering students using the Unity game engine and Autodesk modelling tools. An HMD and Leap Motion were used to provide gesture control. The results showed that gesture control and IVR facilitated the knowledge transfer processes and enhanced the comprehension potential of learners. Bharathi and Tucker (2015) used both immersive and non-IVR for engineering design lessons for distance-learning students. The performance outcomes and application completion time of IVR users were significantly better; however, according to the participants, the joystick controller decreased the level of presence.

4.1.2.5 Art

Parmar (2017) developed IVR dance teaching environments with Kinect and non-IVR dance teaching environments using the Unity Game engine. According to the research results, the IVR environment was more helpful for remembering, understanding, applying, and analysing choreography. The telepresence and social presence perceptions of IVR learners were significantly higher than for the other learners. Another benefit was that the participants' attitudes towards computer programming became more positive after using the IVR application.

RiftArt was developed to teach an art history lesson, allowing teachers to configure artwork models inside a virtual museum room. Teachers added to the multimodal annotations during the lesson. The students were able to synchronously observe the teachers' interactions in the VR using Web technologies. HMD and PC technology were used to test RiftArt, and the results highlighted the motivational effects of the HMD-based version (Casu et al. 2015). Park et al. (2017) developed an immersive model-crafting environment using HMD and Leap Motion technologies. They compared and evaluated both the immersion and interaction potential of the environment against a non-immersive one. As might be expected, VR users had more immersion and interaction thanks to the gesture controls provided.

Fig. 4-13. VR for art appreciation lessons

Fassbender et al. (2012) explored the learning effectiveness of teaching music in the VirSchool environment. They used three monitors and a partial CAVE to provide immersion in the teaching of history lessons using both music and non-music settings. They applied the parametric tests of a paired sample t-test and ANOVA on the data gathered from 48 participants. According to the results, the information recall and retention using a 3-monitor setup in the condition without music was better than under the other conditions.

Fig. 4-14. Collaborative VR environment

4.1.3 VR applications for in-service & professional training

The improvement of professional skills requires the experiencing of various cases to learn how to solve different issues specific to a particular field. Professional training cannot always provide the necessary on-the-job knowledge and skillset development because of problematic risk, speed, or social factors. IVR technologies offer significant potential to gain the required experience for in-service and professional training.

Teacher education is highly important in the shaping of the characteristic abilities of children, and adapting to up-to-date technologies has an essential role to play in it. Computer-based VR environments are currently used for the educating of teachers for classroom management, special education, and up-to-date technologies. According to the results of Passig's (2011) study, after experiencing some 3D VW training scenarios regarding dyslexic students, the cognitive awareness and detection capabilities of teachers significantly increased in contrast to participants who received a video training environment.

There are a few studies on IVR for teacher education. One immersive, collaborative VR project was developed to support the classroom management skills of teachers and teacher candidates. The IVR environment was designed using Unreal Engine and Autodesk tools, with Oculus DK2 and Kinect as hardware components. In this IVRLE, the teachers could randomly experience 500,000 possible different classroom situations involving 24 virtual students in a 3D virtual classroom. The application was based on an individually developed behaviour tree algorithm. During the teacher experience, the supervisor could observe the decisions and actions of the teacher on a 2D monitor. This IVR was applied to 22 teachers, and the data gathered showed that the technology acceptance level of the teachers increased. IVR was also useful in terms of critical usability factors such as safety and comfort, believability, simplicity, acceptability, extensibility, affordability, and mobility (Lugrin et al. 2016).

Another IVR environment was designed and developed using the Unity game engine and Autodesk tools to simulate drug usage in schools. The teachers experienced learning scenarios with the Oculus Rift HMD. The EEG, heart rate, and head movement of the participants were logged and analysed before and after the IVR implementation to determine the variance in emotional status and moods of the teachers. Results revealed that before IVR implementation, the teachers had not accepted to take responsibility or control of the drug usage of their students. According to researchers, the teachers may either have lacked awareness or were apathetic towards the issue. However, after the teachers experienced the IVR application, a substantial impact on emotional states and moods was observed against drug usage (Stavroulia et al. 2018).

IVR has positive effects for doctors in providing an idea of the operating room experience. A virtual operating room and patient were designed and applied to both practising doctors and university staff to demonstrate the impact of presence using a CAVE-, HMD-, and PC-based VR system. According to the results, the CAVE and HMD were useful for the participants, but the four-wall CAVE was more effective for real doctors' sense of presence. That might have occurred because as Ochs et al. (2019) suggested, the expertise level of participants has a role in their perceived sense of presence.

IVR systems are not only used for visualisation and inspection in the engineering field but are also useful tools for engineers' in-service training. For example, VRETS was developed using an Oculus Rift and Leap Motion, and it was found to be an easy to operate LE thanks to intuitive interaction. The interest, immersion, satisfaction, and perceived learning effectiveness of participants were more positive than before after using VRETS (Im et al. 2017).

Multimodal sensory IVR was used to develop an ERAU lab to support immersive technologies for the fields of education, medicine, and the military. A considerable team created the lab shown in figure 4-15 using an HTC Vive, Oculus HMDs, and several additional hardware components (Haritos and Fussell 2018).

Fig. 4-15. VR training for space

IVR has been used for astronaut training processes for a long time (Kong, Liu, and An 2018) thanks to the unique chance it offers to gain professional experience in a low-cost, low-risk, realistic environment with unrivalled opportunity. Hybrid systems of astronaut training have more complex infrastructure because of specialist functionalities such as the Virtual GloveboX. This multi-user system was developed to simulate the scientific experiments of biology and chemistry applications in space using high-resolution computer graphics, magnetic tracking, and haptic feedback devices (Twombly et al. 2006). Yue et al. (2016) developed an immersive astronaut training device and experimentally evaluated the presence, immersion, pleasure, satisfaction, and fatigue levels of the users using data from ECG, reaction times, error rates, and video recordings. The results showed a better user experience and learning performance, but the high level of fatigue was still an unsolved issue for the IVR.

IVR not only simulates high-risk conditions for professional training, but it can also be used to teach social skills. The familiarity of employees with the social situations they might encounter increases, and they might feel more confident after experiencing different cases using IVR. According to a massive project with a multidisciplinary team, Nedel et al. (2016) argue that IVR has the potential to reduce workplace accidents. Before developing their simulation, they gathered data from 200 volunteer participants to determine risk factors and build psychosocial behaviour profiles. Then, they developed IVR environments using both Unreal Engine and Unity. Sense of presence was their first target feature, so they organised their IVR as an HMD-based system and used the Kinect for gesture control. Data gloves were also included but were not useful for the participants. They applied IVR using the mini-CAVE system to avoid cybersickness. Eight main scenarios were simulated: a central place, traffic accident, parking lot, robbery, bank ATM, lottery retailer, and restaurant. Twelve different behaviours were added to each of these scenarios. The perceived presence of 15 employees from different professions was evaluated using several data collection tools, including EEG. The results showed that IVR was sufficient for presence but had issues with regulating the emotional behaviours of participants. According to researchers, the lack of facial expressions of the simulated characters might be the reason for this outcome. There has been similar research on IVR for the simulating of real-life emergencies. A test group used IVR for eight weeks for mindfulness-oriented meditation. The results showed a decreased heart rate and corrugator muscle activity for the participants, which indicated increased mindfulness and reduced anxiety levels (Crescentini et al. 2016).

IVR is used for teaching hazard recognition to different types of workers. Construction workers can experience emergency or accident situations through various 360° environments and receive instant feedback for their actions (Jeelani, Han, and Albert 2017). Easy-to-use and interactive HMD-based intuitive IVR systems have been shown to provide better learning and experience for mining training systems (Zhang 2017). IVR provided short-term learning processes and long-term confidence for underground coal miners with improved orientation in virtual space, motion, and object manipulation skills (Grabowski and Jankowski 2015).

According to Schmid Mast et al. (2018), IVR has the potential to improve interpersonal skill training in organisations by offering constant feedback and good transfer from training to actual work, increasing motivation, experience, and self-efficiency, and decreasing anxiety. Lee et al. (2017) developed 360° and 2D videos for business classrooms, and they only used Cardboard as goggles. The results showed no significant differences regarding the levels of novelty, reliability, and understandability of the content for the 360° video and 2D tablet users. The reason could either be the quality of content or the low-quality output of the Cardboard system, something I have experienced with a 360° business negotiation training project made by Andrew Patterson from the University of Auckland. In my opinion, the lack of fidelity and variety of scenarios are still problems to be resolved if the desired outcomes are to be gained using VR technologies, especially in the field of social science. Interactivity and branched scenario structures should be integrated into these systems.

Fig. 4-16. 360° interview experience for HR

The popularity of sports opens up many opportunities for athletes to use VR to train, increase their skills, and improve their performance. For instance, SIDEKIQ was developed using an Oculus HMD and 4-wall CAVE for American football training. Ten trial playoffs were designed by the coach to train alternative strategies and improve the decision-making processes of players. After three days of IVR implementation, the decision making of the players improved by as much as 60% on specific subjects, including a noticeable improvement in pre-snap reads and in-game decision making (Huang, Churches, and Reilly 2015).

Bideau et al. (2010) developed an HMD-based IVR using motion capture for rugby and handball players. They captured the motions of eight rugby players and 12 handball goalkeepers to animate alternative scenarios. They applied the IVR environment to eight novices and eight expert rugby players to help them detect deceptive movements by estimating the approaching run of attacking players. They evaluated the anticipation skills of the participants using success rates and response time. According to the results, the participants, especially the expert players, had faster responses, and they better judged successful movements.

Similarly, Kojima et al. (2014) developed an IVR for baseball training using a Kinect and Oculus. They captured the movements of learners for comparison with targeted instructor poses. The IVR was evaluated as a useful tool to teach pitching skills after measuring the average throwing distance of participants. These examples demonstrate that IVR is adequate for skill training, even on the sports field.

4.2 AR in Education

AR technologies are more accessible to implement than VR in an educational setting thanks to easy-to-develop marker-based applications and the accessibility of mobile technologies. As mentioned in chapter 3, AR has numerous benefits for students that include increased motivation, satisfaction, learning outcomes, and memorisation through the provision of an accessible LE with constant feedback, tangible digital content, collaboration, and real-time active participation – all while reducing cognitive overload and learning time. On the other hand, some teachers can be resistant to applying new methods and may offer several excuses such as cost or the adequacy of traditional techniques (Lee 2012). Despite the resistance of some teachers favouring legacy methods, AR is being adopted at an accelerated pace in education. Entrepreneurial professionals and researchers have striven to get AR technologies adopted in classrooms in order to enhance and facilitate the learning processes of students in subjects like chemistry, mathematics, biology, physics, astronomy, and other K-12 and more advanced topics (Lee 2012).

4.2.1 AR applications for primary school

AR technologies, such as marker-based ones, are easier to use and adapt to LEs. This section explores current educational AR applications from K-12 up to the adult level. Garzón, Pavón, and Baldiris (2019) investigated the educational AR research of the last eight years in their systematic review study. The results showed that the number of AR studies on education had accelerated year-by-year and the majority of AR studies (65.5%) were executed in K-12 level education, with 1.6% of them for early childhood, 31.1% for primary, 18% for lower secondary, and 14.8% for upper secondary levels. By subject, 49.2% were for natural sciences, mathematics, or statistics, 16.4% for art and humanities, 11.5% for social science, journalism, and information science, 8.2% for information and communication technologies, 6.6% for engineering, manufacturing, and construction, 6.6% for health and welfare, and 1.6% for education.

Preschool AR applications help children to understand tangible and spatial content. Demonstrating this sufficient usage of AR, Yilmaz (2016) developed a marker-based mobile application using electronic magic toys for 5-6-year-old children. This application consisted of puzzle pieces to combine and then a reward for children in the form of visual objects or stories after the completion of their tasks. The researcher interpreted her observations as the children played interactively and liked the application, and 33 teachers evaluated this application as a useful teaching tool. Cascales et al. (2013) developed marker-based AR for teaching about animals to preschool children. The research results highlighted a significant improvement in learning outcomes for the experimental group. Tacgin and Ozuag (2018) developed Kartoon3D to facilitate children's learning processes for the teaching of letters, words, numbers and mathematical equations in three languages – Turkish, English, and Dutch. This application has not been experientially evaluated with children. AR is also capable of being used to teach spatial geometry concepts to preschool children. The study of Gecu-Parmaksiz and Delialioğlu (2018)/Gecu-Parmaksiz and Delialioglu (2019) on 72 preschool children showed statistical evidence of enhanced outcomes for the group, who learned spatial abilities with the aid of AR.

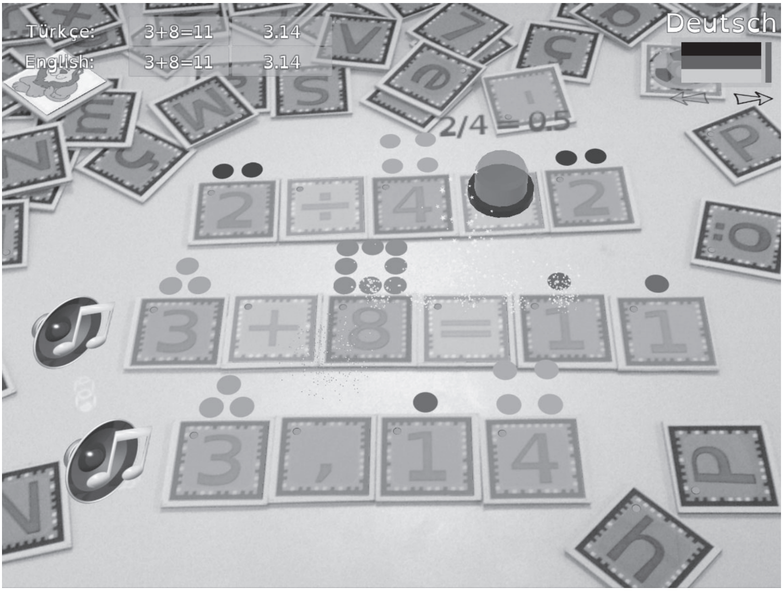


Fig. 4-17. Kartoon3D's mathematical equation teaching interface

There are several AR applications for primary school students. Salvador-Herranz et al. (2013) developed an LMS-integrated desktop AR application to teach ten different topics of various complexities in the natural and social sciences. T-test results between the pre-test and post-test showed the intrinsic motivational impacts of AR increased competence, interest, and the overall effort of the primary education students. Another AR tool was developed for the teaching of astronomy to primary school students, but the application was only evaluated by teachers (Antoniou et al. 2017).

4.2.1.1 AR applications for science training

EcoMOBILE, a location-based AR project, was developed to support middle-school students in learning more about the ecosystem and water quality. The researchers developed a mobile application (FreshAir), and probes were added as an extra hardware component to detect oxygen, turbidity, pH, and the temperature of water samples. Teachers supervised a field trip experience, and data was gathered to determine the attitudes and learning outcomes of the participants. The teachers' opinions and feedback were also used to analyse this collaborative AR application. The results showed that EcoMOBILE, as a student-centred AR, had multiple positive effects on students' comprehension (Kamarainen et al. 2013). AR was also evaluated as a useful and enjoyable learning tool by a group of primary school students who were learning about water cycles (Bogusevschi et al. 2018).

A SMART application was developed to teach fundamental concepts about animals and transportation to second-year students. The data gathered from 54 students indicated that SMART had positive motivational effects and increased the learning performance of participants, especially for the weaker students (Freitas and Campos 2008). Lu and Liu (2015) developed an AR application for primary school students to enhance knowledge of Taiwan's marine ecology and water resources. The results showed that AR had positive impacts on the confidence, satisfaction, and knowledge acquisition of the participants, especially for lower academic achievers.

A marker-based AR was developed to teach primary school students about the digestive and circulatory system of humans. Both 3D visualisation and audio content were used for the digital representation of markers. The AR environment was experienced by 39 fourth-year students using computer and webcam systems. The experiential research results showed that AR was not only useful for motivating students, but also facilitated the knowledge acquisition and retention of the children (Pérez-López and Contero 2013).

4.2.1.2 AR applications for social science training

AR is being used for the teaching of languages to primary school students. A computer-based AR pop-up book was developed based on Keller's ARC model for motivation to teach English skills. After being implemented for five students, the results indicated the positive motivational effects of the AR system (Mahadzir and Phung 2013, Chen et al. 2018).

A location-based AR inquiry LE was developed to provide a conceptual understanding of historical empathy to 53 third-grade students. The results showed that AR increased the conceptual understanding and the historical empathy status of students for both pre- and post-test conditions in contrast to traditional techniques (Efstathiou, Kyza, and Georgiou 2018). Novotný, Lacko, and Samuelčík (2013) used a multi-touch AR system to create learning material for the teaching of cultural heritage (Ruins of Topolcany Castle and the Old Town of Bratislava). Their system consisted of two 2D monitors. Two panels were used, with the background panel providing the interactivity and the foreground panel, which is a transparent overlay, providing a 3D visualisation of the results. This system was, unfortunately, not experientially evaluated.

Fig. 4-18. Mobile-based AR for art and museum experience

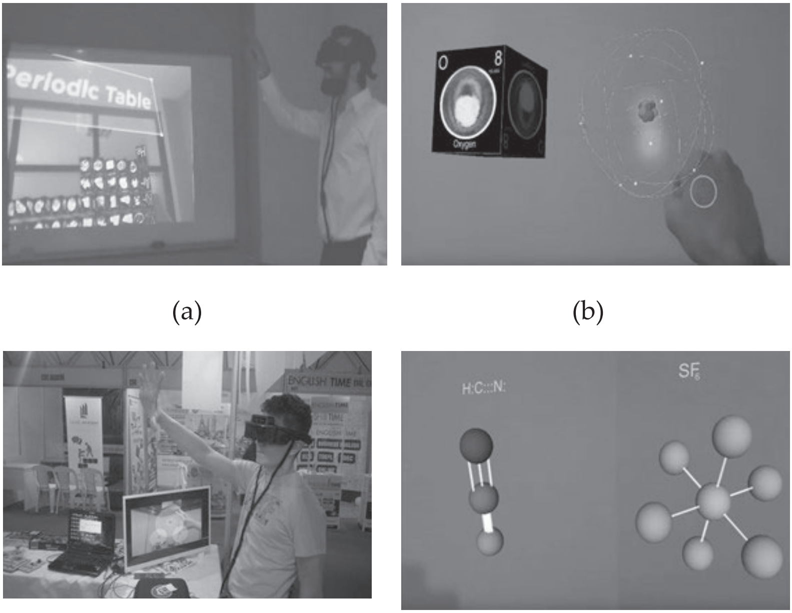
Other research results showed that a marker-based AR application developed to teach artistic elements had positive impacts on students' motivation but it was ineffective for increasing the academic achievements of the students (Sáez-López, Cózar-Gutierrez, and Domínguez-Garrido 2018).

4.2.3 AR applications for high school and university

Xefteris and Palaigeorgiou (2019) developed two different AR environments for the teaching of geography and history topics to undergraduate students who had pre-service teaching experience. They used tablet-based AR, finger interaction, and robotics for their game scenario about a European landmark. Pre-test and post-test results showed that the information recall and spatial relation abilities of the students significantly increased. According to Cronbach's Alpha results, the attitudes of participants were positively affected concerning easiness, focusing, learning preference, learning from robotics, and other associated skillsets.

Fig. 4-19. AR application for learning about Earth

Turan, Meral, and Sahin (2018) developed a marker-based mobile AR based on a physical geography lecture for social science education students. Forty students used the AR application, and the remaining 45 did not. The research gathered data from all of the 95 first-year students. AR increased academic achievement and decreased cognitive load. Mobile-based AR cubes were also used for the training of future chemistry teachers (Yang, Mei, and Yue 2018). Furthermore, my team developed an AR application using gesture control interaction that demonstrated the periodic table and some structures and interactions of atoms and molecules (Taçgın, Uluçay, and Özüağ 2016).



(a) (b)

(c) (d)

Fig. 4-20. Example scenes from our chemistry training applications: (a) Periodic table, (b) Atomic structure, (c) Molecular structure, (d) VSPER model.

Liarokapis and Anderson (2010) developed a low-cost marker-based AR application to teach the combination and functionalities of computer hardware components. They ran a pilot study on undergraduate students in informatics and information science. They added an AR puzzle game to support collaborative learning. According to the participants, the realistic 3D visualisation and interaction enhanced their learning process, and the application was evaluated as a useful tool with which to explore devices outside of the laboratory.

Cuendet et al. (2013) designed three different marker-based tangible user interfaces to develop an AR application reinforcing laboratory applications. They have been actively using these applications (TinkerLab) in logistic lectures at vocational schools. Bacca et al. (2015) developed the marker- and mobile- phone-based Paint-cAR to support the learning process of retouching paint on a 3D model car within the context of a vocational education programme for car maintenance.

Fig. 4-21. Collaborative and multimodal marker-based AR interface for chemistry teaching

Solak and Cakir (2015) designed an AR application for the teaching of English vocabulary. The experiential study results indicated an increase in both the motivation and academic success of the 130 undergraduate students from different disciplines.

There are many AR applications for the teaching of anatomical knowledge (Guerrero et al. 2018, Barrow et al. 2019, Kelly et al. 2018). Guerrero et al. (2018) used a QR-code-based mobile AR application to teach the skeletal system to nursing students and evaluated the data using TAM. According to the results, the motivation and the learning process of the students were enhanced after AR implementation. In another example, 3D character meshes were designed to teach undergraduate students about cells, blood vessels, and muscles. Gamification components were used in the designed meshes, and markers were integrated into them to provide tablet-based AR for the classroom. The majority of the participants evaluated this tool as good at explaining abstract concepts in an enjoyable way (Barrow et al. 2019).

AR has also been used to introduce lab equipment and machine usage in several fields. One such example is a biochemistry lab produced by Naese et al. (2019). Various mobile AR applications have been developed to demonstrate the connections, inputs, outputs, and working mechanisms of electronic lab equipment for the benefit of engineering students (Baloch, Qadeer, and Memon 2018, Martín-Gutiérrez et al. 2015). Juan, YuLin, and Wei (2018) developed an AR application for the reinforcement of the mechanical drawing skills of university students. Their data confirmed that the mobile-AR-supported group was able to use the technology to produce superior mechanical drawing results in contrast to the traditional 2D learners. The proficiency level, according to the course the students were taking, improved in difficult content areas, and there were improvements in spatial imagination capability and learning interest of the experimental group after AR implementation. In another study, a computer-based 3D AR application was developed to teach molecular biology and explain the protein data bank to graduate and undergraduate students. 2D and 3D environments were applied to the 60 participants, and the results showed a significant difference between the 2D and AR groups. The AR group showed increased satisfaction, media usability, and perception, and lower apprehension (Safadel and White 2019).

An ITC VR/AR application was developed using video and mobile technologies to teach undergraduate students in a textiles and clothing programme about sewing machines. It was used by people who had no prior knowledge of the related topics. According to the research results, AR was superior for in facilitating the learners' understanding of sewing techniques and basic terminology (Yip et al. 2019).

4.2.3 AR applications for in-service & professional training

In my opinion, being a highly qualified professional in a field does not bring superior abilities in all areas of perception. Good projects require iterative analysis and the prediction of alternative pathways to achieve the best possible outcomes. AR presents innovative, practical solutions to various business fields, such as medicine, maintenance, and engineering, with the capability to enhance the physical environment. Workers can better observe, evaluate, and train for alternative scenarios thanks to enhanced digital content. AR is also flexible to use because it does not require a completely structured virtual environment for the users and can adequately work in integration with existing physical components.

Fig. 4-22. AR interface for maintenance training

Anastassova and Burkhardt (2009) investigated the reasons for learning difficulties in automotive technicians by gathering data from trainers, training designers, and trainees. According to the results, training designers and trainers had an essential role for trainees but had several constraints in designing proper training material because of the multi-department structure of the company.

There is a need in this case for a dynamic interface that provides accurate and up-to-date information on all vehicle parts. A delay in receiving timely information was the other issue for both training designers and trainers. AR could offer a solution in providing a dynamic, collaborative VE in which for professionals of various disciplines to resolve the challenges of team projects interactively.

One of the rising sub-fields of AR is in maintenance, where it is being used to provide individual and collaborative detection and evaluation possibilities related to physical products. An AR application was developed by Mourtzis, Zogopoulos, and Vlachou (2017) for automotive technicians. The remote collaborative AR interface included a product-service system that provided a synchronous work environment for technicians and manufacturers. They used Vuzix smart glasses, mobile phones, and PCs as hardware components and developed the AR environment using the Unity game engine and the C# programming language. The system transferred malfunction reports at the time of inspection with cloud support. The system not only reduced the working load of expert engineers but also provided a proper work environment for the less experienced technicians. According to the researchers, this system has the potential to reduce cost and maintenance times. In another example, a fiducial marker-based remote collaborative AR application was developed for the teaching of maintenance instruction on how to replace the air filter of an auto engine (Wang et al. 2014).

Fig. 4-23. Co-location collaborative AR interface for vehicle inspection

AR and VR machine laboratory environments have been developed for the maintenance and industrial safety training for technicians, technologists, and engineers. The primary purpose of one study was to organise a safe LE in which to develop the decision-making skills of trainers before they faced hazardous, risky situations. That environment was designed using TAM and was evaluated as a highly useful utility with easy-to-use material by the participants (Velosa et al. 2018).

Occupational safety standards require people to apply appropriate procedures during work and maintenance tasks. The integration of AR systems into high-risk working areas helps to decrease workplace accidents. Tatić and Tešić (2017) developed a marker-based mobile AR application using Unity and Vuforia to provide safety and maintenance instructions following checklist items. They created a learning scenario with guidance from a real worker and utilised a special ID for each user. They placed markers on the machines in the physical workplace for the introducing of procedures. According to researchers, this AR system was useful in reducing accidents for less experienced workers. Pereira et al. (2019)/Gheisari and Esmaeili (2019) developed panoramic AR applications as a low-cost alternative to VR using 360° videos to teach construction safety to avoid workplace accidents.

A location-based mobile AR application was developed as a collaborative tool to reproduce sequenced activities following the agreement and protocol of the Civil Defence Agency. According to the participants, this application provided a low-cost and accessible LE with realistic virtual content of emergency situations (Sebillo et al. 2016).

Fig. 4-24. Gesture interaction using Leap Motion

AR technologies are being used in training medical staff to reduce risks and increase outcomes. Nilsson and Johansson (2008) developed two different HMD-based AR systems to introduce hospital employees to the usage of medical devices. These AR systems, which consisted of technologies and instructions, were evaluated by participants as acceptable for long-term usage. Loukas, Lahanas, and Georgiou (2013) developed a marker-based AR application combining endoscopic instruments for laparoscopic skill training. They used two different tracking algorithms to estimate the 3D poses of surgical instruments. Botden, de Hingh, and Jakimowicz (2009) adapted a suturing training module to the ProMIS AR simulator to develop laparoscopic suturing skills. The assessment scores of intermediate and advanced participants who used the module indicated increased knowledge and reduced suturing time, but the advanced student's practical performance did not change. These findings emphasised the efficiency of AR applications, especially for novice trainers. An HMD-based AR environment was designed to help radiologists learn the breast scan process during mammographic training. Radiologists need to draw marker-points on patients, and the AR training ensured that 80% of those who took the practice became more accurate at doing this (Tang et al. 2018).

Another HMD-based AR was developed using HoloLens and Leap Motion to provide telemedicine service to students in rural areas. The researchers simulated emergency room trauma conditions in the AR environment, and 12 novice participants experienced this scenario via gesture interaction under mentor observation. There were no statistical differences observed between the scores and mental efforts of the HoloLens and full telemedicine setup users. The HoloLens version was evaluated as a more effective learning tool by the mentor who participated (Wang, Parsons, et al. 2017).

Fig. 4-25. Recognising body movements using Kinect

AR systems can enhance sports training. Sieluzycki et al. (2016) developed a judo training AR system using Kinect sensors for both novice and professional judokas. The moves of professional judokas were used to train the system, which then compared those movements against those of participants to evaluate their accuracy. A collaborative mobile-based AR application was developed to teach boulder climbing skills and how to determine the best climbing routes (Daiber, Kosmalla, and Krüger 2013).

As illustrated by these examples, AR systems can provide collaborative, skill-learning, explanatory, and adaptable tools for the teaching of theories and applications to workers, managers, and customers. For this reason, AR is increasingly adopted in both academic and corporate settings, part of the broader trend of AR infiltrating many real-life situations (Lee 2012).

4.3 ID in MR

4.3.1 What is ID?

The systematic design process of instructional environments requires the determination of learning strategies, goals, objectives, and the particular abilities of the target audience to achieve desired learning outcomes. All of this is called 'instructional design' or ID. The primary purpose of ID is to organise a LE to increase learning outcomes. An ID can be applied to face-to-face or electronic LEs, and each environment, technology, topic, and learning strategy indicates different preferences and methods for the making of a LE.

ID presents a roadmap to facilitate learning, and it follows the ideal decision-making processes to solve a particular learning issue. The initial step in establishing an ID requires the probing of the learning problem on a specific topic. Then, the optimum solution is selected from a pool of possibilities. This process includes numerous variables, such as determining learners' features and prior knowledge status, learning strategies, techniques, technologies, and even design specifications. The harmony and compatibility among these variables are essential in selecting and designing a LE; hence, needs analysis can be executed during this process. After determining these components, you are ready to create your environment. The systematic design process requires the creation of a conceptual storyboard that should represent the prototype for the LE. The storyboard should include theoretical information, interactions, results, evaluation techniques, and any other relevant components. Every detail should be listed, designed, and clarified on the storyboard to provide a logical structure of the material for each member working on the design and development process.

These stages require several actors from different disciplines, such as subject experts, instructional designers, media specialists, and developers. The variety of actors depends on the technical requirements and the context of the LE. If every actor approves the designed storyboard, you can start to develop your learning material. The instructional material development process requires an iterative evaluation and revision processes until the final and most effective version of the learning material is reached. The best method by which to understand and measure the effectiveness requires the implementation of the content by designers or subject experts with consideration of the target audience. This cyclic process – develop, evaluate, and revise – is continued until the finalised version of the material is reached.

This section presents but a short summary explaining the fundamentals of the ID process. It is possible to add stages, actors, and applications as per specialist needs. Numerous ID models offer generalised pathways for instructional designers. They are, however, unlikely to provide a fool proof direction for you. In my opinion, the selected learning strategies and technologies, and the manner in which knowledge is presented can help determine the general framework for a particular process. With this customisation in mind, each ID would need to offer a new and unique implementation. Each material development and ID process should use project management phases in order to be systematic and scientific. I think a design-based research methodology presents a useful framework for arriving at a proper ID process.

According to Morrison, Ross, and Kemp (2012), such systematisation of the design process is related to learning theories, information technologies, system analysis, educational research, and management. The correct methodology selection is necessary for such a scientific-based, multi-disciplinary, and systematic chain. According to Barab (2006), Barab and Squire (2004), Raspopovic, Cvetanovic, and Jankulovic (2016), and Wang and Hannafin (2005), the material development process should be executed in a way that is iterative, systematic, and scientific.

4.3.2 Characteristics of the ID process

As mentioned previously, the main purpose of ID is to increase the learning outcomes of individuals by providing proper supplementary materials (Taçgın and Arslan 2016). The decisions made within it depend on the cognitive abilities of learners to organise digital content (Keengwe, Onchwari, and Agamba 2014, Beetham and Sharpe 2013). The four main components and stages of ID are offered in figure 4-26.

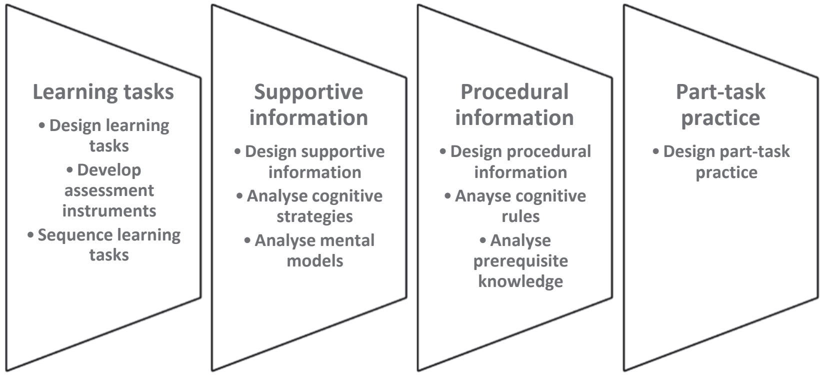


Fig. 4-26. Four blueprint components of ID 4C/10S adapted from (Van Merriënboer and Kirschner 2012)

The ID method selection and application should be based on the educational needs analysis that is conducted as the initial step (Raspopovic, Cvetanovic, and Jankulovic 2016, Wegener and Leimeister 2012, Beetham and Sharpe 2013). The scope, target abilities, presentation types, measurement, and methods to be evaluated should be determined at this stage (Raspopovic, Cvetanovic, and Jankulovic 2016). Then, the storyboard has to be prepared comprehensively, containing screens, media, interaction, visuals, sounds, and other components. After evaluating and updating the storyboard, the material can be developed using appropriate tools, and a pilot study can be executed to assess the capability of the material. Finally, the completed material can be produced to achieve the desired learning outcomes (Bork and Rucks-Ahidiana 2013, Lai and Savage 2013, Raspopovic, Cvetanovic, and Jankulovic 2016, Beetham and Sharpe 2013, Paquette 2014).

The ADDIE model offers a general framework for not only ID processes but also project management, scientific studies, and more. The cyclical process of revising ID models and approaches is frequently structured on the five fundamental steps of ADDIE: analysis, design, implementation, development, and evaluation

(Raspopovic, Cvetanovic, and Jankulovic 2016, Wang and Hannafin 2005, Barab and Squire 2004, Barab 2006, Lin and Hsu 2013). Whether they be administrators, technicians, designers, teachers, or learners (Barab and Squire 2004, Sims 2012), the duties of the managers of successful ID processes according to content specifications are categorised in figure 4-27.

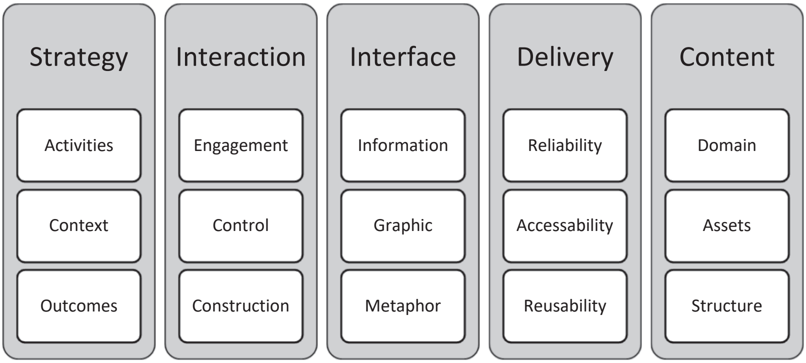


Fig. 4-27. Design for a learning model adapted from (Sims 2012)

The ID is executed by educational technologists or instructional designers, who should plan the design of the new environment using instructional principles (Cengizhan 2007). In my opinion, each lecturer or teacher should know the essentials of the ID process in order to design and enhance her LEs. Subject specialists should organise the information (Keengwe, Onchwari, and Agamba 2014) and evaluate the suitability of the presented components in accordance with the learning outcomes (Raspopovic, Cvetanovic, and Jankulovic 2016, Desai and Mevada 2015, Wegener and Leimeister 2012, Paquette 2014, Macleod and Sinclair 2015).

The primary responsibilities of educational technologists are educational needs analysis and the determining of the requirements of the storyboard. They also have an active role in the development phase to prepare the learning components, which can take the form of visuals, audio, movies, fictional scenarios, and integration

(Raspopovic, Cvetanovic, and Jankulovic 2016) following their expertise. Because of this cooperative process, all of the communication channels should be functional, and the evaluation phase should continue during each of the stages (Raspopovic, Cvetanovic, and Jankulovic 2016, Desai and Mevada 2015, Wegener and Leimeister 2012, Paquette 2014). This repetitive cyclical structure indicates the suitability of design-based research methodology for material development processes (Raspopovic, Cvetanovic, and Jankulovic 2016, Wang and Hannafin 2005, Barab and Squire 2004, Barab 2006). After determining the design features, the required hardware and software components of the material can be selected, synthesising all of the requirements.

4.3.3 MR ID models

The learning material has to be suitable to constructivist epistemology (Wang and Hannafin 2005, Macleod and Sinclair 2015), meaning that it should direct students to solve problems and think critically by using the most appropriate learning methods and principles. Although subject experts should analyse the primary knowledge before learning material is offered to the students, structuring the LE requires the excellent organisation of the experience being presented and management of participant responses to various scenarios. If it is all done correctly, students become able to reach secondary knowledge following behaviourist learning philosophy.

The constructivist approach aims to prompt meta-cognitional abilities in the individuals – analysis, synthesis, evaluation – to support comprehensive learning (Wang and Hannafin 2005, Macleod and Sinclair 2015). Constructivism emphasises the giving of primary knowledge to learners to scaffold and structure individual knowledge. For this reason, active participation, problem-solving, discovering, experiencing, and inquiring have paramount significance in the design of constructivist LEs. The basis of the learning materials has to be transformed from behaviourism to constructivism (Macleod and Sinclair 2015, Mullin 2013, Beetham and Sharpe 2013, Keengwe, Onchwari, and Agamba 2014) when managing ID processes.

The design principles and components of the structured LE are generally constructed on specific cognitive learning strategies, which have been formulated after much investigation of the information transfer process of the human brain during learning. Cognitive learning strategies aim to increase transferred knowledge from short-term memory to long-term memory by facilitating the dual coding process, increasing attention and memorisation, and reducing learning time.

The power of AR and IVR LEs comes from the enablement of these processes. The enhanced visualisation of AR environments supports imagery, and the perceptions of being enveloped in IVR environments provide total immersion for the experiencing of real-world cases. It has to be noted that the learning outcomes and effects of MR environments should still be evaluated through more research and should be matched with brain-based learning approaches.

Both the active participation and collaborative learning prospects of enhanced MR environments have the exclusive potential to provide components that promote problem-solving and inquiry in LEs. According to some scholars (Kirkley, Tomblin, and Kirkley 2005, Kirkley and Kirkley 2005), the integration of both game components and emerging technologies into the LE can enhance practice-based skills in classrooms. The combining of game components and learning practices facilitates the design of constructivist LEs using cognitive strategies.

The majority of today's learners are digital natives and will rely upon technological equipment for the duration of their lifetime. Games are one of the most popular and desired forms of fun for them. We know that game components such as levelling, badges, scenarios, leader boards, character development, and enhancement in a VW have the potential to motivate players. The extrinsic motivators of games provide intrinsic motivation for the players and could be the reason for addiction when it occurs. Instructional designers call this phenomenon gamification, and it has been used in designing LEs. Gamification also has the potential to be integrated into MRLEs.

According to Jonassen (1997), learning problems can be well-structured or ill-structured. Well-structured problems point clearly to further steps and exact solutions, and ill-structured problems require different cases and synthesising to find optimum solutions. Offering different scenarios to teach autism spectrum disorder learners about appropriate expressions and responding to their selections using face expression via recognition systems (Ip et al. 2016, Lorenzo et al. 2016) can be a good example of the VR-based teaching of ill-structured problems. Teaching words, letters, or mathematical equations and evaluating the results with Kartoon3D can be an example of teaching well-structured problems (Tacgin and Ozuag 2018).

As mentioned above, it is not possible to say that a particular ID model can provide the desired outcomes for your LE. The stages and strategies are not always easy to grasp for the custom LE you have in mind. There are numerous ID models by which to design traditional LEs, although using these traditional techniques is not always suitable in the design and development of 3D and immersive MR environments. We need more research on immersive or 3D environments to understand the cognitive processes of individuals who experience them.

Table 4-1. ID components in MR environments (Tacgin 2018)

Features of the environment	Learning method	Key features
Discovery	Discovery-based	Interactivity Navigation Instruction and guidance Monitoring Degree of immersion High fidelity Embodiment Recording Instant feedback Repeatability Context Design components Motivators Learning outcomes
Embodiment	Individual	
Experimentation	Experiential	
Questioning	Inquiry-based	
Problem-solving	Problem scenario	

The appropriate learning methodologies and techniques for MR environments are offered in table 4-1. Some studies relate to the ID processes of 3D AR/VR environments. The majority of current models investigate computer-based VWs instead of MR, such as the sample and parameters presented by Chuah, Chen, and Teh (2011), the models from Chen, Toh, and Fauzy (2004) and Goodwin, Wiltshire, and Fiore (2015), the design proposal of Hanson and Shelton (2008a), and the model made by Dalgarno and Lee (2010). These models generally have not been put through experiential evaluation.

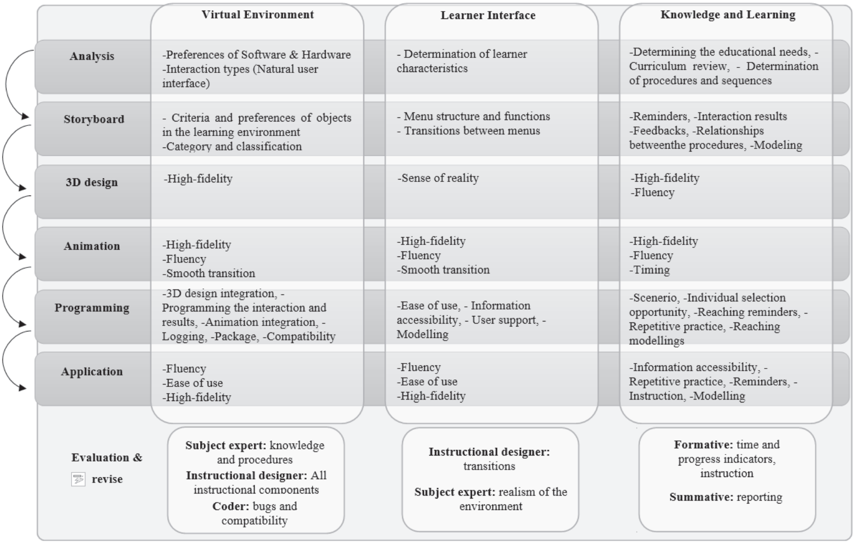


Fig. 4-28. Sensory IVR simulation development model in procedural learning (Tacgin 2018)

The Experiential Modes (EM) of Appelman (2005) are a general and flexible structure to determine suitable pathway and design components for MR environments. EM can be helpful in detecting the stages and sub-factors for each related phase of a project to clarify the stimulus for learners' perceptions. I strongly suggest reading Appleman's original article to understand the main ideas of this concept.

Also, I proposed and experientially tested an ID model for IVR to teach concepts and procedures (Tacgin 2018) as offered in figure 4-28.

4.3.4 Should I use MR technologies for my teaching process?

The answer to this question is found in a needs analysis, which can be based on the research that has been conducted about the learning circumstances appropriate for MR.

MR environments can be productive for both knowledge acquisition and skill training, especially with the intuitive interaction opportunities these systems enable. The skill training process requires repetitive practice in either realistic environments or scenarios. HMD-based hybrid MR systems can provide simulated low-risk and repetitive experiences for trainees. For instance, the expertise for the use of a specific vehicle, machine, or instrument in the physical environment is usually gained through practice over a long-term period because this is necessary for the required development at the psychomotor level. Such skills, which consist of sequential rules and procedures, can be relevant training for professional life.

Regarding knowledge acquisition, the strong visualisation potential of MR helps in the explaining of hard-to-understand complex systems or intangible concepts. Both the simultaneous and repetitive representation of various ideas in the form of visuals, texts, or audio objects facilitate mental imagery and thereby assist the brain’s dual coding process. Thus, the memorisation of concepts by trainees can increase due to the advantages of MR.

High-fidelity visuals and scenarios are the keystones to teaching in IVR. Several scenarios in various structured environments can be represented, for which trainees can observe sets of alternative consequences and thereby gain situational learning. A branched LE requires good interactivity provided by a high level of immersion, which translates into active participation and simplifies the knowledge acquisition process.

MR systems present strong LEs for both individual and collaborative learning processes. In particular, multi-user supported co-location AR applications can be helpful for working together to learn the same content. Trainees' communication and collaborative learning skills are supported when they experience the same MRLE. Remember that providing a debriefing session and discussion with the trainees helps to develop their communication and critical thinking abilities.

Moving away from the research and theoretical background, MR systems can be suitable for the following learning purposes:

- Teaching skills in a repetitive environment
- Teaching the sequential procedural knowledge and rules for particular skills
- Demonstrating the mechanics of intangible or complex concepts
- Representing alternative scenarios and phenomena under the trainer's decisions to provide situation or discovery learning
- Regulating the attitudes of learners using alternative scenarios
- Experiential, problem-based, or inquiry learning
- Making a low-risk LE for high-risk situation learning

A case diagram is offered in figure 4-34 to help you with your selection process.

The target audience's physical specifications, cognitive styles, and prior knowledge regarding the related topic are the other significant factors to consider when deciding on the learning technique of your course. Research indicates motivational effects for the majority of MR applications, although it should be noted that IVR environments have more effective learning outcomes for teenagers and adults than children. There are few studies concerning IVR usage on children. As discussed earlier in this book, there are several reasons for this situation, such as the poor ergonomic structure of HMDs, cybersickness issues, and content suitability problems. A lack of studies does not mean MR is not fit for early childhood or the K-12 level. AR is more proper for these levels than IVR because of its collaboration and visualisation capabilities. Children's familiarity with mobile devices makes AR systems more natural to use for them.

AR provides unique LEs for professional and in-service training, particularly in the maintenance, engineering, and medical fields. These fields share a common need for collaboration and visualisation as a requirement for learning core skills. Enhanced digital content facilitates the understanding of complex concepts, discussion, and observation of the results of manipulation and interaction with content.

IVR provides capable LEs to improve attitudes, communication, and social skills, especially for special education. The results of researchers have emphasised the effectiveness of AR environments, particularly for novice learners rather than experts.

From this point of view, it is possible to say that:

- IVR can be more appropriate for teenagers and adults
- IVR with high presence can be helpful for both experts and novice learners
- IVR can be more useful for social skill and attitude training
- AR can be more appropriate for novice learners than for experts
- AR is suitable for early childhood, K-12, university, and professional students

- AR is ideal for collaboration and active participation

Now, you can decide the requirements of your MRLE after making an educational needs analysis. I suggest you look up the CRAMP model of Romiszowski (2016) that provides a unique conceptual map by which to decide upon the best pathway with regards to learning techniques.

4.3.5 How do I design my MRLE?

At this stage, you have decided what you will teach using MR systems. The next question is how you will explain your subject and what strategies and techniques are suitable for your MR. Morrison et al. (2019) state that each example of educational content brings along its appropriate strategies and methods. The expanded performance content matrix below in table 4-2 can help to guide your selection process.

Table 4-2. Expanded performance content matrix, adapted from Morrison et al. (2019)

What are you teaching?	Which strategy could be helpful?	Sample methods
Phenomenon	Reminders	Rehearsal, practice, iteration, writing, etc.
Concepts	Reminders, aggregation	Repetition, rehearsal, review, concept map, etc.
Procedures and rules	Aggregation, organisation	Rule-sample, sample-rule, etc.
Methods	Rule-sample, sample-rule, demonstration, practice,	Modelling, sample video, etc.
Social skills	Iteration, reminders, modelling	Role-playing, mental iteration, etc.
Attitude	Modelling, mental iteration, application	Learning scenarios

Creating this matrix for your particular content can be helpful in realising the learning scenario using proper strategies and methods. After determining the learning scenario and adequate strategies, the storyboard can be designed using determined features of digital content and interaction types. All this information also helps identify the appropriate hardware and software components for your project.

If you need a wholly structured VE, you should probably use HMDs to develop the IVR. This environment can include professional 3D content and 360° videos. In each scenario, the hardware specifications will guide you to design the active LE. If you wish to enhance physical reality using digital content, you can develop an AR environment. AR requires the designing of both physical and virtual content, which then will help you to choose the best display and other hardware components. The necessity for high visual quality, collaborative usage, and intuitive interaction suggests the use of HMDs and tracking systems for your AR. Also, the application area – indoor or outdoor – will relate strongly to the specifications needed from your hardware components. For example, if you design an outdoor AR using gesture interaction, you can choose stand-alone and untethered HMDs. The interaction can require integrated motion tracking or environment tracking systems. If you design an indoor AR environment, you can use bulkier devices and additional hardware components. If handheld displays can meet your purpose, you can reach a broad target audience. In this case, physical fiducial markers should be designed separately, and Mayer’s multimedia design principles can be useful in your design process.

4.3.5.1 3D environment design

The majority of current technologies still have several deficiencies that negatively impact upon the active area of users. Designers should know and consider this information before creating a VE.

Based on the limits of the FoV, users can actively observe only the presented particular field of the 3D environment at a given moment in time. It can be constrained in terms of an angle of view that is tied to HMD specifications. More specifically, users can observe the VW from different angles depending on the DoF. For this reason, the most critical learning content should be determined and considered before designing the VE. The initial and essential content should be represented in the main view, and additional materials can be offered in the lateral areas.

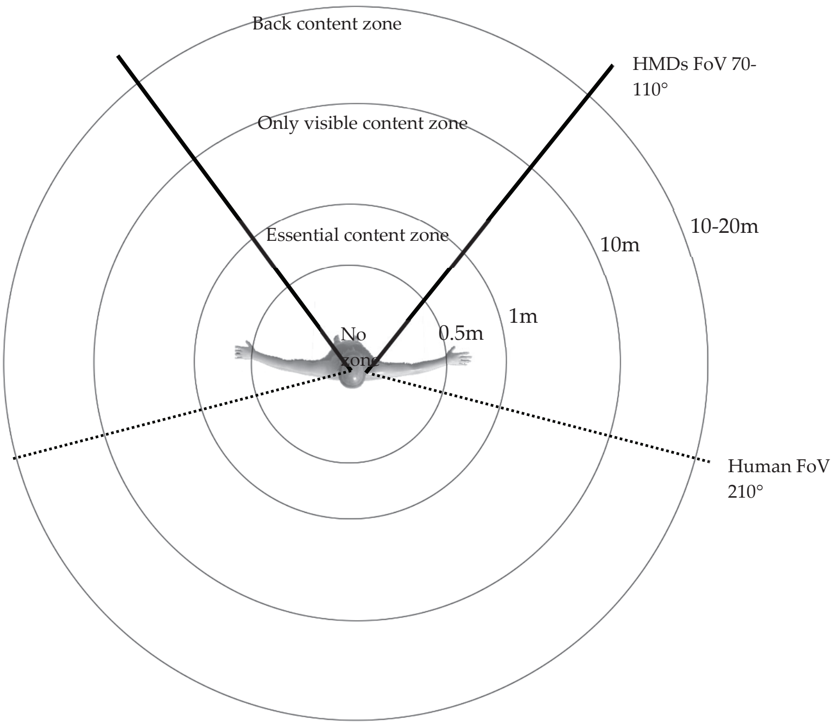


Fig. 4-29. FoV interactive area

Especially for 3DoF HMDs, MR users can generally interact only with the closest virtual objects, meaning 1 to 2 metres away from them. They can get closer to the interactive virtual objects using controllers. If they use 6DoF HMDs and have enough physical space for their experience, they can physically move around to get closer to these objects as well. In every case, direct interaction with the virtual objects requires one to be close, just like in physical reality. The interaction distance can be related to the length of users' arms in the case of the gesture interaction or controller interaction of egocentric designed MR environments. For this reason, the scenes of the VE and the interactive components should be arranged carefully within these limits.

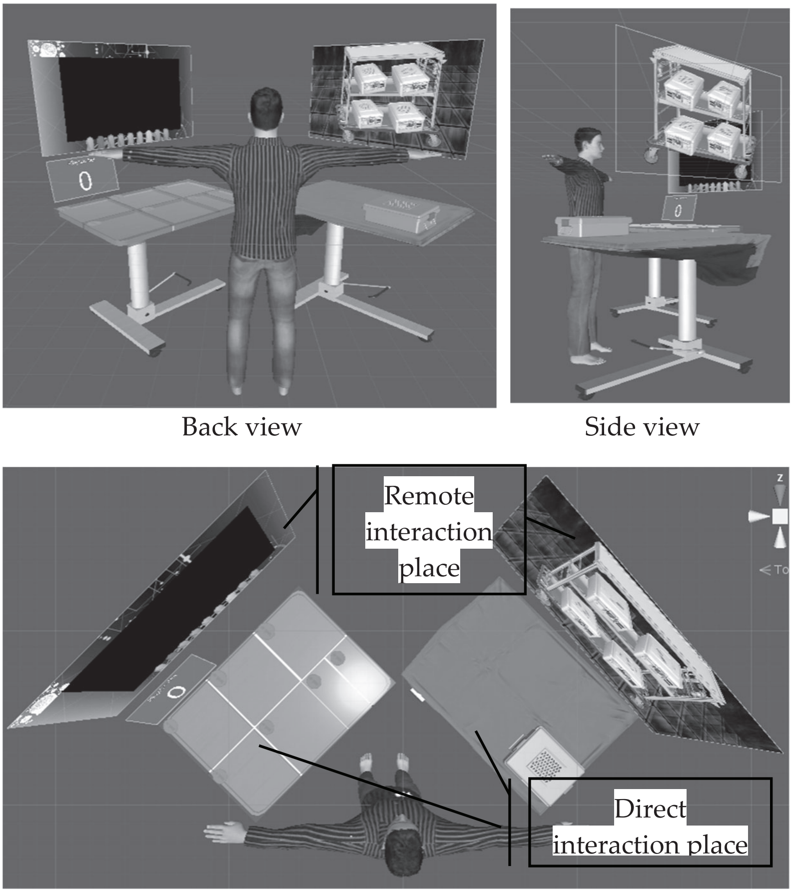


Fig. 4-30. Proper placement of interactive virtual objects in the VE

The interactive virtual objects should be in the foreground, which refers to the optimum distance of a maximum of 1 metre from users. There can be up to a 50-cm gesture interaction space and a 1-metre distance for the remote interaction components. The critical visual elements of a 3D environment can be in the mid-ground with a maximum of 10-metres distance from users. Beyond that distance, only background vision can be offered to users.

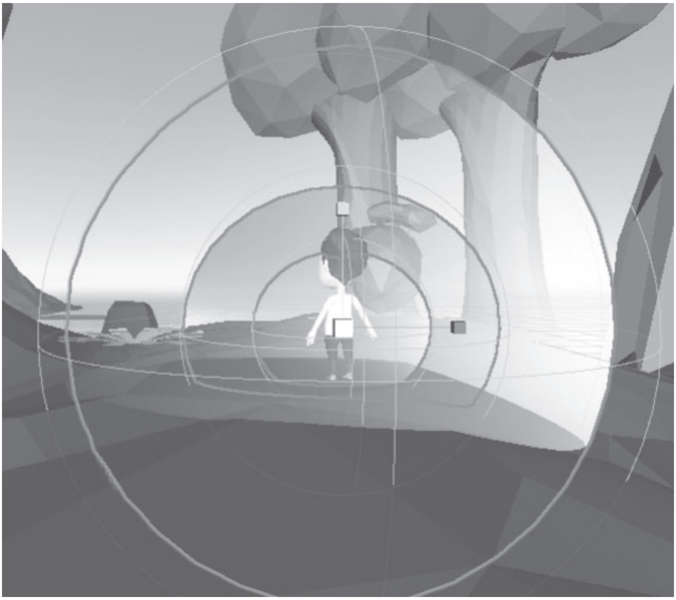


Fig. 4-31. The gradated visualisation of ground spaces

A virtual object can be placed at an ideal distance for interaction for most users, but depending on the HMDs features, extraordinary tall or short users might not match with a horizontal arrangement, thus making your VE completely ineffective. For this reason, determining the demographic characteristics of the target audience before the material development process is crucial.

Interactivity and transaction in the LE are generally represented by menus, buttons, navigation components, and layers.

The physical environment does not naturally include these components, and so these interfaces should be designed using transparent components instead of distinct components. Complete transparency is also not appropriate. In my opinion, the interactive interface components should be designed using the proper colour for that particular real-life environment and transparency should be assigned to these items to help distinguish their virtual presence. Colour theory can be helpful when selecting colour schemes, and VE features can also impact this decision. For example, analogue or triadic colours can be suitable for adult learners. Imagine an operating room that usually includes hospital blue tones; in that case, triadic green tones can work well for the overall interface design. Complementary colours can be more suitable for children to heighten contrast. These selections can benefit from a deeper understanding of colour theory concerning multimedia design and from knowing the physical attributes of the target audience.

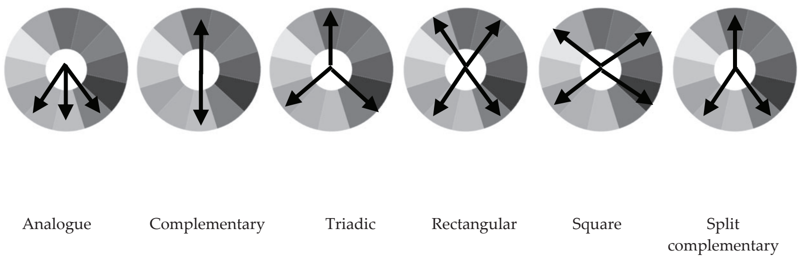


Fig. 4-32. Colour schemes

A good designer not only adds one static button for learners but a series of variations to indicate different circumstances, such as hover, click, visited, and other visual states. According to Alger (2015), complementary colours are more suitable for the highlighting of the interaction possibilities of such buttons. The perceived meaning of chosen icons and metaphors should be considered during the design process of MR environments. Also, audio and haptic feedback are important in increasing the presence of users.

Fig. 4-33. Sample of interactive buttons (Alger 2015)

There is no one single and constant pathway for the 3D environment's design. The characteristics and results of a needs analysis will be what determine the correct design components. Experiencing and evaluating different kinds of VEs can be helpful to ignite your imagination. As has been discussed previously, 3D environment design includes particular requirements in accordance with FoV, DoF, and interaction types, and it uses a transformed version of multimedia design principles.

4.3.5.2 Hints for deciding on your ID

The ID process should be organised using project management and scientific methods. For this reason, the phases of design or design-based research methodology can offer a practical pathway for these designers. The analogy of Romiszowski (2016) is that the ID process resembles the system approach. The excellent progress of a holistic system depends on various sub-systems working in harmony with the sub-components. Each component of a sub-system requires different expertise and teamwork.

All in all, the initial step should be choosing the proper instructional strategy and models following the desired learning outcomes of a particular target audience. The next stage is determining the appropriate hardware and software specifications for your unique MR environment. These will also indicate the project team requirements. The MRLE creation process can require instructional designers, graphical designers, subject experts, and coders. According to Sherman and Craig (2018), you might also need *set designers, prop creators, and sound effects people skilled in hardware integration and probably an audio/video engineer because virtual objects need to be modelled and painted, sounds must be recorded, created, or algorithmically modelled, the physics simulations and world must be programmed, the interface must be designed and programmed. Moreover, the physical hardware must be acquired, integrated, and installed in the venue.*

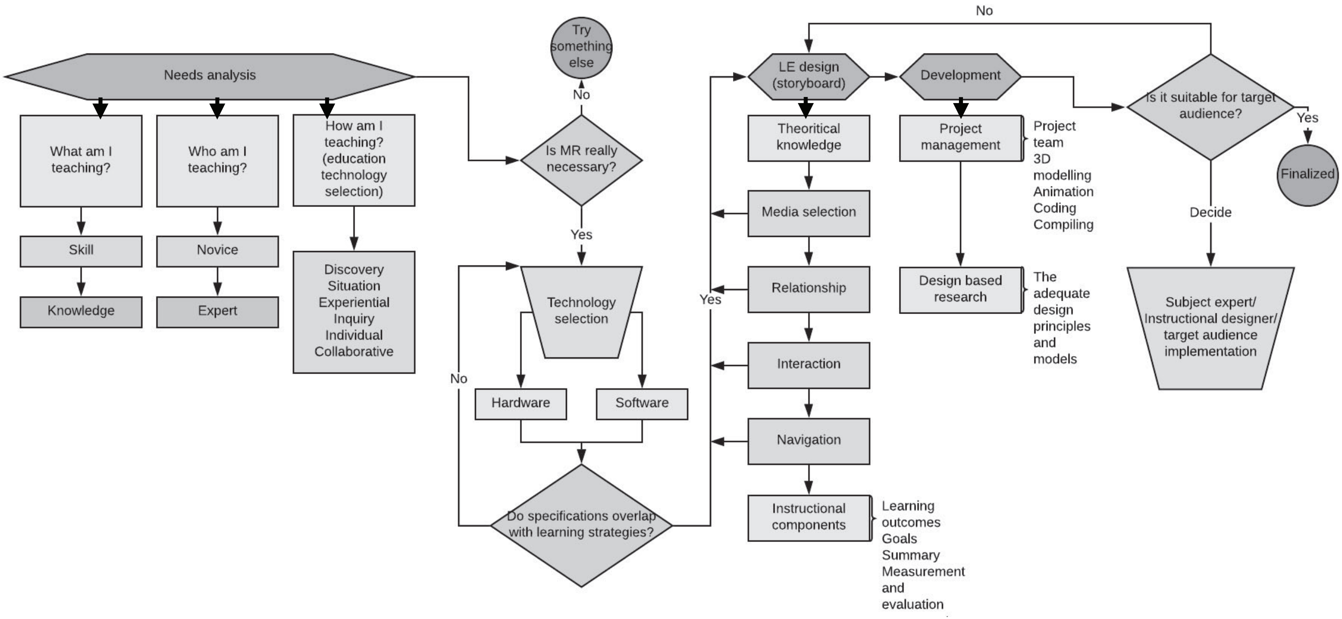


Fig. 4-34. How can I detect the correct pathway for the ID process?

Designing a LE requires the correct representation of theoretical and practical knowledge. For this reason, you should work with subject experts. I can say that according to my experience, the features, interaction, navigation, and capability of the MR development process should be flexible and that both coders and developers should have the authority to reshape functionalities. The current technologies or programming environments do not always match your imaginative expectations, and because of that, both instructional designers and subject experts should be open-minded about alternative solutions. These approaches should be determined at the storyboarding stage of design because changing coding types and designs could be harder later on. The development process should be initiated after gaining the consensus of all team members on what the features of the MR environment should be.

As an additional note, both physical and virtual environments should be carefully designed for AR. The physical environment should be structured, especially when one is making location-based AR. On the other hand, IVR environments can be designed as egocentric or exocentric in relation to the users' placement into the VE. The interaction distance of egocentric IVR designs puts users at the centre of the VE to provide the feeling of 'being there'. Researchers indicate that egocentric design is better (Angulo and de Velasco 2014) for an IVR environment, and it is possibly related to providing better presence and perceived psychological immersion.

There are numerous examples of MRLEs in the literature, but not all of them have had applied ID processes such as SMART, ARCS, TAM, or ADDIE. The majority of the ID models offered for MRLEs have not undergone experiential evaluation. We know that there is no unitary ID model to directly adapt and apply to a particular LE, so you should create a custom pathway using best-practice learning design models and strategies.

4.4 Summary of Chapter 4

- Both AR and VR technologies have large-scale usage in the education field.
- IVR technologies are not widely adopted in primary schools as of 2019.
- IVR is useful for special education to teach attitudes by providing immersive learning scenarios.
- IVR helps students to understand intangible concepts and increase their motivation and academic success.
- IVR is generally used for natural science and social science content in higher education.
- IVR provides numerous outcomes, such as sustainable attention, spatial representation, and orientation for engineering, architecture, and medical students.
- IVR provides a repetitive and low-risk LE for professional learning.
- IVR is especially useful for procedural and skill-based training.
- IVR helps with knowledge acquisition and its transfer to real-life situations.
- IVR can induce cognitive overload.
- AR is usually used in primary education to teach fundamental terms.
- AR increases students' motivation, academic success, attention, knowledge acquisition, and memorisation.

- AR systems are more useful for novice users than for experts.
- AR systems are used for professional training, especially in the maintenance, safety, and medical fields.
- AR helps with the comprehension of spatial relations.
- The success and effectiveness of an MRLE are directly related to the ID process.
- There is no standard ID process; the specifications and outcomes of each LE direct a unique ID process.
- The proper hardware and software components should be selected before the ID and material development process.
- 3D environment design specifications are related to the features of the hardware and software components used.
- The ID process should be organised using project management stages and scientific methods.
- Needs analysis, storyboard preparation, and teamwork are necessary before MR material development.

Chapter Five

An Example IVR Study: Evaluating the design features of a sensory IVRLE

Note from author

This example study is a part of my PhD thesis. I include this detailed description and evaluation of a medical IVR with the hope to inspire intermediate and more advanced readers regarding their own MR project development.

5.1 Abstract

The purpose of this research is to evaluate the design features of a sensory IVRLE that was designed and developed for the teaching of certain preoperative concepts and procedures to nursing students. The methodology of this research consisted of two major stages: (1) investigating the design characteristics of the VRLE and (2) evaluating the design features after VRLE implementation. The VRLE was assessed by two subject experts and three instructional designers to calculate the internal consistency coefficient between the evaluators. Then, the VRLE was applied to each of 14 nursing students four times in a month. After the first implementation, the VRLE was revised according to the recommendations of the participants. The evaluations of instructional designers and subject experts indicated that the design features of the VRLE were sufficient. The nursing students already strongly approved of the application upon the first usage, at an average of 95.71/100 points.

Scores increased over the repeated implementations, but no significant difference was seen among them. Such high scores could have been due to the 3D design components, main menu structure, reminders, and the modelling videos of the VRLE, which were sufficient to teach concepts and procedures to the learners.

5.2 Introduction

The variety of well-designed VEs should increase. If the qualitative design features of these environments are inadequate, it will be difficult to achieve the desired learning outcomes. The corresponding design components differ from the specifications of the software and hardware components used.

Designing an instructional environment requires the application of proper instructional design processes. The adaptation of current ID models to the IVR development process is not always adequate because of the changing dynamics of VEs (Mills and Noyes 1999b, Goodwin, Wiltshire, and Fiore 2015). For this reason, each VRLE development process requires unique management that includes educational needs analysis to determine the topic, the characteristics of the learners, and the desired learning outcomes.

One of the main usages of VR technologies is for education and medical training (Hayden, Seagull, and Reddy 2015, Jensen et al. 2014, Raaschou-Nielsen et al. 2013, Spanager et al. 2013). Medical training has enormous potential to make use of VR systems thanks to providing low-risk, skill-based, and repetitive practice opportunities.

Building up clinical expertise requires core curriculum knowledge, skills, and attitudes to be fed into specialised training modules (Jones et al. 2001). Studies have shown that nursing students now learn via books, lectures, multimedia programmes, and web-based LEs (Ward et al. 2001, Whitson et al. 2006, Kneebone 2003). Several universities provide web-based teaching support to their students through virtual campuses (Kneebone 2003, Ward et al.

2001). The practical skills of learners are supported using expensive dummies and simulators under the lecturer's control (McLaughlin 2012). Although these technologies are sufficient to meet the individual learning expectations of students, they are restricted by their location and are dependent on the lecture format. Also, these expensive systems can only be used by a small number of people (Windsor 2009).

Well-designed VRLEs can provide a solution to resolve these issues. According to Sachdeva, Pellegrini, and Johnson (2008), Herrmann-Werner et al. (2013), and Kneebone (2003), individual learning needs in the surgical field can be met through a proper VRLE after the integration of constant feedback. The environment should contain repetition and be realistic and controllable, and different difficulty levels should be present following the related curriculum.

The repetitive practise opportunities that VR provides can function as self-regulated and flexible LEs for different learning styles. Participants can use VRLEs for on-the-job training as an individual or with multiple users; thus, they become able to work on the same content at the same time and in the same location (Windsor 2009). The repetition and feedback are valuable, but different cognitive styles of learners require various knowledge representation types to transfer information and skills. For this reason, the environment and features designed can have paramount significance for the students.

Learners require safe LEs to discover and learn from their mistakes (Kneebone 2003), and so a LE should provide problem-based scenarios to reach desired learning outcomes (Ward et al. 2001, Davis 1999). In recent years, the problem-based approach has been adapted primarily to surgical education. The problem-based approach requires the definition of the problem, problem-solving concerning the clinical skills, the identification of learning needs, individual study, active participation, and the summarisation of new information. Understanding the underlying causes and discussing them in small groups is necessary for the learning process (Davis 1999). Both the application and evaluation of these stages are highly time-consuming. VRLEs have the potential to increase the effectiveness of this process (Windsor 2009). Computer-based evaluation systems can reduce the evaluation time of the learners and provide a more consistent and objective assessment (Ward et al. 2001, Herrmann-Werner et al. 2013). As a matter of fact, VRLEs allow the implementation of new procedural skills via reusable technologies (Sachdeva, Pellegrini, and Johnson 2008, Satava 2001), provide instant feedback (Kneebone et al. 2002, Herrmann-Werner et al. 2013), and offer realistic clinical scenarios (Kneebone 2003, Kneebone et al. 2002).

5.2.1 Purpose

This study evaluates the design features of a sensory IVRLE (Taçgın 2017b). This VRLE was designed to improve the cognitive and psychomotor skills of nursing students with regard to the pre-operative processes.

Problems to be answered in this study were:

- Does the design-features evaluation of the VRLE show consistency according to subject experts?
- Does the design-features evaluation of the VRLE show consistency according to instructional designers?
- Are the design features of the VRLE sufficient according to the nursing students?
- Are there points of any statistical significance among the learners' evaluations of design features?

5.3 Methodology

The first stage of this study introduces the design features of the VRLE. The second phase investigates the sufficiency of design features by the instructional designers, subject experts, and nursing students.

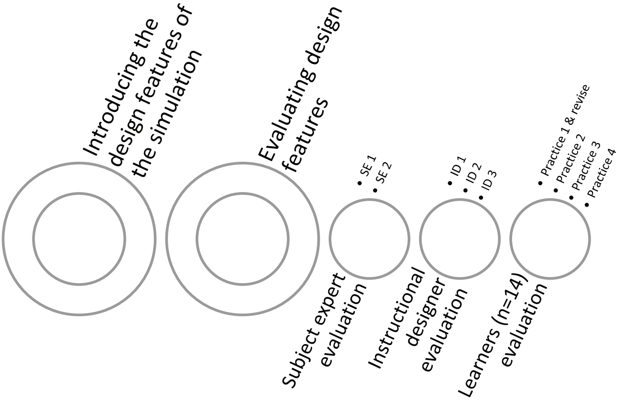


Fig. 5-1. Research methodology

5.3.1 Working group

The finalised version of the VRLE was implemented with 14 volunteer students who were identified using convenience sampling. Each participant experienced the VRLE 4 times in a month. The VRLE also benefited from two subject specialists and three instructional designers taking part to determine the internal consistency and to support confidence in this research's findings.

5.3.2 Data gathering tools

- **The VRLE:** The VRLE was developed to teach the concepts and procedures of the preoperative process. These procedures were: (1) laying out the mayo table, (2) opening surgical containers, and (3) the placement of surgical instruments on the mayo table. As a concept, the names of the surgical instruments of 4 surgical sets – major, minor, urological, obstetrical – were integrated into the VRLE. The VRLE was applied with the participants to evaluate design features.

- **Camera and sound recording:** During the implementation process, video and voice were recorded to evaluate the experience and reactions of participants.
- **Presence and Importance of Design Characteristics survey:** A questionnaire developed by Wilson and Klein (2012) rearranging the sub-scales of Jeffries (2005) was borrowed to evaluate the design components of the simulations. The survey includes 20 items and five sub-categories: (1) objectives and information, (2) student support, (3) problem-solving, (4) feedback/guided reflection, and (5) fidelity (realism).

5.3.3 Data analysis

- **The VRLE:** The researcher examined the design features of the VRLE and presented using screen captures.
- **Presence and Importance of Design Characteristics survey:** The questionnaire was given to all participants after each application. Freidman statistical analysis was used to determine differences among the repeated applications with the nursing students.
- **Subject expert evaluation:** Two subject experts implemented the VRLE, and the Presence and Importance of Design Characteristics survey was taken to evaluate the design features of the VRLE. Cohen's Kappa coefficient was calculated to determine the internal consistency between the subject expert evaluations. Also, the Weighted Cohen's

Kappa coefficient was calculated to determine the level of disagreement of the evaluators.

- **Instructional designer evaluation:** The VRLE was applied with three volunteer instructional designers, and they took the Presence and Importance of Design Characteristics survey. Fleiss's Kappa coefficient was calculated to determine the internal consistency among them.

5.4 Findings

5.4.1 The VRLE interface

Fig. 5-2. Operating room and working space of the nurses

The operating room and its components were modelled as high-fidelity assets using their real proportions to provide a total presence to the users. The active learning and working space were created for the users, and interactive components were added to that area.

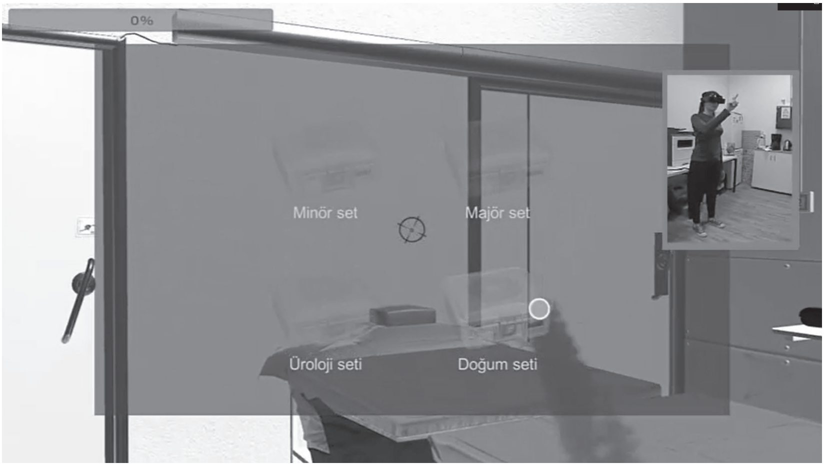


Fig. 5-3. Surgical instrument set selection

As seen in figure 5-3, after initiating the VRLE scenario, users had to select one of the surgical instrument sets from 4 options: (1) minor, (2) major, (3) obstetrical, and (4) urology. Then, they executed the main 12 tasks to complete the learning scenario.

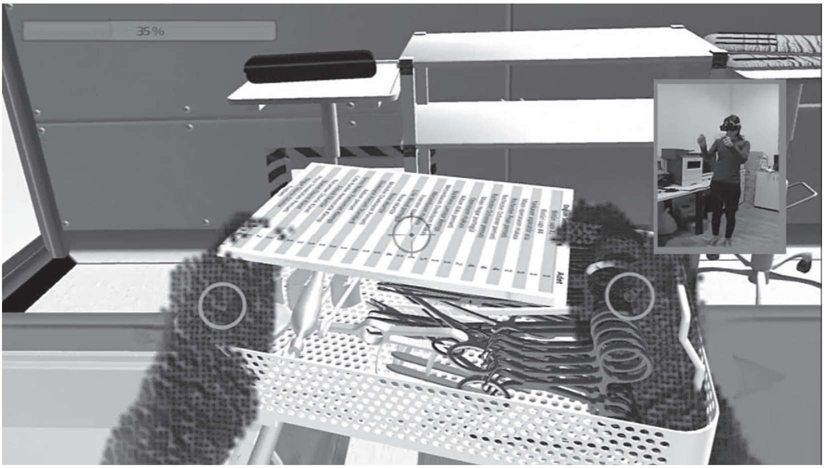


Fig. 5-4. Surgical basket movement with two hands

The interaction during the VRLE was executed via gestures and focusing on the virtual objects. The gesture interactions could be a one or two-handed hold and drop, a pinch, or using the index finger to identify virtual objects.

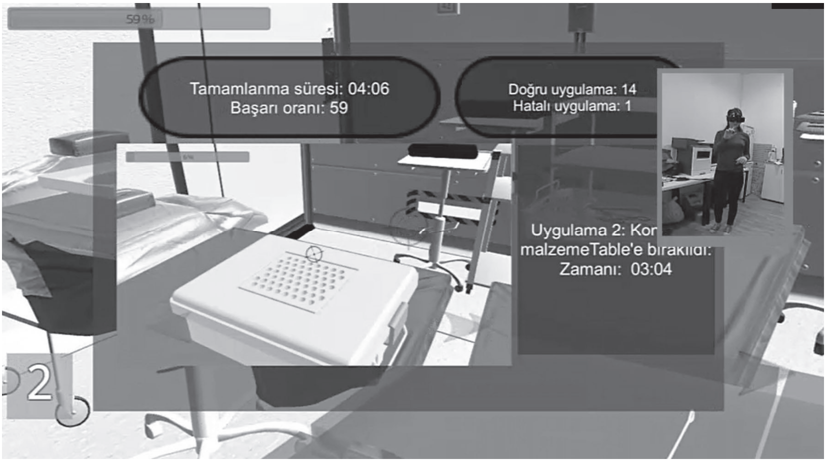


Fig. 5-5. The report screen

The users were able to observe and evaluate their correct and incorrect implementations on the report screen, which logged all interactions and assessed them.

5.4.2 Evaluation from subject experts

The two subject experts evaluated the design features of the VRLE after completing the learning scenario. The distribution of responses is presented in table 5-1.

Table 5-1. The design feature evaluations of subject experts

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total
Strongly agree	0	0	1	0	0	1
Agree	0	0	0	0	0	0
Neutral	0	0	0	0	0	0
Disagree	0	0	0	5	1	6
Strongly disagree	0	0	0	8	4	12
Total	0	0	1	13	5	19

Cohen's Kappa internal consistency coefficient between the evaluators was calculated as 0.148, indicating low internal consistency. However, the evaluators scored nine items (47.37%) similarly, and no subject was marked as 'strongly disagree' or 'disagree'. The issue arises from the fact that Cohen's Kappa analysis counts only exact matches of items. For this reason, the Weighted Cohen's Kappa coefficient was calculated to determine the consistency between the disagreements of the evaluators (0.245). This calculation indicated that the internal consistency between the evaluators should be assessed as fair.

5.4.3 Evaluation from instructional designers

The design feature evaluations of three instructional designers indicated that the design features of the VRLE were sufficient. Instructional designers did not choose 'disagree' or 'strongly disagree' for any questions, selecting only the 'agree' (f=7) and ‘strongly agree’ (f=52) options. ‘Neutral’ was selected for the ‘Independent problem-solving was facilitated’ item.

Fleiss’s Kappa analysis calculated the internal consistency coefficient among the evaluators as 0.724, which indicated substantial agreement.

5.4.4 Are the design features of the VRLE sufficient for the nursing students?

The participants completed the VRLE scenario four times in a month. The 14 nursing students evaluated the design features of the VRLE after each implementation. The overall design of the VRLE did not change for any application. However, instructional components were added to the VRLE after the initial implementation, based upon the wishes of the participants.

Table 5-2. The arithmetic mean and standard deviation values according to the design features

	N	$\bar{x}$	*ss*
Practice 1	14	95.7143	4.69744
Practice 2	14	96.9286	4.53133
Practice 3	14	97.6429	3.71291
Practice 4	14	98.0714	4.32282

The calculated arithmetic mean values were evaluated over 100 points. As shown in table 5-2, the design features of the VRLE were appreciated by the participants from the first (95.71) until the last application (98.07). As seen, the design characteristics evaluation scores of the participants systematically increased.

5.4.5 Is there any statistical significance among the learners' evaluations of design features?

Non-Parametric Friedman analysis was applied to determine the statistical significance among the evaluation scores and repeated practice sessions.

Table 5-3. Friedman Analysis results to determine whether participants have statistical significance among the practice points

	N	$\bar{x}_{sira}$	x^2	sd	p
Practice 1	14	2.18	2.320	3	.509
Practice 2	14	2.64			
Practice 3	14	2.43			
Practice 4	14	2.75			

Despite both having added instructional components into the VRLE after the first application and the increasing evaluation scores, no statistical significance was determined among the ranked means ($p<.05$).

5.5 Results

Despite the use of a 5-point Likert questionnaire, there was low internal consistency among the subject experts. A similar situation was observed in the instructional designer evaluations. However, internal consistency among the raters was high. This high ratio may be due to the use of different internal consistency factor calculation methods. However, since 'Disagree' and 'Strongly disagree' responses were lacking, a 3-point Likert could be suggested to better evaluate the design features of this VRLE.

The design feature evaluations of nursing students had high value (95.71) for the first practice. The scores increased over repeated applications, and the mean was calculated as 98.07 for the last session. No significant difference was determined as a result of the Friedman analysis. There was no major editing of design features during the implementation process, which could be the reason for obtaining a similar result.

The high evaluation scores indicated that the 3D design components, main menu structure, reminders, and modelling videos of the VRLE were useful in teaching conceptual and procedural information to learners. Also, the interface was useful, and the report screen was efficient. Adobor and Daneshfar (2006) report that the usefulness of the simulation environment has a positive effect on learning. Accordingly, the well-designed user interface might have positively influenced the learning process. Additionally, the high-fidelity design of the 3D operating room and the realistically scaled and detailed design of the surgical instruments were received well by the participants.

5.6 Discussion

Designing a VRLE requires suitable hardware and software components and multidisciplinary specialists. The high-fidelity display design is an essential criterion for providing a presence in the IVRLE. Also, technologies and interaction types are the other factors related to the providing of presence.

This study investigated the design features of an immersive sensory experience. The 3D models and the VW were designed using the inspiration of real-world physical components. The colour selection was suitable for operating room components, and the transparent layers used to present menu items supported immersion. The users perceived the VRLE as natural, and they felt as if they were in a real operating room. The results showed that both the colours and interface of the VRLE were suitable for the medical training environment.

Achieving the desired learning outcomes requires the application of appropriate ID models and strategies to create a sufficient and easy to use interface. From this point of view, instructional components, design, and usability could be submitted as the three fundamental criteria for proper instructional design (Dönmez and Gökkaya 2015).

5.7 Future Work

Today's technologies increase opportunities for visualisation, communication, interaction, and information transfer. This diversity requires both optimal and effective usage of the relevant technologies. IVR offers effective learning methods, especially for practical skills training.

Future studies could use the proposed sensory IVRLEs in other learning fields such as engineering and architecture. The design features of such environments could be assessed, and suitable design criteria could be determined by which to improve learning outcomes. Correspondingly, VR instructional design models could be proposed by which to enhance outcomes for particular teaching concepts.

ABBREVIATIONS

2D	Two Dimensional or Dimensions
3D	Three Dimensional or Dimensions
ADDIE	Analysis, Design, Development, Implementation, and Evaluation
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ANT	Wireless Based Sensor Technology to Display Body Data Such as Heart Rate
AR	Augmented Reality
ARB-MDMP	Augmented Reality Based-Military Decision Making Process
ARCS	Attention, Relevance, Confidence, and Satisfaction
ATM	Automated Teller Machine
AV	Augmented Virtuality
AVCATTA	The Aviation Combined Arms Tactical Trainer-Aviation
BARS	Battlefield Augmented Reality System
BOOM	Binocular Omni-Orientation Monitor
CAVE	Cave Automatic Virtual Environment
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DK	Development Kit
DoF	Degree(s) of Freedom
ECG	Electrocardiogram
EEG	Electroencephalogram
EM	Experiential Mode
f-MRI	Functional Magnetic Resonance Imaging
FoV	Field of View
Fps	Frames per second

GB	Gigabyte
GPS	Global Positioning System
HAD	Head Attached Display
HMD	Head-Mounted Display
HPV	Holographic Particle Velocimetry
HWD	Head-Worn Display
IMU	Inertial Measurement Unit (Includes various built-in sensors for tracking)
iOS	iPhone Operating System
IVE	Immersive Virtual Environment
IVR	Immersive Virtual Reality
K-12	Kindergarten through to 12th grade
LCD	Liquid Crystal Display
LE	Learning Environment
LED	Light Emitting Diode
LMS	Learning Management System
M2P	Motion to Photon
MARS	Mobile Augmented Reality Systems
MIT	Massachusetts Institute of Technology
MR	Mixed Reality
MS	Microsoft
NASA	National Aeronautics and Space Administration
NUI	Natural User Interface
OLED	Organic Light-Emitting Diode
OS	Operating System
PC	Personal Computer
PDA	Personal Digital Assistant
PhD	Doctor of Philosophy or the doctorate by which the title is obtained
QR	Quick Response
R&D	Research and Development
RFID	Radio Frequency Identification
SAR	Spatial Augmented Reality
SDK	Software Development Kit

SMART	Specific, Measurable, Achievable, Realistic, and Timely
STEM	Science, Technology, Engineering, and Mathematics
TAM	Technology Acceptance Model
US	United States
VATS	Video-Assisted Thoracoscopic Surgery
VE	Virtual Environment
VR	Virtual Reality
VRETS	Virtual Reality-based Engine Training System
VRLE	Virtual Reality Learning Environment
VW	Virtual World
Wi-Fi	Wireless Fidelity

GLOSSARY

A

Accelerometer: A sensor for measuring the acceleration of a moving or vibrating body.

Aggregation: A learning design technique to coordinate and organise related content.

Algorithm: A computer-based problem-solving process.

Augmented reality: Enhancing physical reality via digital components.

Augmented virtuality: Embedding physical objects into the virtual environment.

Autism: A disorder which causes social interaction and communication problems by restricted or repetitive patterns of thought and behaviour.

B

Behaviourism: A learning theory that focuses on objectively observable behaviours and discounts.

Binocular: Adapted for or using both eyes.

Built-in device: Stand-alone or consisting of all components in one central device.

C

Cloud: The online storage space.

Cockpit: The control area of pilots.

Cognitive learning: Refers to clarifying the stimulus of the brain during the information construction process

Cognitive load: Using working memory resources more than enough

Cognitive psychology: The scientific field that investigates the mental processes – attention, memory, perception, problem-solving, creativity, and thinking – through related brain- and neuroscience

Cognitive: Conscious activities like thinking, reasoning, and remembering.

Collaborative learning: As a learning approach, two or more learners work together.

Constructivism: This learning theory supports active learners and requires the teaching of how to learn and construct knowledge instead of the providing of direct knowledge.

Cricothyrotomy: An emergency surgical procedure that requires the cutting of a hole through a membrane in the patient's neck into the windpipe to allow air into the lungs.

Cybersickness: The side effects of MR technology usage.

D

Dark energy: An unknown form of energy which is hypothesised to permeate all of space, tending to accelerate the expansion of the universe.

Dark matter: The material postulated to exist in space and that could take any of several forms including weakly interacting particles.

Depth camera: A camera system that can recognise the physical objects in the world.

Discovery learning: Student-centred and constructivist learning technique whereby learners can actively participate and learn by discovery in a learning scenario.

Dyslexia: A kind of learning, reading and interpreting based disorder.

E

Echography: Body scanning technique that uses high-frequency sound waves to reflect the representation of organs.

Elaboration: A learning technique to design instructional environments that require the offering of parts and details of topics.

Endoscopic: Relating to looking inside the human body via additional visualisation devices.

Endotracheal intubation: An emergency medical procedure that requires the placement of flexible plastic tube into the trachea to create an extra airway for the body.

Epistemological: Of the theory of knowledge philosophy.

Experiential learning: Experience-based learning technique, learning by doing.

Eye-tracking: Tracking and recording eye movements onto objects.

F

Fiducial marker: A defined particular object to support imaging and indicate a reference point for visualisation.

Frame rate: The refreshment frequency time of the visuals for displays.

G

Game engine: Contextual software development environment to build games, video, animation, or simulations.

Gamification: Using game components in learning environments to increase intrinsic motivation.

Gesture recognition: Gesture understanding capability of computer due to the executing of commands.

Glove: A hand covering wearable technology by which to interact with a virtual environment via hand and fingers.

Goggles: AR/VR/MR HMDs.

Gyroscope: A sensor to measure and maintain orientation and angular velocity.

H

Handheld display: Portable and mobile hand-sized electronic device, display systems such as smartphones or tablets.

Haptic: Providing tactile sensation as a result of kinaesthetic interaction via force or vibration.

Heuristic: Of self-discovery and problem-solving based learning techniques.

Human-computer interaction: A field that researches human interaction via computer devices.

I

Ill-structured problem: Problems to which the desired solutions are not clear and definite.

Image recognition: Identification systems for image and video.

Imagery: Pairing visual representations in the mind.

Indoor: A stable physical space.

Input device: A device that provides interaction with or manipulation of the digital environment.

Inquiry learning: Student-centred active learning approach that provides questions and problem scenarios to learners.

Inside out: Body integrated augmented reality systems that use tracking cameras placed on the human body to recognise the physical environment.

Interpersonal skills: Emotional intelligence-based, communication, and interaction skills of individuals.

L

Laparoscopic: Of a type of surgery that is executed via a small incision in the abdominal wall.

Lenses: transparent and curved glasses for optical devices.

M

Machine learning: the use of computer algorithms that create new patterns using defined instructions.

Magnetometer, Magnetic sensor: A sensor to measure magnitude and magnetic field.

Maintenance: Technical process of checking, servicing, or repairing devices.

Manikin: A medical learning simulator that represents the human body and reacts as a result of the users actions.

Mental models: Mental models are conceptual frameworks consisting of generalisations and assumptions that affect how we view the world and act in it.

Mentor: A person facilitating someone's learning process by sharing information and guidance.

Mixed design: A research methodology that investigates the differences between two or more independent groups.

Mixed reality: Combination of virtual and physical objects to produce a new environment.

Molecular modelling: A modelling technique to represent the structures and reactions of molecules.

Mutoscope: An early motion picture device.

N

Nervous system: Biological nerve network to transfer nerve impulses.

Neural network: An algorithm depending on a human brain logic structure to understand the relationships among data and offer results.

Neurophysical: Using physical techniques to understand the information-gaining process of the brain and nervous system.

Neuroscience: The field that focuses on the brain and its impacts on behaviours or cognitive functions.

O

Object recognition: Systems that can understand the features of physical objects.

Optical system: Visualisation systems that consist of lenses, mirrors, etc.

Outdoor: The physical environment, out of door, open-air activities.

Output device: Devices to present results to users.

Outside-in: Augmented reality systems that are stable in the environment and track users or the environment from a particular place.

P

Pathologist: A specialist who discovers diseases or reasons of deformation in tissues of the human body.

Photon: Particle of light.

Plugin: An extension for the enhancing of computer software.

Post-traumatic stress disorder: The psychological reaction and symptoms after traumatic events or memories.

Prior knowledge: Previously acquired information.

Problem-based learning: A constructivist learning technique that provides open-ended questions in order to increase the problem-solving and critical skills of learners.

Prototype: A preliminary version of a product, especially a device.

Proximity sensor: A sensor to detect nearby objects or devices without a physical connection.

S

Scaffolding: As a learning term, structuring new knowledge using old knowledge to increase understanding and comprehension.

Secondary knowledge: Organised or interpreted secondary sources.

Sensor: A detection and measurement device to recognise and respond to particular values.

Simulation: An interactive animated environment to imitate circumstances.

Simulator: A machine to imitate situations or events in order that they be experienced.

Situated learning: A learning theory regarding the acquisition of knowledge with respect to real-life situations.

Spherical coordinate system: 3D coordinate system.

Stereoscopic: The visualisation of the same image from 2 angles to facilitate depth perception in the 3D environment.

T

Tactile motor: A device to provide the feel of touch.

Telementoring: Mentoring via telecommunication devices.

Telemedicine: Telecommunication based, distance health care service.

Teleoperator: A remote machine controller.

Tenosynovitis: Inflammation and swelling.

Texture: The appearance of the surface.

Topographical: The representation of parts or features of the human body or organs.

Tracking: Systems to follow movements or motions of objects.

Trackpad, touchpad: An input device.

Trigger: A device or object to set something off.

U

Ultrasonic tracking: Sound and audio recognition and command devices.

Universe: All existing matter and space, cosmos.

V

Virtual lab: Interactive, computer-based simulation software.

Virtual reality: Computer generated digital, simulated environment.

Virtuality: Refers to the extent of the being virtual, the existence, or the potential, and it includes conceptual structure and feeling of everything.

Visual search: Searching and recognising the objects in the physical environment.

W

Wand: Handheld electronic device to control HMDs and virtual environments.

Wearable technology: Technological devices that can be worn or integrated into the body.

WebVR: JavaScript-based online application programming interface by which to experience 3D virtual environments via HMDs.

Well-structured problems: Problems to which the solutions and the steps towards their solving are clear.

Wrist: A wearable device to recognise hand and finger movements to provide gesture interaction.

Z

Zoogyroscope: An early display device to produce a seemingly moving image from a series of photographs.

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