



POLITECNICO
MILANO 1863

Master Degree in
Digital and Interaction Design

*Design of Educational
Experiences for Virtual Reality*

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*“We all need people who will give us feedback.
That’s how we improve.”
Bill Gates*

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We can finish this journey together, far away but hand in hand.

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Abstract
english

Virtual Reality is developing technology with huge potentiality in education. Virtual spaces are safe environments in which new generations of students are stimulated to learn actively through enjoyable experiences.

We analyzed potentials and weaknesses of virtual learning with a focus of User Experience Design in immersive spaces. From a neurological point of view, virtual reality can stimulate our brain and in some cases deceive it; our brain believes that immersive spaces are real and events that happen in virtual environments actually happen because they produce emotions on the user. To make this process happen it is essential to design a credible experience.

There are several design rules to develop credible virtual experiences. In this thesis, we studied the design principle for virtual environments that have been suggested over the years. We focused on the most relevant ones and designed a conceptual framework to support the development of educational applications. We applied our conceptual framework to two real scenarios involving educational experiences for the course of Orbital Mechanics and Solid State Physics of Politecnico di Milano. In collaboration with DEIB, we designed and developed two educational experience, Space Debris VR and Crystallography VR, applying the "Double Diamond Design Process" and the "Instructional design theoretical framework of VR based learning environment". We validated the applications with human source.

Abstract
italiano

La realtà virtuale è una tecnologia con enormi potenzialità nel contesto educativo. Gli spazi virtuali sono ambienti sicuri in cui le nuove generazioni di studenti possono essere stimolate ad apprendere attivamente attraverso esperienze immersive.

Abbiamo analizzato potenzialità e debolezze dell'utilizzo della realtà virtuale nell'apprendimento concentrandoci sulla progettazione dell'esperienza utente in spazi immersivi.

Da un punto di vista neurologico, la realtà virtuale può stimolare il nostro cervello arrivando talvolta ad ingannarlo. Per realizzare ambienti virtuali è essenziale progettare esperienze credibili capaci di intrattenere i nostri sensi.

Esistono molte regole di progettazione per sviluppare esperienze virtuali credibili. In questa tesi, abbiamo studiato i principi di progettazione per ambienti virtuali che sono stati sviluppati nel corso degli anni concentrandoci su quelli più rilevanti e abbiamo progettato un framework concettuale per supportare lo sviluppo di applicazioni educative. Abbiamo applicato la nostra struttura concettuale a due scenari reali che coinvolgono esperienze educative nel corso di *Meccanica orbitale* e *Fisica dello stato solido* del Politecnico di Milano. In collaborazione con il *DEIB*, abbiamo progettato e sviluppato due esperienze formative, *Space Debris VR* e *Crystallography VR*, applicando il "Double Diamond Design Process" e il "Framework teorico di progettazione didattica dell'ambiente di apprendimento basato sulla Realtà Virtuale". Abbiamo infine validato le applicazioni in università con docenti e studenti e durante eventi aperti al pubblico, avendo dunque la possibilità di testare le applicazioni con persone con background e attitudini disomogenee.

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INTRODUCTION

Extended Reality is an area of huge growth and development. The road to achieving the complete development of these technologies is still long from the point of view of software and hardware.

One of the great fields of application of Extended Reality is education. These technologies allow active learning through interaction and experience, elements that are becoming fundamental in the education of new generations.

Virtual Reality is able to trick our brain by proposing credible experiences that we remember as real personal memories because all our perceptual receptors are involved during an immersive adventure. For this reason, this technology has huge potential in education: students have the opportunity to live a personal experience and perceive it with their senses. To make this process happen, it is essential to design a credible environment that entertains our senses without our perceptive system realizing that some detail is not real but simulated.

The user experience (UX) is part of this process. Designers must create an experience that does not initially pose a problem for the user because it is credible, enjoyable and simple, allowing the student to concentrate on the concept that the experience is proposing.

There are a lot of guidelines to follow to design virtual experiences, we focused our attention on the principle related to the design of the interface. We followed the "Double Diamond Design Process" and the "Instructional design theoretical framework of VR based learning environment". During the development process we ideated, designed and developed virtual educational experiences .

In collaboration with DEIB – Electronics, Computer and Bioengineering Department – of the Politecnico of Milan, we designed and developed two educational experience, *Space Debris VR* and *Crystallography VR*, applying the ”Double Diamond Design Process” and the “Instructional design theoretical framework of VR based learning environment”.

The goal of this thesis, therefore, was the study of the design principle for virtual environments and the design of a conceptual framework to support the development of educational applications. The framework has been applied to two real scenarios involving educational experiences that have been validated with human sources.

THESIS OUTLINE

The thesis is organized as follows:

Chapter 1 | Extended Reality

The first chapter explains extended reality, the fundamental concepts of immersion and sense of presence at every level of virtuality—augmented, mixed and virtual—and present their history from an interaction point of view. It presents trends and topic of development and research of extended experiences, updated to 2019.

Chapter 2 | Learning through Extended Reality

The second chapter analyzes the socio-cultural environment and learning skills of the Alpha generation in order to understand the target of the educational virtual application developed. It explains the neuroscience principles that our brain uses during a traditional lesson and during an extended experience. It analyzes and compares virtual educational applications currently on the market.

Chapter 3 | UX and Interaction in Virtual Reality

The third chapter analyzes and synthesizes the fundamentals of human virtual interaction. It focuses on hardware constraints, UX, UI, and ergonomics in virtual reality, which have been reorganized on a scale that goes from design rules that respond to the user's physiological needs to ergonomic ones.

Chapter 4 | Design process for Virtual Educational Experience

The fourth chapter introduces the design process followed the development of the two virtual educational projects. It presents the combination of the *Double Diamond Design Process* and the *Instructional design theoretical framework of VR based learning environment*.

Chapter 5 | Space Debris VR

The fifth chapter presents the Space Debris VR application. It explains the process to define, structure and develop the project. It explains the design evolution, discussing prototyping, user insight and the design iterations of the application.

Chapter 6 | Crystallography VR

The sixth chapter presents the Crystallography VR application. It explains the process of defining, creating the framework and developing the project. It explains the design evolution, discussing prototyping, user insight and the design iterations of the application.

Chapter 7 - Conclusion

The seventh chapter discuss the final outcome of our work and proposes future goals and developments.

Chapter 1

EXTENDED REALITY

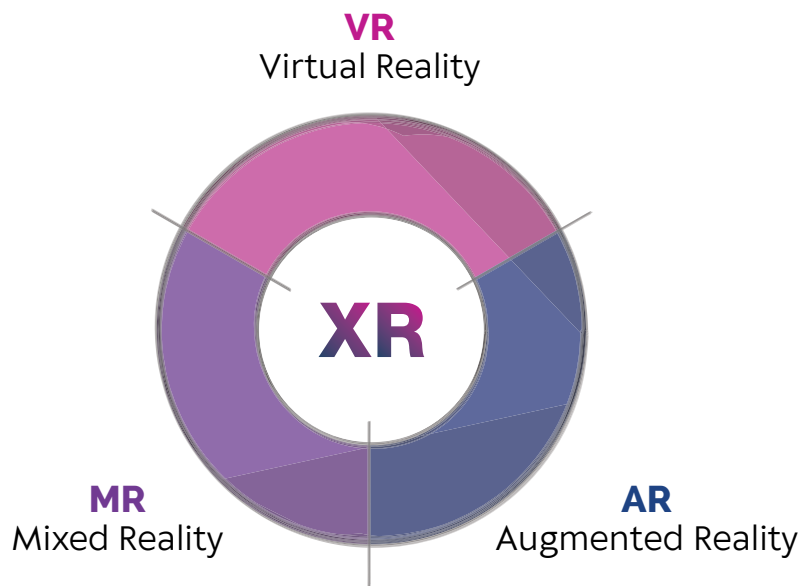


Figure 1.1: *Augmented, Mixed and Virtual Reality.*
Reworking of an image taken from Medium

Extended Reality

“The term Extended Reality or XR has been introduced to describe all the technological solutions that involve the creation of a new level of reality including the entire spectrum from the complete real to the complete virtual.” [1]

Extended reality or XR is a new emerging trend that defines all the environments created for human and machine interactions that combine the real and virtual worlds. It has the goal of expanding the boundaries of the world that we can perceive with our natural senses.

Extended reality is the term that includes virtual reality, augmented reality, and mixed reality, as well as all future realities that technology might bring. Extended reality covers the full spectrum of real and virtual environments that can be experienced through the use of computers and wearables. Extended reality is a term that recognizes the intersection of different technologies and the many ways they will work together to enhance our everyday tasks and signal a fundamental shift in the way people interact with media.

In the future, we will not say “I’m using VR to attend a business meeting”, it will just be a normal day at the office. People will interact with the real and virtual worlds in the same way, without mentioning extended reality’s distinct categories and their underpinning technologies.

To better understand extended reality, it is important to define two of its main components: immersion and sense of presence.

1 Unity 3D, XR glossary, <https://unity3d.com/what-is-xr-glossary>, (accessed July 20, 2019).

1.1 Immersion and Sense of Presence

To understand the differences between extended experiences it is fundamental to understand immersion. Immersion is the act of dipping something in a substance and completely covering it. It might be something physical, such as plunging your body into water, or metaphorical, such as becoming totally immersed in a project.

The concept of immersion in an extended reality scene is the act of diving into another artificial world. In the context of virtual reality, immersion is the condition in which the user loses awareness of the fact that they are actually in a virtual world, experiencing the virtual world with all of their senses and able to interact with the virtual environment.

To define the level of immersion of the experience, we need to consider the types of interaction that the user can establish with the extended experience.^[2] It is fundamental to define how the user will be immersed in the virtual experience and how they will be able to react and interact with digital objects and the environment.

From a design point of view, it is really important to understand how the user will receive output from the virtual environment—generally using a head mounted display, smartphone, headphones and haptic devices—and how they will give input to it through controllers, eye tracking, body and hand tracking. These elements are fundamental to guide the experience of the user and to create a sense of presence in the scene. They are used to split the concept of presence as two interrelated phenomena: telepresence, the sense of “being there”, and social presence, the sense of “being together with others”, including people, animals, avatars, and so on.^[3] Telepresence in the virtual environment happens when users

2 Steuer, Jonathan. “*Defining Virtual Reality: Dimensions Determining Telepresence*”, *Journal of Communication*, 42, no. 4 (1992). 73-93.

3 Lehman, R. M. and Conceição S. *Creating a Sense of Presence in Online Teaching: How to “Be There” for Distance Learners*, San Francisco: Jossey-Bass, 2010.

have the impression or feeling that they are enjoying an experience at a location remote from their own immediate environment. Social presence means interactions with others in the online environment. It is common to replace the meaning of a sense of presence with the terms of being there and being together.

Sense of presence is what makes virtual reality magic; it is the feeling of actually being in a virtual world. This sense of presence will cause incredulity, but users will believe the virtual environment to be real, reacting to stimuli as if they were in the real world. ^[4] To create a real presence that involves all the senses, the user needs to be convinced that they are in another reality. Currently, virtual reality is able to satisfy our vision and hearing, and there are some significant developments regarding touch, but there is still a lot of work to be done regarding the sense of smell and a huge job to do for taste.

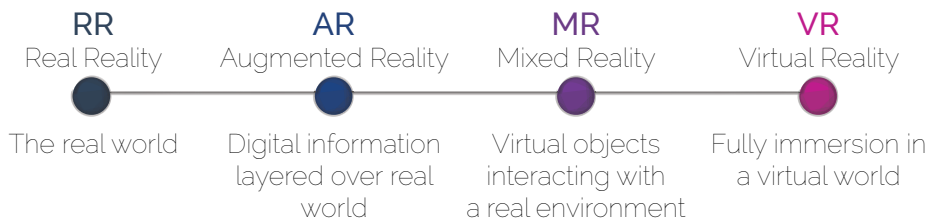


Figure 1.2: Reworking of an image taken from P. Milgram and F. Kishino
A taxonomy of Mixed Reality Visual Displays. (1994)

4 Rogers, Sol. "Why Is Presence Important For Virtual Reality?." VR Focus. <https://www.vrfocus.com/2017/11/why-is-presence-important-for-virtual-reality/>. (accessed July 25, 2019).

Real Reality

Augmented Reality



The real world



Digital information layered over real world

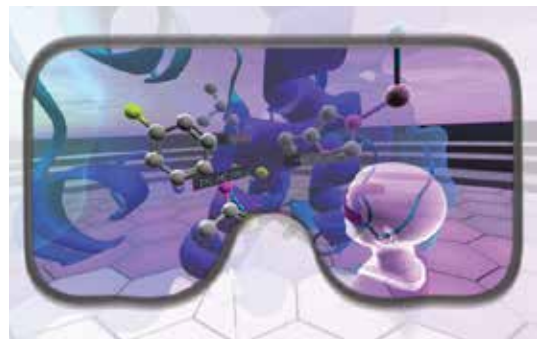
COMPUTER-GENERATED

Mixed Reality



Virtual objects interacting with a real environment

Virtual Reality



Fully immersion in a virtual world

REAL WORLD

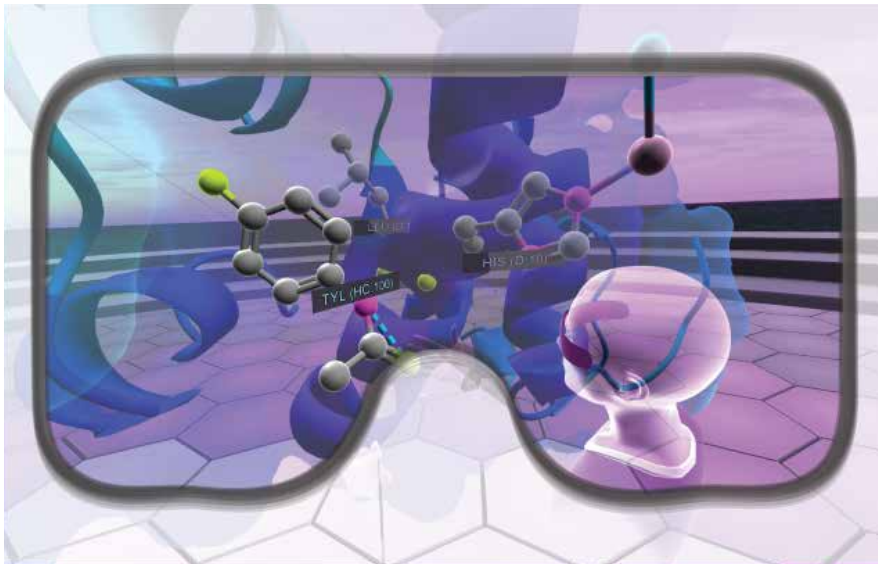
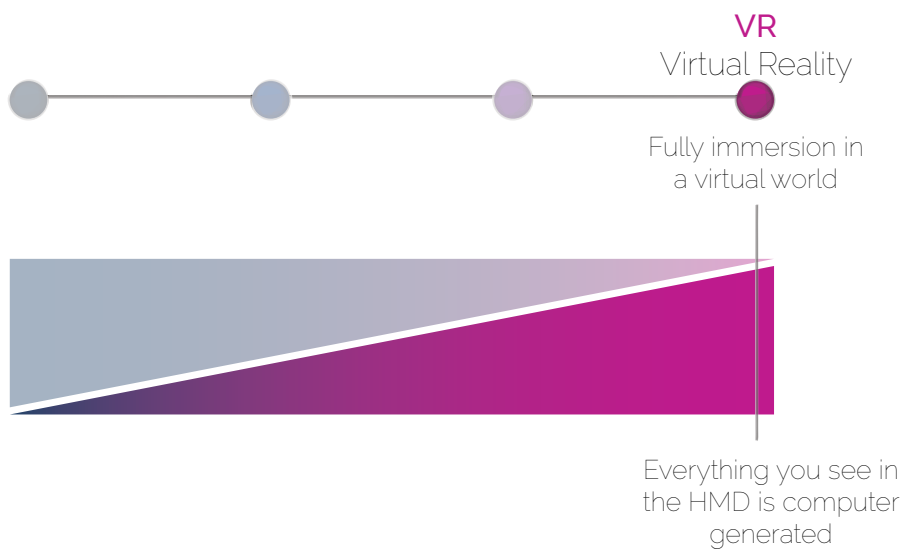


Figure 1.3: *Virtual Reality*.
Reworking of an image taken from P. Milgram and F. Kishino (1994)



1.2 VR | Virtual Reality

“Forty-third VR Definition: A new art form that must escape the clutches of gaming, cinema, traditional software, New Economy power structures, and maybe even the ideas of it’s pioneers ”.

“VR is a twenty-first-century art form that will weave together the three great twentieth-century art forms: cinema, jazz, and programming ”.

Jaron Lanier ^[5]

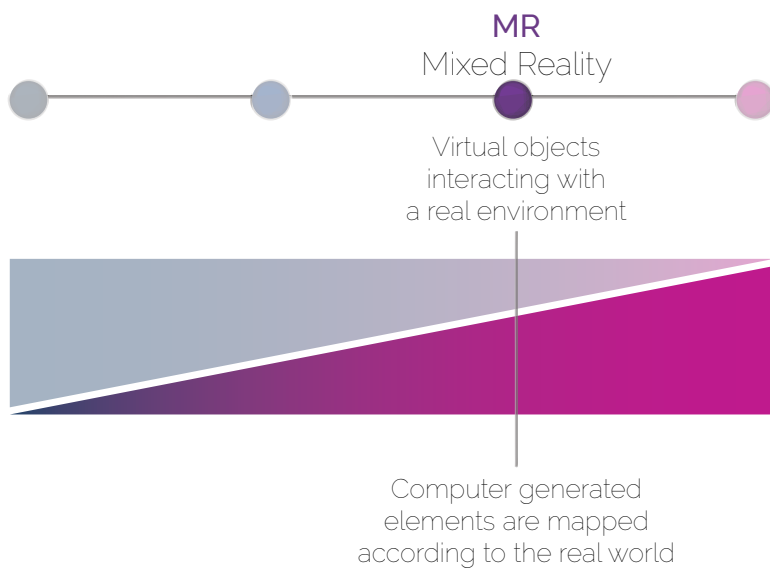
Virtual reality or VR is the use of computer technology to create a simulated environment. Virtual reality applications use headsets to fully immerse users in a computer-simulated reality. Unlike traditional interfaces where users watch a screen, virtual reality places the user inside an experience. The user is immersed and able to interact with virtual worlds by simulating as many senses as possible, such as sight, hearing, touch, even smell. The computer becomes a gate to an artificial world.

Virtual reality artificially isolates the user from real reality (RR), replacing it completely, absorbing the user’s gaze. A very wide range of head-mounted displays (HMDs) have been created for virtual reality. Virtual reality immerses the viewer not only visually, but it also aspires to a complete immersive simulation that includes all the senses.

⁵ Lanier, J. *Dawn of the New Everything: Encounters with Reality and Virtual Reality*, New York: Henry Holt and Co. 2017.



Figure 1.4: *Mixed Reality*.
Reworking of an image taken from P. Milgram and F. Kishino (1994)



1.3 MR | Mixed reality

“MR is a particular subclass of VR related technologies that involve the merging of real and virtual worlds.”

Milgram and Kishino

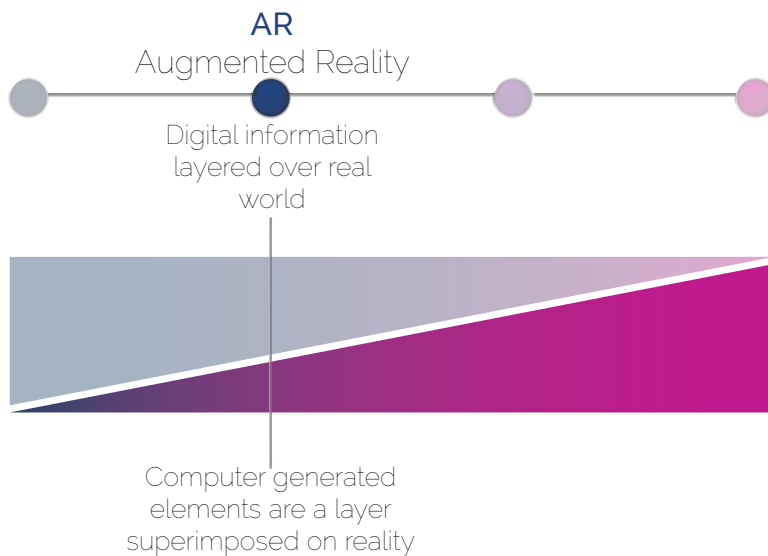
Milgram defined mixed reality as a technology that blends real and virtual worlds along the “reality-virtuality - continuum” (RV) which connects completely real environments to completely virtual ones. ^[6]

Mixed reality lies in between virtual and augmented reality. It blends real and virtual worlds to create complex environments where physical and digital elements can interact in real time. It takes from augmented reality the overlaying of synthetic content in a real-world environment. It takes from virtual reality the interactivity of the contents and the fact that users can manipulate the virtual objects in physical space.

⁶ Milgram P. and Kishino F. “A taxonomy of Mixed Reality Visual Displays.” IEICE Transactions on Information and Systems E77-D, no. 12(12) (1994). 1321-29.



Figure 1.5: *Augmented Reality*.
Reworking of an image taken from P. Milgram and F. Kishino (1994)



1.4 AR | Augmented Reality

“AR system combines real and virtual objects in a real environment, it merges reality and virtuality with each other and it runs interactively, in three dimensions and in real-time.”

Azuma [7]

Augmented reality is the integration of digital information with the user’s environment in real time. Unlike virtual reality, which is a completely artificial environment, augmented reality uses the existing environment and overlays new information on top of it.

There are three types of augmented reality, depending on the type of trigger activating the virtual layer: marker-based, markerless and location-based.

In marker-based AR, the digital world is anchored to the real world. For example, to augment the page of a book, the user points the camera at a particular page. The camera then recognizes a distinctive picture or shape on the page and the animation can start immediately, tracked to the appropriate place on the page. The user can also move the physical book around and see the virtual world “stick” to the real surface of the page.

In markerless AR, the user moves the virtual objects. This type of augmented reality, for example, can be used to place virtual furniture inside a real room. This allows the user to visualize different combinations of objects, styles and location directly at home.

With *location-based AR*, the virtual world is in a physical space. These types of applications tie augmented reality content to a specific location. This type of augmented reality can be used to give directions on a city street the user is not familiar with. Through their phone’s camera, the user can see a virtual road sign displaying the street name, and directions are displayed right on top of the physical roads in front of the user.

7 Azuma R.T. “A Survey of Augmented Reality.” Presence: Teleoperators and Virtual Environments 6, 4 (August 1997). 355-385.

1838
Stereoscopy



1929
Flight simulator

1956
Sensorama



1961
Motion tracking

1972
180° FOV

1891
Frame rate

1935
VR concept

1969
VR interaction

1977
Gesture recognition



1960
First HMD

1.5 History of Extended Reality

Timeline of historical events, technological and interaction development

● **1979**

Eye-tracking in VR



● **1987**

Speech recognition

● **1992**

First MR experience

● **2017**

VR wireless



● **1985**

Haptic interaction



● **1991**

VR on Mars

● **2012**

VR consumer product

STEREOSCOPY

1838

Charles Wheatstone demonstrated that the brain processes different two-dimensional images from each eye into a single object of three dimensions. Viewing two side by side stereoscopic images or photos through a stereoscope gave the user a sense of depth and immersion.

FRAME RATE

1891

Thomas Edison and William Dickson invented the Kinetoscope. It sent a piece of film between a lens and a light bulb so that the viewer, peering through a peephole, could see images at 46 frames per second (fps).

FLIGHT SIMULATOR

1929

Edward Link created the first commercial flight simulator. It was completely electromechanical and was called “Link trainer”. Flight simulators and in general military applications are one of the most prolific fields where VR has grown during history.

VR CONCEPT

1935

Stanley Weinbaum released “Pygmalion’s Spectacles” a science fiction story. The story’s main character wears a pair of goggles which transports him to a fictional world which stimulates his senses aptly and features holographic recordings.

STEREOSCOPE

1938

Wheatstone invented the stereoscope, a device that allowed users to see two stereoscopic images and gave the illusion of looking at a larger 3D image, and eventually led to the creation of the popular View-Master stereoscope.

SENSORAMA

1956

Cinematographer Morton Heilig created Sensorama, the first VR machine. It combined multiple technologies to stimulate all the senses: there was a combined full-colour 3D video, audio, vibrations, smell and atmospheric effects, such as wind. Heilig thought that the Sensorama was the “cinema of the future” aspiring to total immersion.

FIRST HMD

1960

Heilig also patented the Telesphere Mask which was the first head-mounted display (HMD). This provided stereoscopic 3D images with wide vision and stereo sound. There was no motion tracking in the headset at this point.

MOTION TRACKING

1961

Comeau and Bryan, two Philco Corporation engineers designed the first motion tracked system. It had built-in video screens for each eye and a head-tracking system. However, this was not used for virtual reality, it was developed for the military scope. A remote camera imitated the head movements so the user could look around the setting.

REAL-TIME VR

1965

Ivan Sutherland, a computer scientist, presented his vision of the Ultimate Display. The concept was of a virtual world viewed through an HMD which replicated reality so well that the user would not be able to differentiate from actual reality. The user being able to interact with objects.

HMD TRACKING

1968

Sutherland and Bob Sproull, created the first virtual reality HMD, named The Sword of Damocles. It could show simple shapes that changed perspective with user's head movements. It was never developed beyond a lab project because it was too heavy for users to comfortably wear.

VR INTERACTION

1969

Myron Krueger developed experiences using computers and video systems. Videoplace was the first interactive VR platform. It consisted of dark rooms with large video screens to surround the user, using computer graphics, projectors, and position sensing.

180° FOV

1972

General Electric Corporation built a computerised flight simulator which featured a 180-degree field of vision by using three screens surrounding the cockpit.

1st PERSON EXPERIENCE

1977

Aspen Movie Map was created by MIT. It is the first interactive map of the history anticipating by 30 years the interactive map of Google. It was created using photographs from a car driving through the city. There were no HMDs but it was the use of first-person interactivity and it suggested that VR could transport people to other places.

GESTURE RECOGNITION

1977

Scientists at the Electronic Visualisation Laboratory of the University of Illinois developed the first wired glove, the Sayre Glove, that could turn finger movements in electrical signals. This may have been the beginning of gesture recognition.

EYE-TRACKING IN VR

1979

McDonnell-Douglas Corporation integrated VR into its HMD for military use. The VITAL helmet was the first HMD able to follow the pilot's eye movements to match computer-generated images.

HAPTIC INTERACTION

1985

Jaron Lanier and Thomas Zimmerman founded Virtual Prototyping Lab Research. This company is known as the first company to sell VR goggles and gloves. They developed a range of virtual reality gear including the Dataglove and the EyePhone HMD. A major development in the area of virtual reality haptics.

VR DEFINITION

1985

Lanier coined and popularised the term “Virtual Reality”.

SPEECH RECOGNITION

1987

British Aerospace used the HMD similarly to Furness’ Super Cockpit and developed the Virtual Cockpit which also featured speech recognition.

3D AUDIO

1989

Scott Foster founded Crystal River Engineering Inc, after receiving a contract from NASA, to develop the audio element of the Virtual Environment Workstation Project (VIEW); it was a VR training simulator for astronauts. Through this company real-time binaural 3D audio processing was developed.

INDOR AR NAVIGATION

1990

The term “augmented reality” was coined at Boeing by Tom Caudell. He proposed to replacing the large plywood boards, which contained individually instructions to guide workers inside the factory, with a head-mounted apparatus that would display specific instructions for each worker.

VR ON MARS

1991

Antonio Medina, a NASA scientist, designed a VR system to drive the Mars robot rovers from Earth in supposed real-time despite signal delays between the planets. This system is called “Computer Simulated Teleoperation”.

VR MEET GAMING

1991

The Virtuality Group launched Virtuality, VR arcade machines where gamers could play in a 3D gaming world. This was the first mass-produced VR entertainment system. A Virtuality pod featured VR headsets and real-time immersive stereoscopic 3D images.

AR REMOTE ASSISTANCE

1992

Louis Rosenberg developed one of the first functioning AR systems, called Virtual Fixtures. It was a pioneering platform consisting of an overlay of augmented sensory information upon a user’s perception of a real environment in order to improve human performance in both direct and remotely manipulated tasks.

CAVE

1992

Chicago Electronic Visualisation Laboratory developed a VR system called CAVE Automatic Virtual Environment. The user was placed in a room that has screens instead of walls. Images of the environment were then projected on those screens to create a feeling of immersion.

FIRST MR EXPERIENCE**1992**

Julie Martin creates the first augmented reality Theater production, “Dancing in Cyberspace”, featuring acrobats who danced within and around virtual objects on their physical stage.

AR EXPOSITION**1994**

Jeffrey Shaw creates The Golden Calf an AR installation. The viewer could pick up and hold a monitor similar to a tablet, and see an augmented golden calf standing on top of a pedestal. By moving the monitor around the real pedestal the viewer can examine the 3d animal from above, below and all sides.

VR MEET PSYCHOLOGY**1997**

“Virtual Vietnam” is a virtual reality simulation of Vietnam War combat. The application was created to treat veterans suffering from post-traumatic stress disorder, a debilitating psychological condition.

OPENSOURCE AR**2000**

Hirokazu Kato created the ARTToolKit, an open-source computer tracking library for creation of strong augmented reality applications that overlay virtual imagery on the real world. The ARTToolKit is still used widely to complement many augmented experiences.

VR GOOGLE MAPS**2010**

Google introduced a stereoscopic 3D mode for Street View (street view was born in 2007).

RIFT PROTOTYPE**2010**

Palmer Luckey, an 18-year-old entrepreneur, created the first prototype of the Oculus Rift headset. It featured a 90-degree field of vision, which had never been seen before, and relied on a computer’s processing power to deliver the images. This new development boosted and refreshed interest in VR.

MAGIC LEAP**2010**

Magic Leap is a U.S. startup company that is working on a head-mounted virtual retinal display, called Magic Leap One, which superimposes 3D computer-generated imagery over real world objects, by projecting a digital light field into the user’s eye.

AR IS MY ‘PUBLIC SPACE’**2010**

Sander Veenhof and Mark Skwarek build “WeARinMoMA”, A collective of eight internet artists transformed the Jackson Pollock room in the New York City Museum of Modern Art into their own augmented reality gallery—without the museum’s permission.

VR CONSUMER PRODUCT

2012

Luckey launched a Kickstarter campaign for the Oculus Rift which raised \$2.4 million.

AR MANUALS

2013

Car manufacturers begin to use augmented reality as the age vehicle service manuals. The Volkswagen MARTA app (Mobile Augmented Reality Technical Assistance) provide Virtual repair assistance, allowing service technicians to foresee how a repair process Will 100k on the vehicle in front of them.

WEARABLE AR HMD

2013

Google designed Google Glasses with the mission of producing a ubiquitous computer. Google Glass display information in a smartphone-like, hands-free format. Is starting the trend of wearable AR.

VR LOW COST

2014

Google released the Cardboard - a low-cost and do-it-yourself stereoscopic viewer for smartphones.

HOLOLENS

2015

Microsoft announces Windows Holographic and the HoloLens augmented reality headset. The headset utilizes various sensors and a processing unit to blend high definition “holograms” with the real world.

WEARABLE VR

2015

HTC released its HTC VIVE SteamVR headset. This was the first commercial release of a headset with sensor-based tracking which allowed users to move freely in a space remaining bound by a cable.

VR WIRELESS

2017

Oculus Go marks a new era for VR, one in which anyone can simply slip on a headset and dive into virtual realms. Though not perfect, it offers a comfortable fit, solid build, good visuals and the promise of more great content to come.

1.6.1 Virtual Reality is at the Head of Growth

Virtual reality is growing a lot in a really short time. Worldwide, VR market volume is expected to reach 98.4 million sales by 2023. Growth is forecast across all regions and countries, with China leading the way.

2019 is turning out as a great year for VR, providing a solid base for growth. Oculus Quest, Facebook's standalone headset, has created a lot of interest.

The shift from tethered to standalone VR headsets represents a paradigm shift; we have a truly mobile platform that is good enough to facilitate user experiences.

This month, Road to VR reported that the monthly-connected VR headsets on Steam have surpassed 1 million for the first time. May 2019 was a record month Virtual Reality; more than 1 million monthly-connected headsets on Steam. "Year over year, monthly-connected headsets on Steam are up 80%." ^[8]

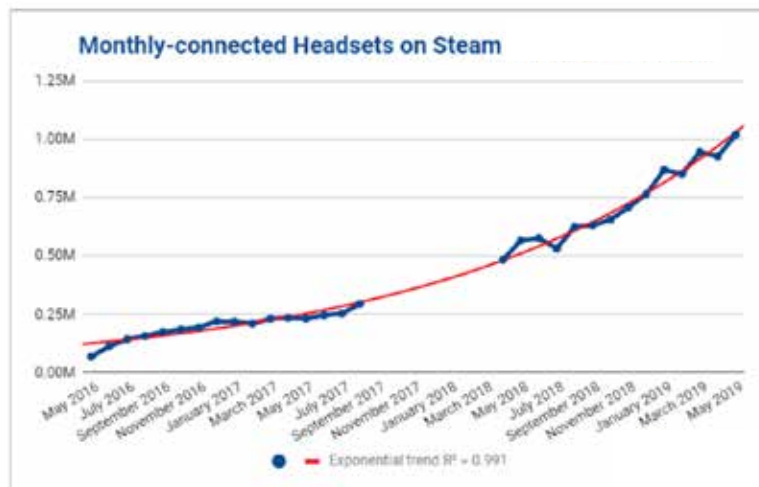


Figure 1.14: Monthly connected HDM on Steam.

8 Lang, Ben. "Analysis: Monthly-connected VR Headsets on Steam Pass 1 Million Milestone." Road to VR. <https://www.roadtovr.com/monthly-connected-vr-headsets-steam-1-million-milestone/>

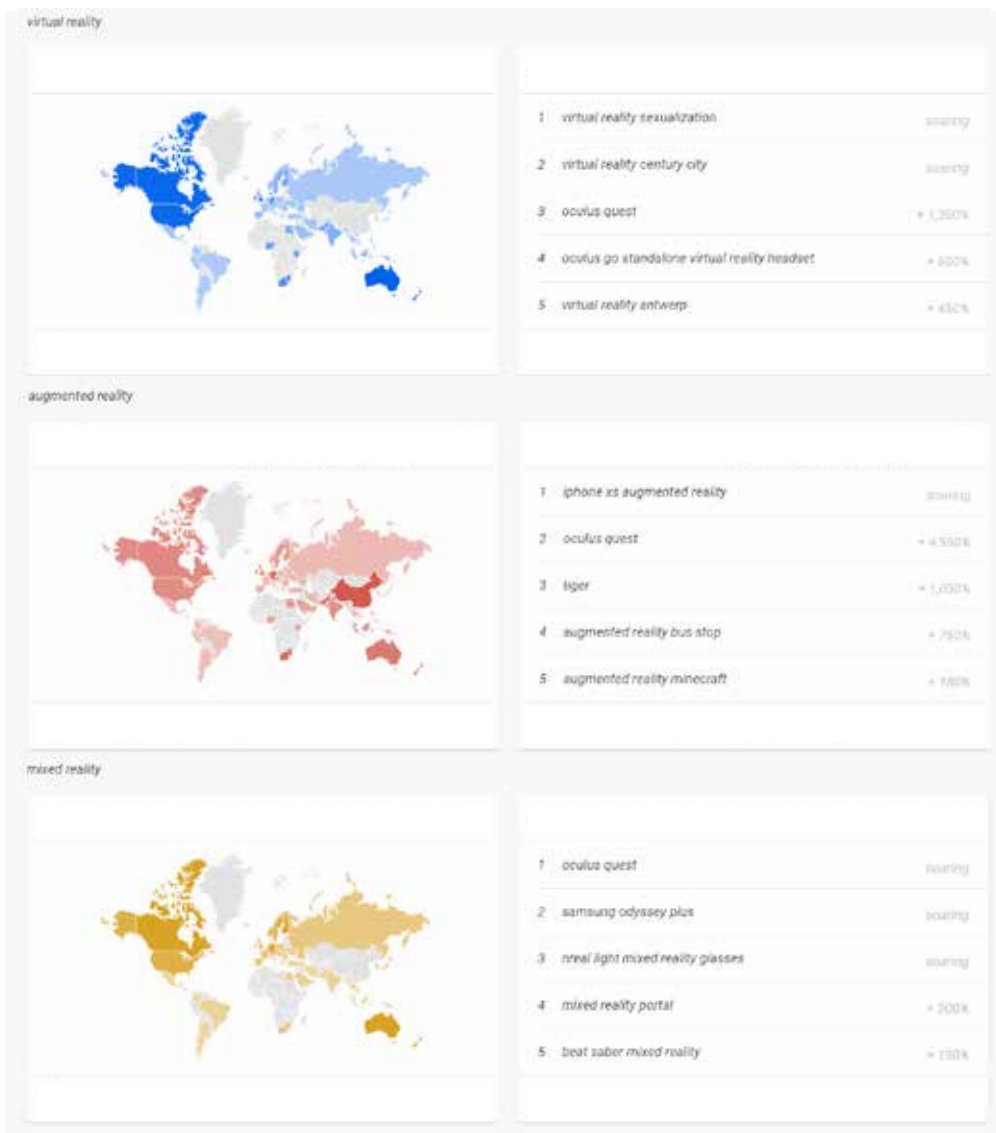


Figure 1.13a: *Google Trend, comparison VR, MR, AR.*
Update to 5th August 2019

1.6.2 Worldwide Interest in Extended Reality

Where Virtual Reality, Augmented Reality and Mixed Reality are more popular? ^[9]

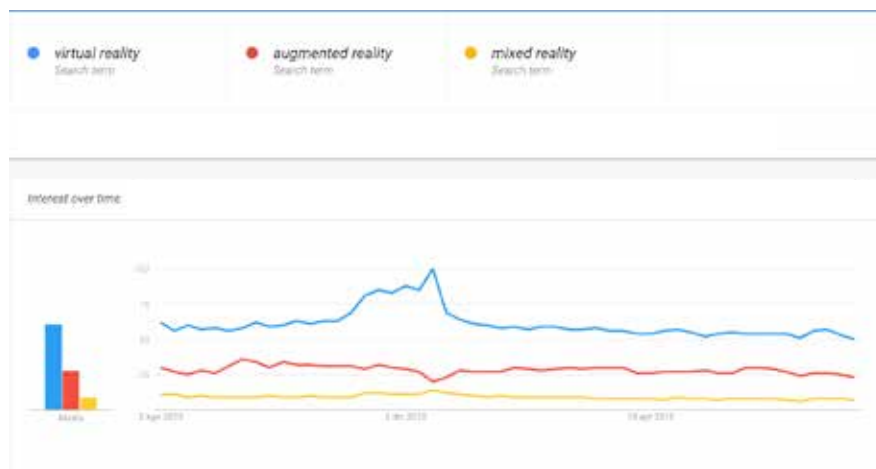


Figure 1.13b: *Google Trend, comparison VR, MR, AR.*
Update to 5th August 2019

Analyzing the data provided by Google Trend, it is clear that virtual reality is the most widespread technology, followed by augmented reality and mixed reality.

It may be interesting to understand which areas of the world are more receptive to these technologies. Also, in this case, Google Trend helps us, showing us where the three types of extended reality are most sought after on the web. It confirms that America is the home of virtual reality while China is the leader in augmented reality. We can see that Germany is the European power in VR, MR and AR, followed by Scandinavia and England, and that South Africa occupies an important place in the development of applications for architecture.

⁹ Worldwide date from Google trend (update to 5th August 2019).

1.6.3 Extended Reality Contents Trend

Extended reality is expanding in many areas. According to Virtual Reality (VR): Global Market Analysis, Trends, and Forecasts report made by Globe Newswire in Dublin, published the 25th of June 2019, these are the main contents for 2019.

Artificial intelligence and Extended Reality

Artificial intelligence and machine learning are fast-growing sectors in tech. Bringing them together with augmented and mixed reality systems is a natural extension of many of the things that are best suited to computer vision. When it comes to augmented reality, computer vision, AI technology allows computers to understand and label objects in the field of vision. Computer vision and other similar technologies will continue to develop and become more sophisticated.

One of the most fertile markets for this binomial is online and retail shopping. By pairing consumer profiles with augmented reality and mixed reality, retailers can identify customer needs based on their environments and provide them with recommendations.

The coupling of these two technologies is entering our daily life, for example with Snapchat and Instagram filters that allow users to overlay bunny ears and fun graphics on selfies is an example of AI technology combined with augmented reality.

When it comes to virtual reality, the virtual environments and the inhabitants within it will also become more intelligent. The role of voice control will increase, allowing the reduction of icons and menus within the virtual world.

AI and extend realities are young technologies; they are growing fast and becoming very powerful, as we can see in gamer that is controlled in video games. In a short time, these technologies will become more intelligent and will react and adapt to an individual's play style.



Figure 1.15: *Aumented shopping*, Habitant.

Extended Reality in training and teaching

Virtual environments allow students to practice anything from construction to flight to surgery without the risks associated with real-world training, while augmented environments create a layer of information that can be given to the student in real time on objectives, hazards or best practices.

Oculus Go is used to train employees in soft skills ranging from compliance to customer service. This technology is particularly useful for the retailer to learn to use new vending services in virtual environments before development in stores. The US Army has announced a deal with Microsoft to use HoloLens technology in military training. Soldiers will get real-time readings on their environment. This will include real-time biometric control for soldiers with the objectives of developing pathfinding, target acquisition and mission planning.

Virtual and augmented reality are able to reduce training risks and costs. We will see an increasingly rapid growth of adoption in industries involving work with expensive tools and equipment or hazardous conditions throughout 2019.



Figure 1.16: *Svevens Immersive Studio*

Consumer Entertainment VR

Previous generations of Virtual Reality headsets have been limited because of their cost or the power of the computer to support the experience. Nowadays, stand-alone headsets incorporating powerful, dedicated computer technology are becoming consumer products. This means more immersive entertainment experiences and an unprecedented level of realism at a low cost. As well as being mobile, the new generation of headsets will improve the technology powering the virtual experience by including features such as eyeball-tracking and increased field-of-view. Again, this will help users feel they can interact and explore in more natural ways.

It wasn't so long ago that no one had even really heard about augmented reality. And then Pokémon Go was released and everything changed. The technology didn't even really need to work right for people to start getting excited. Even the mere promise of something close to virtual reality was enough to spread excitement all over the world.

As has been mentioned in the previous paragraphs, the gaming world is getting passionate about VR applications, and access to SteamVR is growing exponentially. But it is not just gamers who are passionate about extended reality. The world of cinema is also gaining ground, as Morton Heilig had predicted with the invention of Sensorama.



Figure 1.17: *Beat Saber on Steam*

Some filmmakers have already begun making films specifically for virtual reality. Five years ago, Sundance Film Festival's New Frontier program proved that VR filmmaking should explode in 2019. Creators had already started branching out and incorporating technological advancements into their films, including augmented reality, artificial intelligence and connected devices, to create more dynamic ways of storytelling. Filmmakers are just starting to look beyond the formats provided by headset manufacturers like Oculus, Samsung and HTC as they are not necessarily cost-effective or user-friendly like the traditional cinema or the home DVD experience. For filmmakers, the future of VR lies in innovation and development to find ways to adapt technology that works well in the gaming world to the film world.

Extended environments becoming collaborative and social

Facebook, the social media giant believed extended reality would become vital to the way we build shared online environments. This year, Facebook's VR Spaces platform, which allows users to meet and socialize in VR, moved out of beta and Tencent has announced that it is looking into adding VR to its WeChat mobile messaging system, the most widely used messenger app in the world.

Conference calls are becoming a huge trend because participants have the opportunity to see and interact with each other, even if collaborative spaces are often undermined by the lack of a direct personal presence. We must not forget, however, that this area is only at the beginning. In fact, Microsoft is moving forward with a beta of a video-calling system that employs augmented reality to create holographic-style representations of participants. Ford's Ford X in-house incubator has been developing a spatial system to create shared AR workspaces for its employees, and pioneers such as Spatial are leading the way with AR tools for the boardroom and office where users can see virtual whiteboards and pinboards, as well as collaboratively work on design documents overlaid on real-world objects. Combined with the predicted increase in sales of VR and AR headsets, this could mean that 2019 is the year we experience meeting and interacting with realistic representations of our friends and family in virtual reality for the first time.



Figure 1.18: Facebook Social VR for Oculus Rift

Business Applications

The use of virtual reality and augmented reality in manufacturing and Industry 4.0 is not fiction; it is increasing the digital transformation. The trend for 2018 outlined by Oracle confirmed that enterprise VR has helped businesses go beyond the limits of two-dimensional communication to build, through social virtual reality, relationships with customers, partners, and employees, for truly effective and efficient demand generation.

Simulation models and the use of extended reality can speed up the entire production chain, maintenance, logistics and assist factory staff, who can better perform their tasks if they have the information they need in front of their eyes with free hands. Companies are planning to streamline processes like training, providing self-help to workers through augmented manuals. It will smooth processes and flows.



Figure 1.19: *Joinpad, Augmented Reality for enterprise*

Chapter 2

**LEARNING WITH
EXTENDED REALITY**

Learning with Extended Reality

“Every child has the potential to be a genius, but today’s teaching models have failed to realize this truth. VR unleashes children’s potential by letting them learn new concepts using a multi-modal model, thereby enabling the brain to grasp new concepts in the way that’s most natural to them. VR can be the best tool and platform to improve educational results.”

Alvin W. Graylin - China President at HTC

A research report recently conducted using the ViveVR platform has found that VR-based education delivers rewarding outcomes in the classroom, offering substantial evidence to encourage the development of technology in the academic field.

The case study, “The Impact of VR on Academic Performance”, published in November 2016 by Beijing Bluefocus E-Commerce Co., Ltd. and Beijing iBokan Wisdom Mobile Internet Technology Training, conducted at select high schools in Beijing, shows that teaching through virtual reality improves student test scores and knowledge retention compared with traditional classroom education.¹² This experiment intended to show the difference between traditional teaching and VR-based teaching in a high school in Beijing. The class was divided into two groups, and they had two tests at a different time. One group adopted VR-based teaching and the other group traditional teaching. A test was taken immediately after teaching to show the difference between the two groups in their academic performance as well as learning efficiency. The second test was taken two weeks later to see how long the two groups remembered the information. Those who follow the VR lesson achieved average scores of 93% on the final test versus the average 73% achieved by those who had not. Another test given

two weeks after clearly demonstrated that students in the VR group outperformed those in the traditional learning group. Students in the VR group scored an average of 90% while those in the traditional education group scored an average of only 68%.

There are manifold benefits in the use of virtual reality in education, such as active learning experience, an immediate engagement that helps students to develop personal skills, improved concentration, and a better understanding of complex theories and concepts. The physicality of virtual reality increases retention.

The Digital Generation ^[10] is growing up constantly connected to the world around them through smartphones, tablets, and computers. Because of this hyperconnectivity, they will learn differently than past generations. It is important that we understand how they learn and interact with the world in order to teach them more effectively. They are the first generation using extended reality and other new technologies to enhance their education.

10 Beijing Bluefocus E-Commerce Co., Ltd. and Beijing iBokan Wisdom Mobile Internet Technology Training, *The Impact of VR on Academic Performance*, Beijing, 2016

2.1 Socio Cultural Environment

2.1.1 Generation Alpha

To understand why virtual reality is gaining so much power in education and why it has been declared as one of the most valuable solutions in the classroom of the future, we should understand who is going to use this technology, Generation Alpha or Net generation. ^[11].

Generation Alpha is a term coined by social researcher Mark McCrindle to describe the people born in 2010 onwards. ^[12] They are the sons of intelligent devices; they live in a connected world where physical and digital environments merge into one. This generation will be the most technologically literate generation ever.

From a neuroscientific and psychologic point of view, every generation is in some ways different from the previous one in terms of learning because of cultural norms and traditions ^[13]. 16 Baby Boomers (born between 1940 and 1960) were sitting in quiet rows of desks, and learning was very formal and structured. However, Generation X (born between 1960 and 1980) did more group work with a more relaxed and interactive learning process. Millennials (born between 1980 and 2000) were taught using multisensory and multimodal methodologies, and Generation Z (born between 2000 and 2009) has moved into learner-centered approaches with kinesthetic opportunities and interactive furniture and spaces. The parents of the Alpha Generation are the late Generation X and Millennials; they are the 30-40-year-olds who have

11 Turk, Victoria, *Understanding Generation Alpha*, Wired Consulting, 2017 *Performance*, , Beijing, 2016

12 D. Oblinger and J. Oblinger, *Is It Age or IT: First steps toward understanding the Net Generation*, Educause and North Carolina State University, 2005

13 Barnes, K., Marateo, R. C., and Ferris, S. P. "Teaching and Learning with the Net Generation." *Journal of Online Education* 3, no. 4. (2007).

learned the futility of having expectations regarding career and the future world on their skin and are training their children with the logic of openness to multiple possibilities. Generation X and Millennials ^[14] are aware of the failure of their own development and for personal success.¹⁸ You will never hear a Millennial saying “If I graduate in time and with good grades, I will find a good job.” Today, younger parents are inclined to teach multiple roles to children to give them the most concrete view of life.

2.1.2 Learning Skills are Changing

What kind of learners will they be?

“All children are geniuses; by giving them an opportunity to learn using all their senses and through the VR experience, children are able to learn in a more natural and experiential manner that unleashes the potential within them.”

To understand what kind of learners they will become, it is important to know them understanding their approach to life, their attitude and their skills. The real question to understand what kind of student will use Virtual Reality it is: who is Alpha Generation? ^[15]

Digitally Literate

Having grown up with widespread access to technology, the Alpha Generation is able to intuitively use a variety of IT devices and navigate the Internet. Although they are comfortable using technology without an instruction manual, their understanding of the technology or source quality may be shallow. They have a horizontal approach to knowledge due to their hyper-connection attitude.

¹⁴ H. J. D. Culala, *Educating generation alpha: What are the demands of the 21st century workforce?*, Plenary speech delivered at Digital Education Kuala Lumpur Convention Centre (KLCC), Malaysia, 2016

¹⁵ Ted Dintersmith, <https://teddintersmith.com/about-ted/>, (accessed August 8, 2019)

Visually literate

They are intuitive visual communicators and are able to express themselves using images. They are able to link together images, text, and sound in a natural way. They will refuse to read large amounts of text, whether it involves a long reading assignment or lengthy instructions. Their ability to move between the real and the virtual is instantaneous expanding their literacy well beyond text. Because of the availability of visual media, their text literacy may be less well developed than previous cohorts.

Connected

Since when they were born the world has been a connected place and more than any preceding generation they have seized on the potential of networked media. Alpha generation is always connected.

Immediate and active

They are able to respond quickly and expect rapid responses in return. They are inductive discoverers, they learn better through discovery than by being told.^[16]

Focus on skills, not on content

The WHAT is out there already. The HOW and the WHY are now the critically important pieces for learning. Students need to learn how to think, not what to think, and that includes being metacognitive about their own actions and choices.

Social

Many of their exchanges on the Internet are emotionally open, sharing very personal information about themselves. Significant numbers of teens assume an online identity that is different from their own. Although technology can't change one's personality, introverts, for example, use the Internet as a tool to reach out. Extroverts can make their circle of friends even larger.

16 Dintersmith, T. "Prepare Our Kids for Life, Not Standardized Tests, TEDxFargo." <https://teddintersmith.com/about-ted/>. (accessed August 8, 2019).

Cultivate soft skills

Students in generation alpha are going to need classroom experiences with soft skills such as dealing with their own behaviour and the behaviour of others, physical interactions with others, self-regulation, and goal setting.

Attentional deployment ^[17]

They are able to shift their attention rapidly from one task to another and may choose not to pay attention to things that don't interest them

Engagement and Experience

The Net Gen's experiential nature means they like doing things, not just thinking or talking about things. In the last couple of years, there has been a renewed emphasis on critical thinking and creative problem solving, particularly through collaborative efforts. They will use digital interactions and virtual connections to make, prototype and play. By doing they will think, by acting they will elaborate on the processes to do something unique or to solve authentic problems.

<i>Birth period</i>	<i>Today age</i>	<i>Socio-cultural period</i>	<i>Keyword</i>	<i>Purpose</i>	
2001- today	less than 10 y.o.	IoT, AI	#no limits #feel	amplification	Generation Alpha
2002-2009	Between 10-19 y.o.	Economical crisis - mobile	#pragmetism #istant	experiment	Generation Z Centennials
'80-'90	Between 20-34 y.o.	Boom Social Media	#condivision #destruction	vision	Generation Y Millennials
'60-'80	Between 35-49 y.o.	Consumerism	#imagination #obtain	desire	Generation X
'40-'60	Between 50-74 y.o.	'68 revolution	#positivity #change	opportunity	Baby Boomers
Before 1945	More than 75 y.o.	World War	#value #community	solidity	Silent Generation

Figure 2.1: F. Capaci, "Post Millennial Marketing", Kantar Italia

17 BBC. <https://www.bbc.com/worklife/article/20190220-how-can-a-distracted-generation-learn-anything>. (accessed August 8, 2019).

2.2 Extended Reality Education

“The purpose of education is for me to become me in the context of the society in which I live, so I can truly contribute to my society. School should be about finding out what you’re good at preparing for lives of purpose, lives of contribution.”

Ted Dintersmith

2.2.1 Neuroscience

Unlike the old approaches that saw us as *tabula rasa* to be filled with knowledge, today’s children are seen as active subjects of their own training process, for which they contribute themselves in the first place, with their own characteristics, favourites on the other side by teachers, environments and parents.

One of the areas where Virtual Reality might be most effective is *experiential learning*, which is defined as any learning that supports students in applying their knowledge and conceptual understanding to real-world problems or authentic situations where the instructor directs and facilitates learning [18]. Any type of activity related to experiential learning, not only helps teachers to cover the topics needed, but also helps to increase students’ motivation to learn. According to the University of Texas at Austin, experiential learning brings many benefits to students, such as producing more autonomous learners, deepening learning, and helping students to apply the skills learned through authentic activities.

The potentiality of Extended Reality is not only about productivity and efficiency but is also about the way we learn and behave. Our thought is embodied, we think inside with our body and it mediates our thinking. Elderly physical activity is reduced, and even their memory, but if we give to an old man the power to move faster and fly in a virtual world, suddenly

18 Wurdinger, S. D. and Carlson, J. A. *Teaching for Experiential Learning: Five Approaches That Work*. Lanham, MD: Rowman and Littlefield Education, 2010.

their ability to remember their own life increases.

First of all, it is important to understand that our brain is like an illusion factory. It has evolved letting human being to adapt to the environment. Though the external stimuli are read by our senses, it is our brain the one that sees, feels, tastes, smells, hears. This is called practical illusion. ^[19]

Our brain creates its own reality based on experiences lived in the past and sensory information around us, which is easy to deceive by optical illusions. When we see something that is familiar to us, we immediately predict what will happen next. Our brain is constantly predicting the future, and the more it does it, the more sense of presence and realism makes us feel. Virtual Reality is able to generate a sense of presence, as mentioned in the first chapter, which makes our brain confused. We perceive physiological and emotional reactions really similar even if our brain does not react to Virtual Reality as he behaves in a real situation but virtuality is able to trick our brain and our perception.

However, Extended Reality affects the brain; it drives high levels of visual attention in the brain, almost double that of non-extended tasks, elicits a surprise response in the brain and gives us the opportunity to store into memory 70% higher for non-extended experiences. These data arrive from *Layered* ^[20], neuroscientific research that investigated the future of AR and its implications for brands.

“At Neuro-Insight we’ve researched brain response to many different media, and this study has shown that AR delivers exceptionally high attention levels - 45% higher than the average we see for TV viewing or general online browsing.”

Heather Andrew

Nowadays Virtual Reality hardware are not the greatest of their technical development, the search is fast and as we can see the market is populating more and more quickly with

19 Gómez Mascaraque, Raquel. “That’s how Virtual Reality plays with your brain.” Ideagoras. <https://www.ideagoras.biz/thats-virtual-reality-plays-brain/>. (Accessed August 20)

20 Ung, Josie. *“Layered, the future of Augmented Reality.”* Mindshare UK in partnership with Zappar, April 2018

new devices that are more and more powerful and reactive. Companies are developing an ecosystem of control inputs that will combine to make augmented reality and virtual reality environments incredibly responsive and adaptive to user behavior. Great strides have already been made with motion capture, haptics, eye-tracking, and natural language processing. A startup company called Neurable developed brain-computer interfaces (BCI) for HTC that allow the user to control scene interaction through human brain activity.²⁸ The benefits of BCIs in extended reality are many and unique. BCIs analyze patterns of brain activity to determine user intent. This tech is already capable of scrolling menus, selecting items, launching applications, manipulating objects, and even inputting text using only brain activity.²⁹ In the long run, we expect that augmented reality and virtual reality headset companies will integrate brain sensors directly into their products. They will do it because extended reality really affects our brain and we react in an unpredictable way, and we still don't know where this technology will be able to reach.



Figure 2.2: Neurable Vive, Vr 3000

2.2.2 Learning with Extended Reality

“I hear and I forget, I see and I remember, I do and I understand.”

Confucius

VR is the key to committing information to long-term memory is the creation of emotional experiences that trigger the brain to mark this information as significant.

Augmented reality and mixed reality are some of the most powerful tools in this respect. In a recent neuroscience experiment commissioned by the media agency, Mindshare^[21], it was found that augmented reality experiences elicit significant attention, emotional and memory encoding spikes in users’ brains compared to traditional video and interactive online experiences.

Dale’s Cone^{[22] [23]} of Experience is a model that incorporates several theories related to instructional design and learning processes. During the 1960s, Edgar Dale theorized that learners retain more information by what they *do* as opposed to what is *heard*, *read* or *observed*. his research led to the development of the Cone of Experience. Today, this *learning by doing* has become known as *experiential learning* or *action learning*.

Dale’s Cone of Experience is a visual model that is represented by a pyramid with different stages, starting from concrete experiences at the bottom of the cone then it becomes more and more abstract as it reaches the peak of the cone. Also, according to Dale, the arrangement in the cone is not based on its difficulty but rather based on abstraction and on the number of senses involved during a learning activity. The experiences in each stage can be mixed and are interrelated that fosters more meaningful learning. According to Edgar Dale, after 3 weeks we are going to remember 10% of what

21 From *virtual reality to neuroscience*, Mindshare’s Huddle, 28 November 2014

22 M. Molenda, *Cone of Experience*, Indiana University, 2003

23 J. A. Jackson, *Myths of Active Learning: Edgar Dale and the Cone of Experience*, University of North Dakota, 2016

we read, 30% of what we see, 50% of what we see and hear, 70 % of what we say and 90% of what we do.

Extended reality is so powerful in education because every experience is concrete and gives students the opportunity to try, act and do. Extended reality learning is based on the base of the pyramid.

Every representation requires mediums; there are a lot of mediums like sound. If we want to explain our sensation, we can explain it, but what if instead of explaining we can just give the other person the opportunity to be us, to feel and experience exactly what we are perceiving? ^[24] ^[25]



Figure 2.3: *We Are Alfred*, 2016

“The real power of VR is the ability to revolution is not only what we understand, but even who we think we are, to be totally new kind of people, to think new thoughts.”

“If you want to teach people a new way of thinking, don’t bother trying to teach them. Instead, give them a tool, the use of which will lead to new ways of thinking.”

Rachel Sibley

24 VRFocus, *Experience Seven Minutes of Empathy With Medical Project We Are Alfred*, 2016

25 R. Sibley, *9 Ways to Innovate with VR & AR*, <https://www.youtube.com/watch?v=W4-aWYiXzCA>, TEDxBerlinSalon

According to the study, the results of which were published in the Journal of Medical Education, the potentialities of teaching through VR are a lot. ^[26]

Visualization

This benefit is more appropriate for children of the alpha generation that acquire information visually. Using VR helmets, it can simplify the learning process and help people remember everything faster.

They enjoy followed by the need for learning

In the stereotype of students, school is not fun. VR video simulations allow students to explore different realities and have an alternative learning experience that is impossible in the traditional classroom. Wearing a VR headset, students can experience high-quality educational visualizations that have a positive impact on the whole learning process. VR can help students easily understand complex concepts, theories, and subjects. They are able to digest and retain complex information at a much higher rate. Using VR and AR, pupils want to learn, they need it, they strive for getting more knowledge. Such learning activities don't feel like work and students enjoy the learning process that increases their motivation.

Eliminates language barriers

Language differences can be challenging in today's multicultural societies. If students want to study in a foreign country, they need to achieve fluency in a foreign language to be able to understand the material if they are taught in another language. With Virtual Reality, language translation can be built into the software and there will be no language barrier that can prevent students from achieving their educational goals. Virtual Reality visualizations can be experienced in any language.

Safety

Students can do everything they want in a virtual environment, including different physical exercises, fly over new cities, assemble planes, and everything is completely safe since a virtual environment can't harm an individual.

Better focus

Students can focus on new material and not look aside. Moreover, desk neighbours won't disturb each other since they will be involved in the process of learning. Their attention will be focused on the learning process only.

Efficient teamwork

If the task requires teamwork, students can unite together in a virtual environment and perform the necessary tasks. It will help them build friendly relationships and show how important harmonious teamwork can be.

Eliminates time and travel issues

Learning and growing with virtual reality is an exciting option while training at a different place. Virtual Reality field trip opportunity eliminated time and travel issues keeping the main focus for manufacturers. Using headsets, the trainee can explore limitless opportunities in every sphere.

2.3 State of the Art

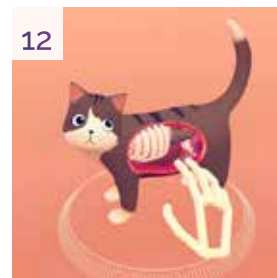
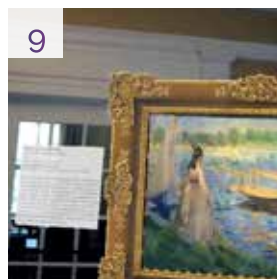
“Learning with Extended Reality”

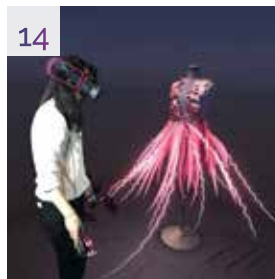
“You need Virtual Reality to understand high level science or high level math. It’s very helpful to explain third and fourth dimensional things that people are constantly addressing in quantum physics. [...] you can start to feel sensations on VR, that has gone too far.”

Jaden Smith

In the following paragraph, we are going to analyze and compare twenty extended experiences for education. They each have different structures, topics, technologies and interactions. After a brief description, we are going to compare them through the benchmark. The purpose of this comparison is the analysis and the synthesis of the different components of extended teaching experiences. It helps to understand when augmented, mixed and virtual reality were used, what kind of experiences have been created, what are the learning objectives, what is the student’s and the teacher’s role, what are the elements used to create the experience and with what purpose, and how much importance has been given to hearing, sight and user action.

2.3.1 Experience Description





- 1** *Discovering Space*
- 2** *HoloStudy Demo*
- 3** *Nefertari: Journey to Eternity*
- 4** *Architecture VR*
- 5** *Mr builder*
- 6** *Labster*
- 7** *My Lab*
- 8** *Meeting Rembrandt*
- 9** *Boulevard Arts*
- 10** *Human Anatomy VR*
- 11** *Dynamic Anatomy*
- 12** *Cat Explorer*
- 13** *Newtons Apple*
- 14** *Tilt brush*
- 15** *Oliveti Virtual training*
- 16** *AR assistance*
- 17** *Noda*
- 18** *Mind Map AR*
- 19** *Rumii*
- 20** *Virtual Speech*



Figure 2.4: *Discovering Space*, Oculus Store

1 *Discovering Space*

Platform: *Gear VR, Oculus Go*

Learn about the solar system through an intensely engaging experience. Orbit around the earth and visit the far side of the moon. Fly in close to moon's surface and understand the formation of lunar features. See Earth from a completely new perspective. Visit Mars and its companion moons. Fly in low and close over some of Mars' ancient geological features. Go deeper into the Solar system. Gaze upon Jupiter's swirling clouds and swing around to some of its fascinating moons.



Figure 2.5: *HoloStudy Demo*, Microsoft Store

2 *HoloStudy Demo*

Platform: *Hololens*

HoloStudy is a series of geology, physics, chemistry and biology lessons. The lessons are designed specifically to give you all the possibilities of HoloLens during the educational process. Set off on an incredible journey with virtual professors, dive into the complexity of science.



Figure 2.6: *Nefertari: Journey to Eternit*, Oculus Store

3 *Nefertari: Journey to Eternit*

Platform: *HTC Vive, Oculus Rift*

In Egypt's legendary Valley of the Queens lies Queen Nefertari's tomb, one of the windows into ancient Egyptians' journey towards the afterlife. Nefertari's tomb has been scanned with millimetre accuracy to give us the opportunity to be immersed in the story of its art, history, construction, and mythology through interactive elements. The app allows you to walk through Queen Nefertari's tomb, guided by some first-rate narration and interaction points teach students about the history, culture and construction of the tomb.



Figure 2.7: *Architecture VR*, Arch Daily

4 *Architecture VR*

Platform: *Oculus Rift, HTC Vive*

Architecture VR gives architects and customers the experience of a building before it is built. With virtual reality, you create an immersive experience that touches clients emotionally and presents architectural ideas in the best way possible. Inspire your customers with the ease of navigation and high frame rates, change the lighting, colors and texture. Move through the plan of the house.



Figure 2.8: *Mr Builder*, Microsoft Store

5 *Mr builder*

Platform: *HoloLens*

The MR Builder application was developed by HoloGroup, especially for architectural and construction companies. The architect and customer wear HoloLens and see simultaneously one and the same holographic model of an apartment complex, industrial facility or architectural landscape. They can scale, rotate or move the model. Also, highlight and hide certain details and layers. You can even get inside the building on a 1x1 scale. Bring all your ideas and vision to the client.



Figure 2.9: *Labster*, Labster

6 *Labster*

Platform: *HTC Vive, Oculus Rift*

A virtual chemistry laboratory simulator, where the students can perform virtual experiments before they go into the real laboratory. Everything it's possible, even dangerous experiments because the student is in a secure environment. The app contains a theoretical lesson, lab simulations, mysterious science CSI murders case and quiz that give a full dashboard to understand where the students are at.

Figure 2.10: *My Lab-Holo*, Microsoft Store

7 *My Lab-Holo*

Platform: *Hololens*

This is an interactive periodic table for chemistry students. It explains the heart of chemistry, the tiny interactions and invisible characteristics of elements that make them behave vastly differently. Augmented reality app MyLab aims to make a connection between textbook concepts and observational experiments by offering an interactive periodic table which also visualizes the hidden structures of the elements.

Figure 2.11: *Meeting Rembrandt*, Oculus Store

8 *Meeting Rembrandt: Master of Reality*

Platform: *Gear VR, Oculus Go*

This app gives you the chance to meet Rembrandt. Travel back in time and feel what life might have been like in the Dutch Golden Age. Go inside the house of Rembrandt to get a glimpse into the life of one of the most famous painters of all time. The rich environment you enter into is visually stunning because of the unique techniques used to heighten the quality to the highest level possible on the Samsung Gear VR.



Figure 2.12: *Boulevard Arts*, Microsoft Store

9 *Boulevard Arts*

Platform: *HoloLens*

Boulevard Arts is an immersive art and culture platform, in collaboration with the Case Western Reserve University, on developing an application for HoloLens, that enables virtual visits to London's Courtauld Gallery and the British Museum. People can see 18 works from all over the world using the app with a HoloLens device. They can see holograms of paintings and historic objects, with each piece of artwork accompanied by an extended label and audio narration.



Figure 2.13: *Human Anatomy VR*, Oculus Store

10 *Human Anatomy VR*

Platform: *Gear VR*, *Oculus Go*

With hundreds of 3D models featuring models of the Integumentary system, the skeletal, lymphatic, respiratory, cardiovascular systems... You will be able to spin, zoom and slice any of these components up into sections. Most medical students will be able to afford an Oculus Go and this app giving them a much better resource tool to look at and study.



Figure 2.14: *Dynamic Anatomy*, Microsoft Store

11 *Dynamic Anatomy*

Platform: *Hololens*

Dynamic Anatomy is a project by Leiden University and the Leiden University Medical Center that explores the possibilities of using the Microsoft HoloLens within higher education. This website aims to share the details of the experiment, display results and connect with others in the domain of mixed reality for education. It enables the medical holograms in the app to move with the human body in real time, three-dimensional models for students to learn from, using their own bodies as learning tools.



Figure 2.15: *Cat Explorer*, Youtube

12 *Cat Explorer*

Platform: *HTC Vive*

HTC Vive and Leap Motion combined VR and hand-tracking technology, allowing users to explore the insides of a cat with their hands. The interactive program allows the user to explore the inner workings of a friendly cartoon feline, exploring the cat's skin, muscles, organs, vascular system, and skeleton.

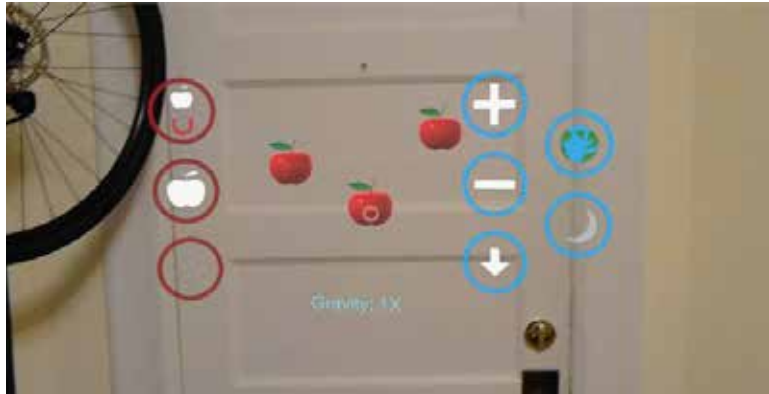


Figure 2.16: *Newtons Apple*, Youtube

13 *Newtons Apple*

Platform: *Mobile*

Newtons Apple is an educational program to demonstrate the effects of different gravity via the Microsoft HoloLens. Explore Earth, Moon, Reversed or customized gravity using apple holograms. It allows pushing the apples around in different gravity settings.



Figure 2.17: *Tilt Brush*, Oculus Store

14 *Tilt Brush*

Platform: *Oculus Rift, HTC Vive*

Tilt Brush lets you paint in 3D space with virtual reality. The room is the canvas and user's imagination is the palette. From a virtual palette user can select from a variety of brush types and colours. Movement of the handheld controller in 3D space creates brush strokes that follow in the virtual environment. Users can export their creations of room-scale VR pieces in 2D and 3D format.



Figure 2.18: *Olivetti Virtual Training*, AnotheReality

15 *Olivetti Virtual training*

Platform: *HTC Vive*

Olivetti need to train unskilled technicians on field, responsible to install and maintain their multipurpose printers. Due to time and budget constraints, they decided to create a VR Academy to increase retention rate and training reach. Thanks to Virtuademy, products and procedures were recreated in VR with extremely high fidelity. The experience guides the users through the simulation of every step, with practical learning by doing approach.



Figure 2.19: *AR Assistance*, Microsoft Store

16 *AR Assistance*

Platform: *HoloLens*

AR Assist helps workers perform their jobs better by providing the knowledge needed to perform complex tasks without years of experience or training. Utilizing a combination of task management, knowledge markers that display relevant data, and wayfinding to the next task site, providing an unparalleled level of traceability and oversight. Assist is hands-free and provides the opportunity to communicate with expert assistance.



Figure 2.20: *Noda*, Youtube

17 *Noda*

Platform: *Oculus Rift, HTC Vive*

Traditional mind maps are two dimensional, but Noda intuitively adds a third dimension thanks to the power of natural input via the Rift and Vive. It also allows the user to tag, color, and resize nodes and more. Users can easily draw lines to connect nodes, import lists of names from TXT and CSV files, images as JPG, PNG, or BMP, and save and load their mind maps.



Figure 2.21: *MindMap*, Microsoft Store

18 *MindMap AR*

Platform: *Hololens*

Holo Mind Vector adds another dimension to our popular Mind Vector app by augmenting 3D mind maps with the real world. Hololens allows for a richer, more immersive feeling than present forms of viewing mind maps while allowing the user to be aware of their environment.



Figure 2.22: *Rumii*, Oculus Store

19 *Rumii*

Platform: *Oculus Rift, HTC Vive*

Instead of meeting up with friends to share videos, hang out and play games, the app is designed as a professional tool for work meetings and education spaces. Aiming to replace video conferencing, users adopt virtual avatars and then communicate over voice chat while sharing materials over a range of features like desktop sharing, 3D model loading and web browsing.



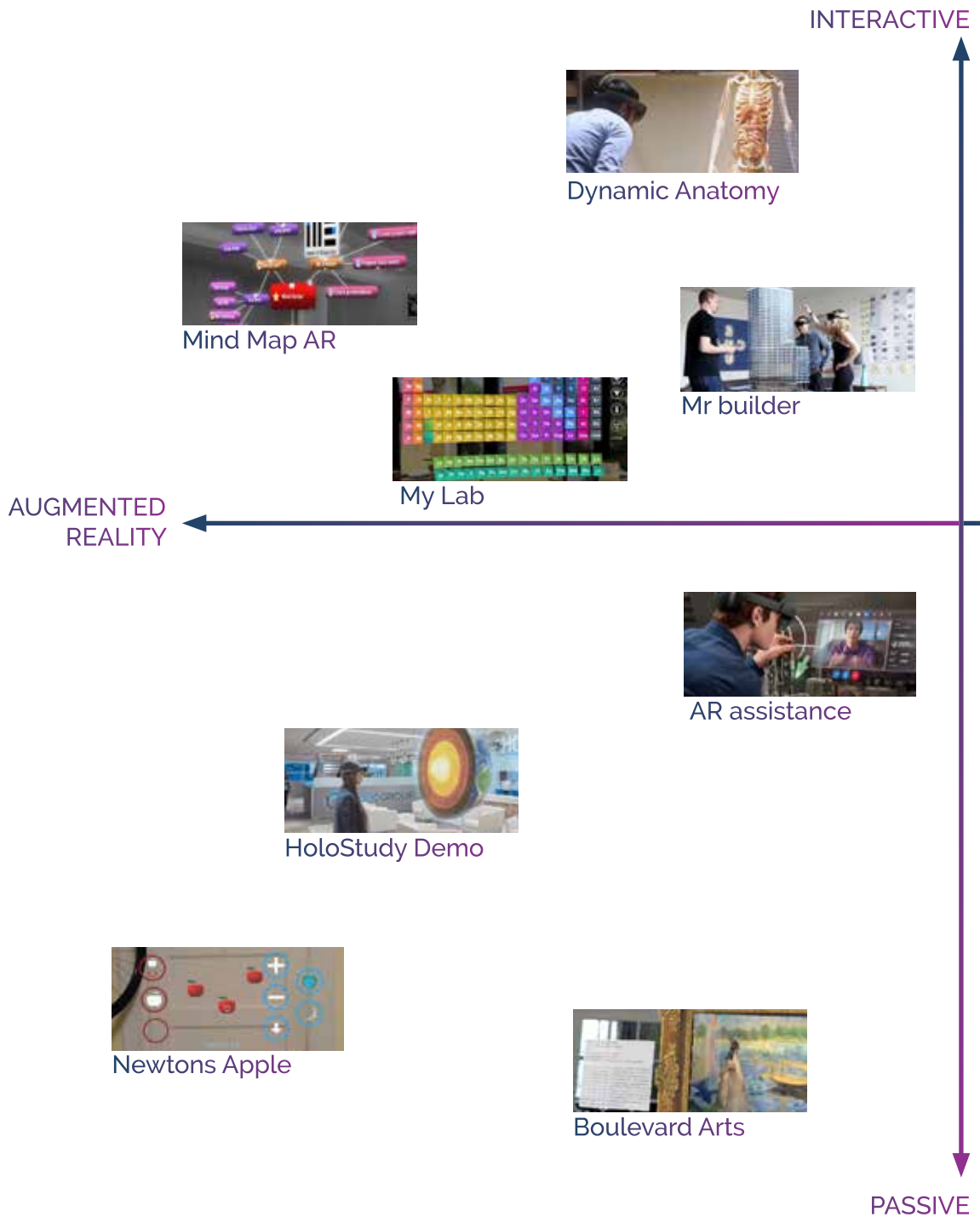
Figure 2.23: *Virtual Speech*, Oculus Store

20 *Virtual Speech*

Platform: *Gear VR, Oculus Go*

VirtualSpeech is a speech learning app that offers various types of speaking and realistic virtual simulations in which to practice speaking skills. It offers a wide variety of courses and simulations to choose from, such as public speaking, job interviews, business networking and boardroom presentations. The product can track eye contact, voice attributes, speed of delivery and use of filler words. You can also record your training sessions for further review.

2.3.2 Benchmarking



INTERACTIVE



Noda



Human Anatomy VR



Tilt brush



Rumii



Oliveti Virtual training



Labster

VIRTUAL REALITY



Cat Explorer



Architecture VR



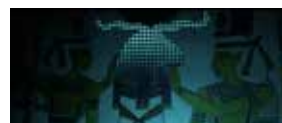
Virtual Speech



Meeting Rembrandt



Discovering Space



Journey to Eternity

PASSIVE

Chapter 3

HUMAN VIRTUAL INTERACTION

3.1 Instructional Design for Virtual Reality

“In the early 1930s, Dr Montessori understood that learning relied on how our physical bodies interacted with the environment. For her, the environment was physical. Today, we are able to digitize our environments and the affordances approach infinity.”^[17]

Instructional design is the creation of experiences and materials to improve the acquisition of knowledge and skills. The instructional designer follows a designing process to develop learning materials and evaluate its effectiveness. This discipline provides a practical and systematic process of teaching that stimulates the student in an active way.

Virtual reality offers promising instructional benefits, even if there are still many issues that need further investigation. Gustafson classified low-cost 3D visualization and walk-around experiences as a revolution of learning, and Rieber demonstrated that this technology has the potential to facilitate the acquisition of complex thinking and problem-solving skills.^[28] The Virtual reality learning experience should be designed to create engaging interactions that help the learner assimilate new information, ideas and concepts, resulting in the acquisition of new, transferable skills.

We already talked about the principles that are required for virtual reality learning experiences and that are fundamental to create effective learning with these technologies. The following diagram made by Karl Kapp, assistant director and faculty member at Bloomsburg University’s Institute for Interactive Technologies (IIT), summarized the

²⁷ Johnson-Glenberg, M. C. *“Immersive VR and Education: Embodied Design Principles that Include Gesture and Hand Controls.”* Frontiers in Robotics and AI 5 no. 81 (2018)

²⁸ C.Christou, *Virtual Reality in Education*, University of Nicosia, Cyprus, June 2010.

fundamental characteristic of a virtual experience such as participant-centered, contextually situation, action-oriented, consequentially experienced and collaboratively environment. This diagram will help us understand the process that we need to follow to design a virtual learning experience. [29]



Figure 3.1: Principles for Creating a Successful Virtual Reality Learning Experience, Reworking of an image by K. Kapp, published the 7 of January 2017.

David Jonassen was an educational reformer whose ideas have been influential in instructional design, educational technology and learning with media. In 1999, he wrote about the essential components for designing virtual learning experience. The model conceives of a problem, a question, or a project as the focus of the environment and the user, with various interpretative and intellectual support systems investigating it. The goal of the learner is to interpret and solve the problem or complete the project interacting with the scene.

This typology of learning is anchored in authentic contexts; learners must manage complexity and think like practitioners. Problem-based learning presents a lot of elements that users need to understand and manage with active, constructive, and authentic learning.

29 Jonassen, D. *Designing constructivist learning environments.* In *Instructional-design theories and models: A new paradigm of instructional theory*, edited by C. Reigeluth, 215-239. University Park: Pennsylvania State University, 1999

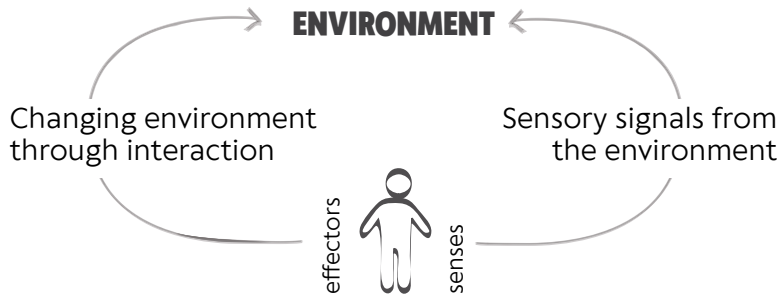


Figure 3.2: *The perception-action loop*, Reworking of an image by C. Christou, published in June 2010.

Jonassen developed a design model referring to the elements that the environment should contain and the skills that the user should use to interpret the problem and solve it, learning in an active way. The experience must provide interest by engaging the student. The problem should be defined and structured so that the learner can define immediately the emergent aspects of the problem. In this way, the learner will be motivated to solve it and to understand the metaphor behind it. This type of learning approach requires a customized structure with different elements, such as unstated goals and constraints, possess multiple solutions paths, possess multiple criteria for evaluating solutions, have an unpredictable outcome and require learners' judgments about the problem and to defend their judgments by expressing personal opinions or beliefs.

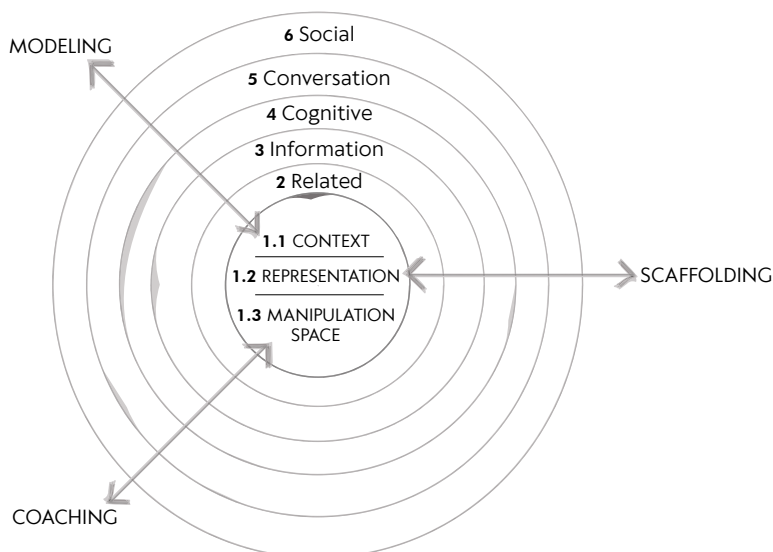


Figure 3.3: *Model of social constructivist learning design*, Reworking of an image by Jonassen, 1999.

In 2004, Chen, Toh and Wan adapted designing constructivist learning environments Jonassen's scheme in the Instructional design theoretical framework of Virtual Reality based learning environment. [30]

They divided the design process in macro-strategy, which according to Reigeluth and Merrill, concerns the selection, sequence, and organization of the subject to be presented and micro-strategy that basically, involves how to effectively present the content. [31] [32]

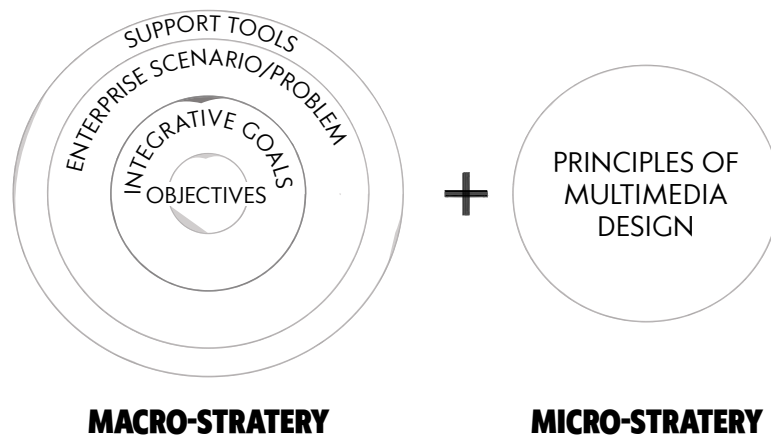


Figure 3.4: *Instructional design theoretical framework of VR based learning environment*, Reworking of an image by Chen, Toh & Wan, 2004.

30 Chen, C. J. and Teh, C. S. "Enhancing an instructional design model for virtual reality-based learning." *Australian Journal of Educational Technology* 29 no. 5 (2013). <https://doi.org/10.14742/ajet.247>.

31 Reigeluth, C. M. and Bunderson C. "What is the design science of instruction?". *Instructional Development Journal* 1 no. 2. (1978) 11-16. <https://doi.org/10.1007/BF02968229>.

32 Chuah, K. M. and Chen, C. J. "Unleashing the Potentials of Desktop Virtual Reality as an Educational Tool: A Look into the Design and Development Process of ViSTREET." Faculty of Cognitive Sciences and Human Development University Malaysia (2008).

Principle of Macro-Strategy

Objectives

Identifying the types of learning - labels, verbal information, intellectual skills and/or cognitive strategies - and the respective learning objectives (Gagné & Merrill, 1990)-

Integrative goals

Determining the integrative goals by combining several interrelated objectives that need to be integrated into a comprehensive purposeful activity (Gagné & Merrill, 1990).

Enterprise scenario or problem

Identifying the enterprise scenario that must be played out in conducting the enterprise, (Gagné & Merrill, 1990). This problem comprises three integrated components: problem context, problem representation, and problem manipulation space (Jonassen, 1999).

Support tools

Providing various interpretative and intellectual systems to support constructivist learning through the problem posed. These may include related cases, information resources, and various cognitive tools (Jonassen,1999).

Instructional activities

Providing instructional activities to support constructivist learning, which includes modelling, coaching, and scaffolding (Jonassen, 1999)

Principles of Micro-Strategy

Spatial contiguity

Learners learn better when corresponding words and pictures are presented near rather than far from each other on the screen (Mayer, 2002)

Coherence

Learners learn better when extraneous words, pictures, and sounds are excluded rather than included (Mayer, 2002).

Modality

Learners learn better from action, animation and narration than from images and on-screen text (Mayer, 2002).

Guided exploration

Learners learn better when visual navigation aid is provided as it enables them to stay oriented while navigating in a virtual environment (Chen & Wan, 2008).

3.2 Hardware Constraints for Designing

Enjoying a virtual experience with one device rather than another can completely change design, interaction and perception. We could describe the differences in HMDs currently on the market, but it would not be the real purpose of this paragraph and would not be useful because, in 6 months a new device with new properties and new constraints will appear. The intent is to become aware of how much an HMD can make a difference in the design of an experience. The best device does not exist. Each piece of hardware has pros and cons. It is important to evaluate the device in accordance with needs, budget and characteristics of the experience being designed. We will describe the main differences from the manual and the differences that anyone trying devices could personally verify.

Tracking

Degrees of freedom (DoF) refers to the number of basic ways a rigid object can move through 3D space. There are six total degrees of freedom. Three correspond to rotational movement around the x, y, and z axes, commonly termed pitch, yaw, and roll. The other three correspond to translational movement along those axes, which can be thought of as moving forward or backward, moving left or right, and moving up or down. ^[33]

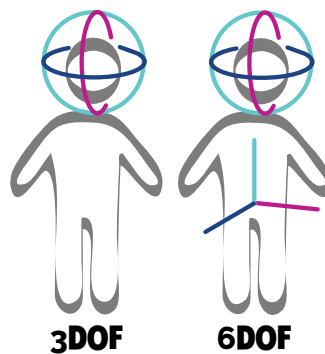


Figure 3.5: 3 and 6 Degree of freedom

33 Google developer, December the 1, 2018, <https://developers.google.com/vr/discover/degrees-of-freedom>, (accessed August 16, 2019)

VR headsets and input devices are generally 3 DoF or 6 DoF. 3 DoF means we can track rotational but not translational motion. For the headset, that means we can track whether the user has turned their head left or right, tilted it up or down, or pivoted left and right. Oculus Go is a 3 DoF headset. 6 DoF means we can additionally track translational motion. That means we can track whether the user has moved forward, backward, laterally, or vertically. Oculus Rift is a 6 DoF headset. 6 DoF gives higher immersion, but it is expensive. 6 DoF hardware and software is far more complex than 3 DoF. Complex experiences need an infrared or optical tracking system to track specific points on the headset and controller in 3D space. 6 DoF increases the price of hardware, software, time of development and needs a powerful computer to run the experience. 3 DoF is a standalone device, which means that it is wireless and doesn't need a computer to be powered. In June, Oculus presented Oculus Quest, the first standalone 6 DoF headset. While it does not have the power of Rift, it is the first in a long series. Mixed reality headsets should also be able to do room-scale tracking even though the tracking is a bit less stable.



Figure 3.6: Immersive design, Wired

Visualization

The *Frame Rate*, in the context of Virtual Reality, it's the frequency of reproduction of the frames that compose the final image for each viewer's eye. If the display frame rate does not the flickering user, who can produce for a long time, is a quite high sickness.

Latency is the delay between action and reaction. The latency of the system will ensure that the user will not see the visual stimuli he expects the moment he waits for them, but slightly later. The sensitivity to latency is an individual parameter and varies from individual to individual, but values greater than

15ms can cause VR sickness.

Frame Rate higher than 70 Hz, corresponding to a refreshing time of the image of 14.3 ms, represents already a necessary condition to have a low latency system. In fact, part of the latency is linked to the acquisition time of motion sensors. As the user moves the head, the device should display the resulting changes immediately. Any significant delay will cause to the brain the reject of the virtual world and cause loss of presence. High latency can also cause simulator sickness. In AR, high latency can cause virtual content to be misaligned with real-life features. For the user's comfort, latency must be lower than 20ms.

Minimizing latency is one of Virtual and Augmented Reality's biggest challenges. Human brains can detect very small latency in the visual and audio systems. These systems have to bring latency low enough to be undetectable by the brain.



Figure 3.7: *Frame rate, frame extrapolated from 24 FPS vs. 60 FPS Gaming.*

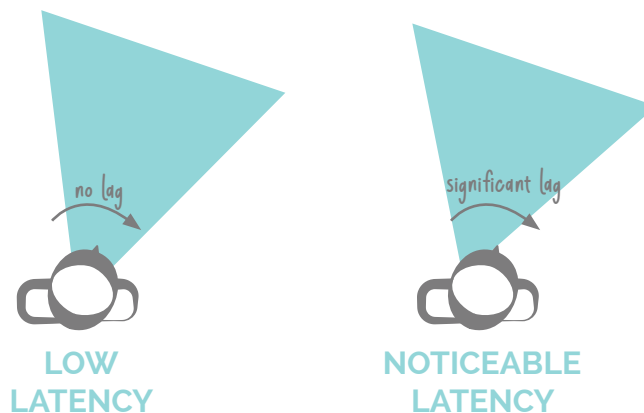


Figure 3.8: *Lag and latency.*

Screen Resolution and image quality will make experience more comfortable and will also foster the immersion. However, is not necessarily needed the highest resolution to achieve the aim of the experience but it is important to be conscious of the resolution of the device you are designing for in order to change the level of detail achievable.



Figure 3.9: *Space debris VR icon's evolution.*

Field of view (FOV) is the open observable area a person can see through their eyes or via an optical device. FOV is an important factor for immersion. However, it is not needed to cover the full field of view of the human eye (180 degrees) in a virtual experience. In general, 110 degrees are enough. Furthermore, a wider FOV also means more pixels, so more computer power required.

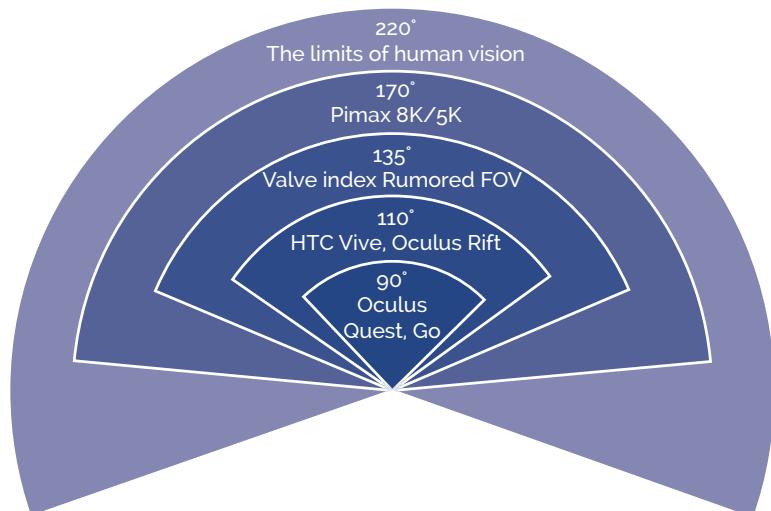


Figure 3.10: *Comparison of Headset's field of view.*

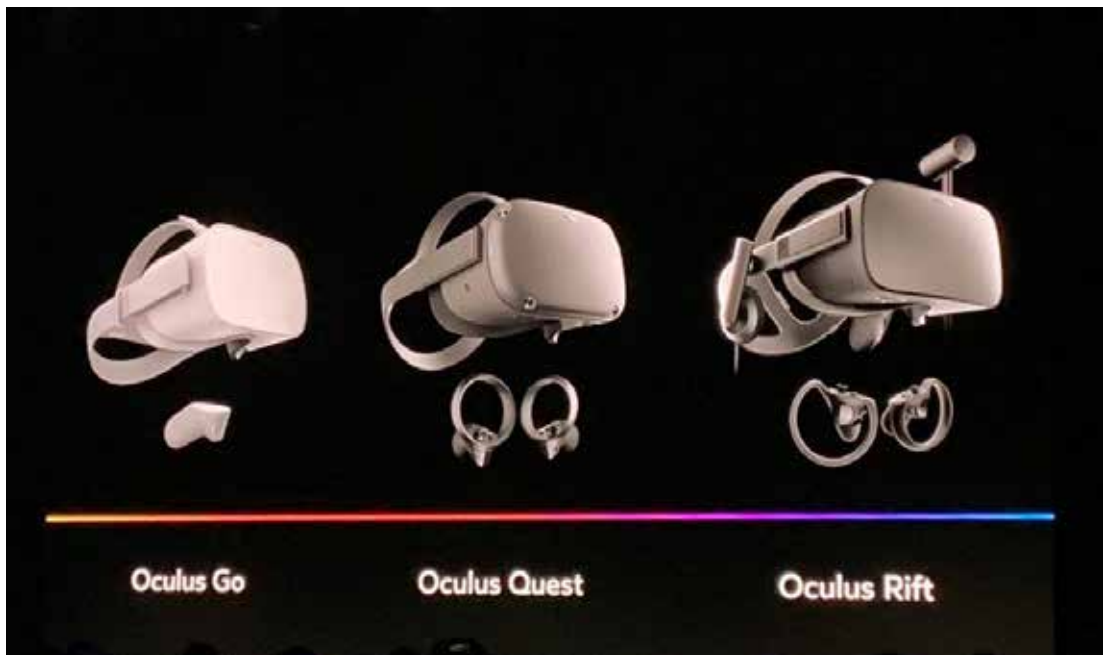


Figure 3.11: *Comparison of Oculus Go, Oculus Quest, Oculus Rift.*



Figure 3.12a: *Walk the Plank VR*.

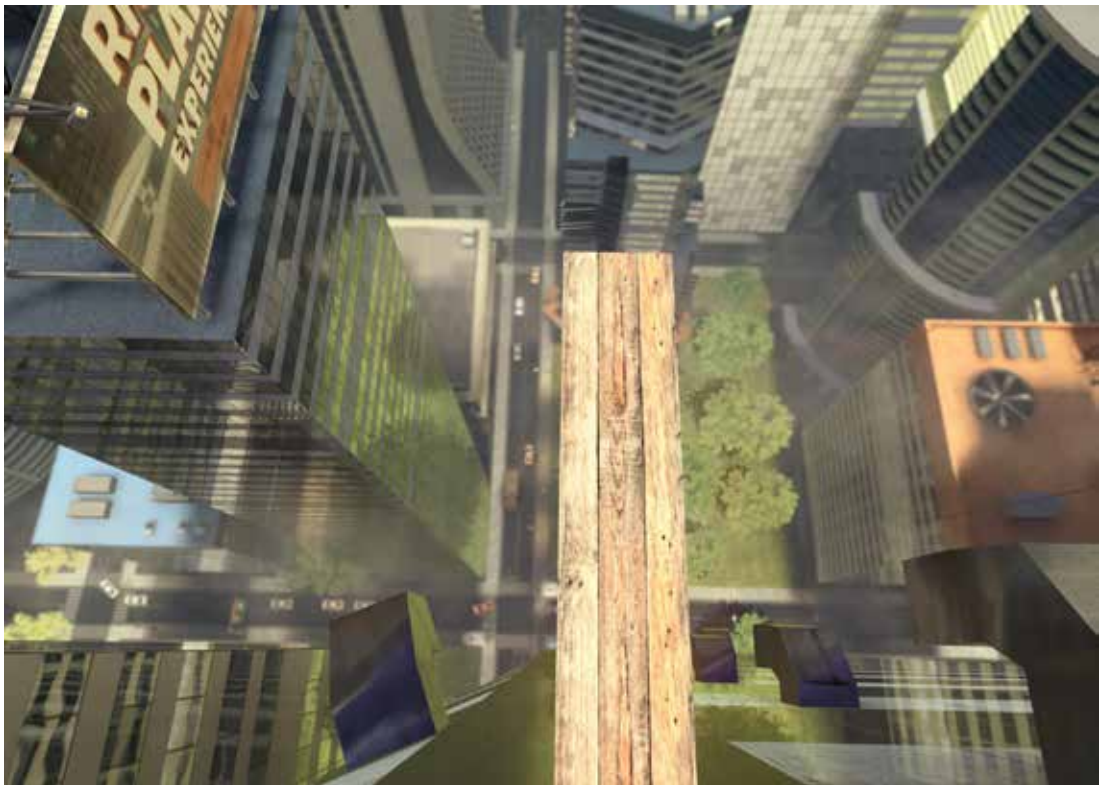


Figure 3.12b: *Walk the Plank VR*, first person point of view.

3.3 The Fundamentals of User Experience in Virtual Reality

“Interaction design is based on making the machine-man interaction as natural and intuitive as possible, but what happens if this interaction is completely or partially virtual?”

In this paragraph, we are going to explain the fundamentals of user experience in virtual reality. There are a lot of guidelines to follow to design virtual scenes. These rules come from different fields, and right now there is no complete guide to approaching virtual design. In the following pages, there is a synthesis of the fundamental recommendation from the Oculus developer website ^[34], Google developer ^[35], Wired theory ^[36], the study of Mike Alger ^[37], academics documents ^[38] ^[39] and personal errors and experience.

First of all, it is important to specify that every person is different and reacts to the virtual experience in different ways. This is an important point to be clarified, especially as regards physiological reactions. As has been explained in the first chapter, when we wear glasses, our brain believes what our eyes see and, therefore, it responds as if the situation were real. If, for example, we look at a landscape from the thirtieth floor of a building in virtual reality, we will feel a sense of emptiness and, people suffering from vertigo will get dizzy, as if they were really on a cliff.

34 Oculus developer, <https://developer.oculus.com/design/> (accessed August 18, 2019).

35 Gogle developers, <https://developers.google.com/vr/elements/overview>, (accessed August 18, 2019)

36 Wired, <https://www.wired.com/2015/04/how-to-design-for-virtual-reality/>, (accessed August 20, 2019)

37 M. Alger, *Visual Design Methods for Virtual Reality*, MA Moving Image, September 2015

38 S. M. LaValle, *Virtual Reality*, University of Oulu, 2019..

39 M. Marseguerra, M. Morisio, *User experience di un'applicazione di Realtà Virtuale*, Master degree in Computer Engineering, Politecnico di Torino, October 2017

But this reaction is subjective. Those who suffer from vertigo will be dizzy, while those who do not suffer from it will have no problem launching themselves from the tallest skyscraper in the world. In this sense, every reaction is personal and we need to consider that all the rules that will be presented in the following paragraphs are design principles studied and tested on population percentiles.

Considering what has just been expressed, we can say that the first rule for designers and developers is *testing*. Developers who test their own experiences can predict the discomforts of their users. Testing apps with a variety of people with different susceptibility levels to VR is strongly recommended to assess how comfortable the experience will be for a wide audience of users.

In 2015, Mike Alger, who graduated in 2016 in London with a master's degree focused on the design of interfaces for virtual reality interaction, published his manifesto for the research and design of user interfaces for ergonomic multitasking in virtual reality, mainly focused on interaction design for operating systems and browsers. Its purpose is to explain the intentions, the hypotheses and the motivations of his university projects of study of the passage from the rectangular interface of the computer monitor to the virtual reality devices. Alger ^[40] ^[41] ^[42] ^[43] underlines how virtual designers must develop web design patterns and become environment designers and base interactions on different gestures, for example by using more parts and capabilities of the human body, such as gaze tracking and air gestures. The process of designing a completely new interaction paradigm requires a large amount of consideration, which Mike Alger presents, for the first time, in his “Interaction Design for Virtual Reality” Manifesto.

40 M. Alger, *MCE 2018: How we design for VR*, <https://www.youtube.com/watch?v=49sm52fG0dw>.

41 M. Alger, *VR iInterface Design Manifesto*, <https://vimeo.com/116101132>

42 M. Alger, *VR Interface Design Pre-Visualisation Methods*, <https://vimeo.com/141330081>

43 M. Alger, *Designing VR for Humans*, <https://www.youtube.com/watch?v=fEMDo-SBO1g&feature=youtu.be>

He focuses his attention on virtual reality user interface for ergonomic application of multitasking productivity. It is an open field and a lot of hardware is emerging in this consumer market, but there is a lot of work and research to do in the next 15 years to arrive at a solid and conscious design methodology. Now, we sit in front of a screen, but in the future, we will wear a head-mounted-display (HMD) to do all the activity that we now do with computers, our phones and all the devices that we use every day.

The point is that an interaction designer is trying to create simple and cheap hardware and software that will not require any kind of training. Right now, using an HMD for a new user is not so intuitive, but we know that a good product is easy and natural to use because it is part of our human nature to do something in a certain way.

When we design for the screen, there is a boundary. There is a precise way to receive information and to give input to the system. The problem with extended technologies is that there is not this boundary, that we are immersed in a world and we can attract user attention with color, light, movement, shadow, noise, music, emotion, environment, UI, avatar, and all the senses are involved in the experience. In front of the user, there is no screen. There is a world. This seems simple because we live in a complex 3D world, but the challenge for virtual reality is to insert the screen's activity into an environment. So how can we interact naturally with 3D virtual elements that were born on a 2D screen? How can we replace the monitor with an HMD?

User experience for virtual reality tries to bring new studies into the virtual to design effective interfaces, but there are still no clear and precise ideas. We are still in a testing phase. We have content like pictures, videos, text, 3D models. Then we have applications to create and consume content. We need to organize content in groups and folders and we unconsciously create metadata that we can understand and navigate through icons and micro-interactions. In virtual reality, we want to do stuff, create stuff, organize stuff, interact with it. But how will it look? How will it be understandable? What is graphical user interface in virtual reality?

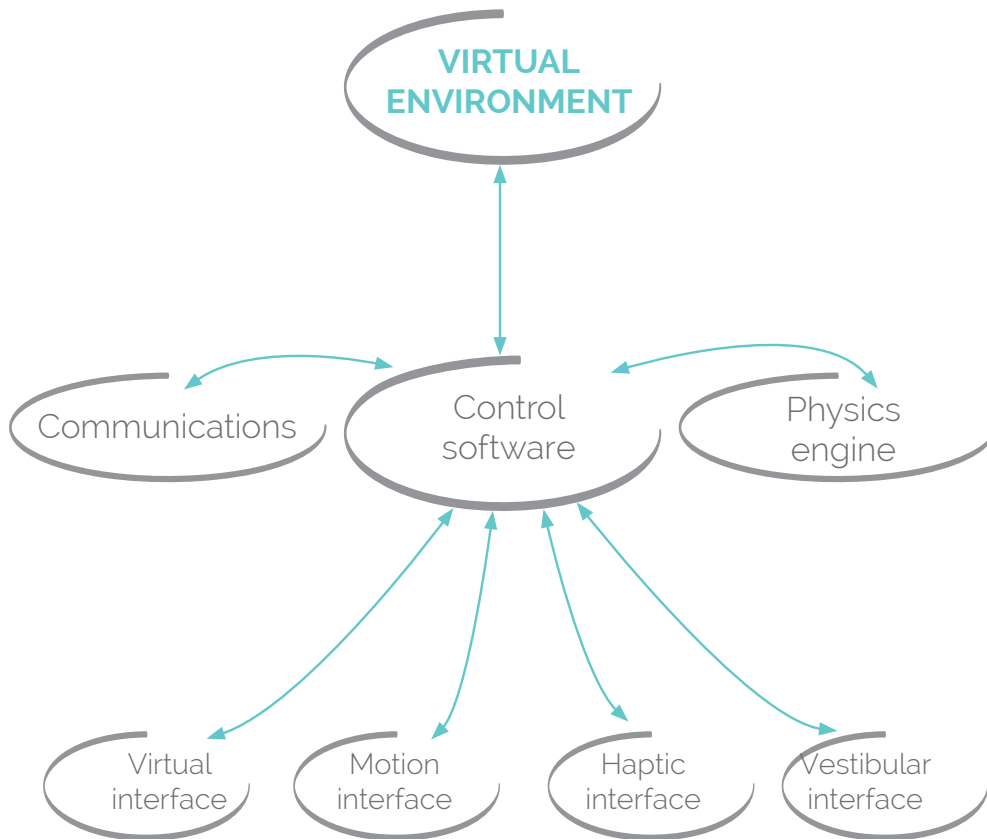
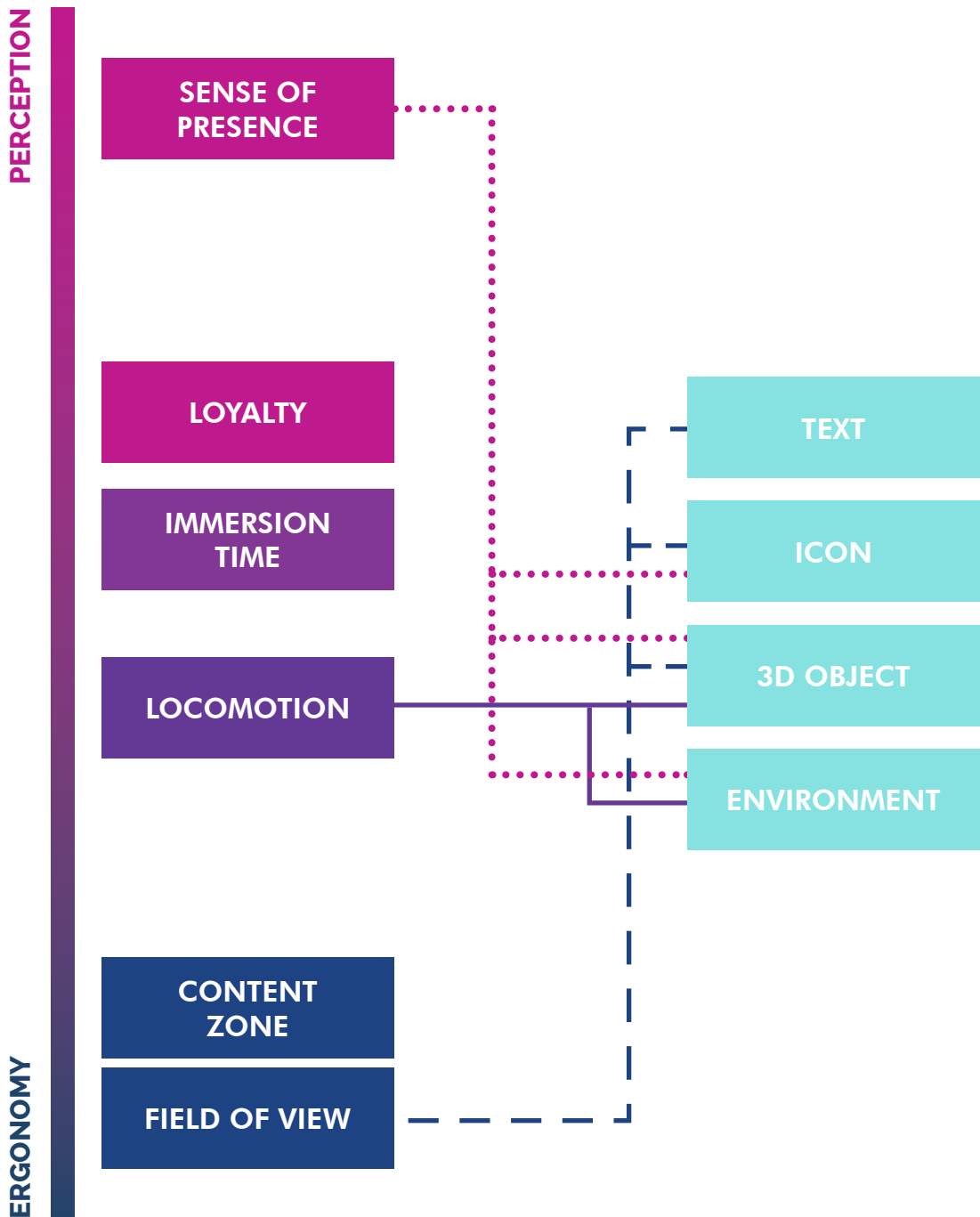


Figure 3.14: *Schematic view of a VR system.*, Reworking of an image by C. Christou, published in June 2010.



Always TEST!

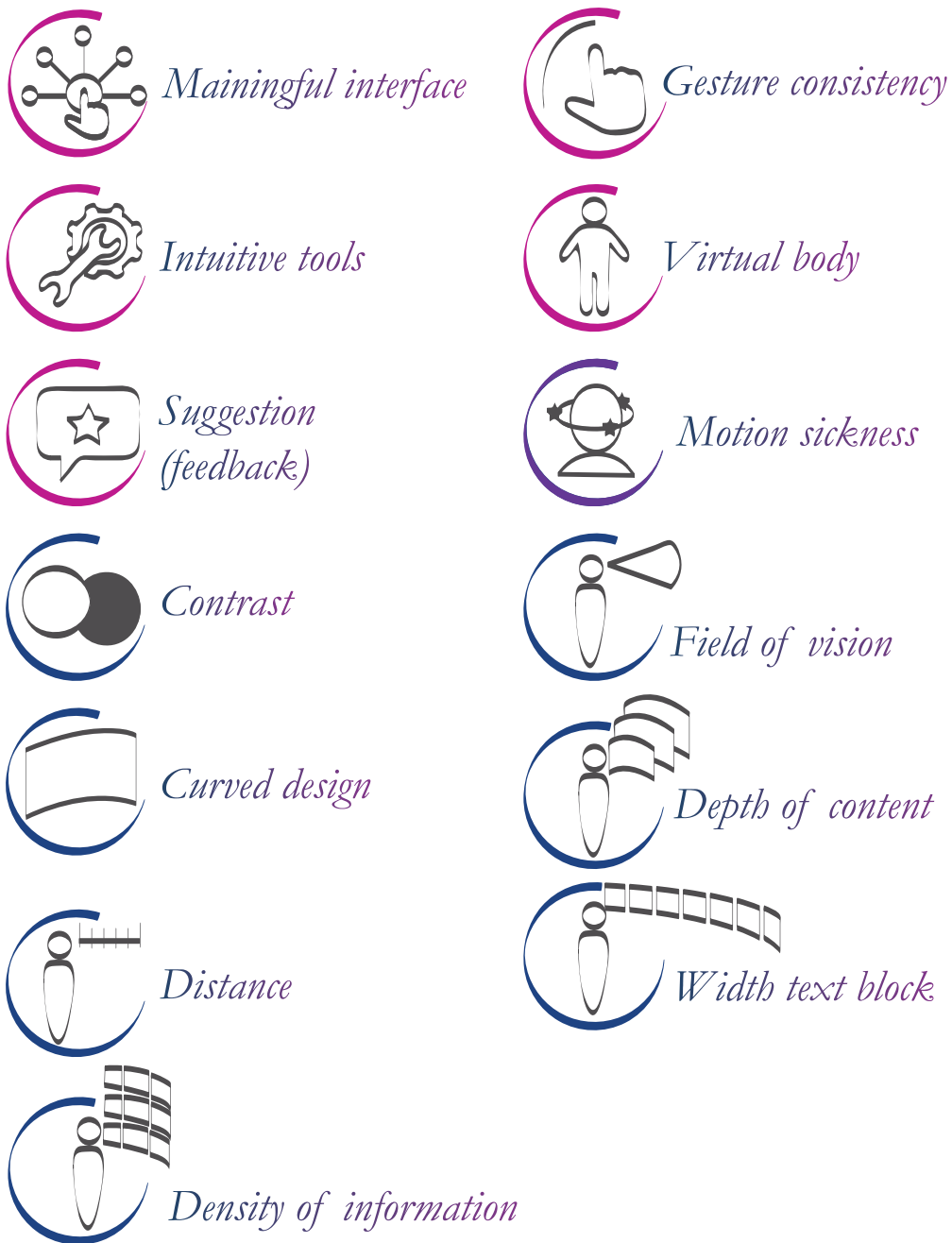


Figure 3.15: Synthesis of the fundamentals of User Experience in Virtual Reality

3.3.1 *Physiological Principles*



Sense of presence

Sense of presence is a crucial factor to consider when talking about human interaction within virtual systems. It is the presence, or the level in which the person feels immersed in the proposed experience. It is often used as a quality measure to evaluate, develop and optimize virtual content^[44]. There are a lot of elements to consider in order to provide a sense of presence that allows total immersion in the virtual context.




Virtual body

Associating a body with the user can have several disadvantages if done incorrectly. It is preferable to have no body rather than the wrong one, that is, a body that does not respond to user input. It becomes preferable to define only certain parts of the body that can be easily managed. One example is the hands and the forearm. The human brain is very good at imagining and filling empty spaces. In this case, it is preferable not to have the forearm, which is difficult to simulate, and leave only your hands.




Figure 3.16: *Oculus touch controllers.*

44 Bystrom, Barfield, and Hendrix, 1999; Riva et al. 2011; Riva et al., 2007

 *Gesture consistency*

Every headset has a controller or a set of gestures to interact with the scene. In a complex scene, we can use a lot of different interactions, but considering the level of expertise of the user, it is better to simplify the number of buttons and gestures. Today, everybody talks about virtual reality, but not everybody uses it frequently. The best interaction is simple, so the design of the informational architecture of the experience is very important. It is better to have one button rather than a deeper level of interaction and it is better to link every level of the taxonomy to a gesture in order to give gesture consistency to the interaction of the experience.

 *Forced behaviour*

Avoid forcing user behavior by moving it unintentionally in the scene, unless you want to create discomfort. At the moment in which a user moves against his or her will, the senses of presence and immersion are lost, causing sickness.

 *Meaningful interface*

The interfaces must be related to the experience world and must not be decontextualized. Use real-world cues when appropriate, for example if the user has to take a picture, design a real camera instead of a button. The holographic elements must fit together perfectly with the environment. They help the impression and the reading. Avoid mixing 2D and 3D GUI. Users must be able to orient themselves in the scene and if they feel lost, they must be able to orient themselves immediately. For this reason, it is better to position the interactions, especially the 2D ones, in the same area of the scene. This area will be a diegetic interface or the experience control panel. You can design a table, a wall, a panel attached to the avatar's arm or a toolbox. This depends on the metaphor you want to create; no matter what shape it has, it will always have to be visible for the user.

 *Intuitive tools*

It is important to simplify the interactions as much as possible. UI, icons, buttons, must be clear and simple. The use of intuitive metaphor can be really helpful to create concrete

interactions. For example, if the user is taking a picture, we can design a button or we can give them a 3D camera that they can take when they want to snap a screenshot of the scene. It will be more natural and intuitive for the user.

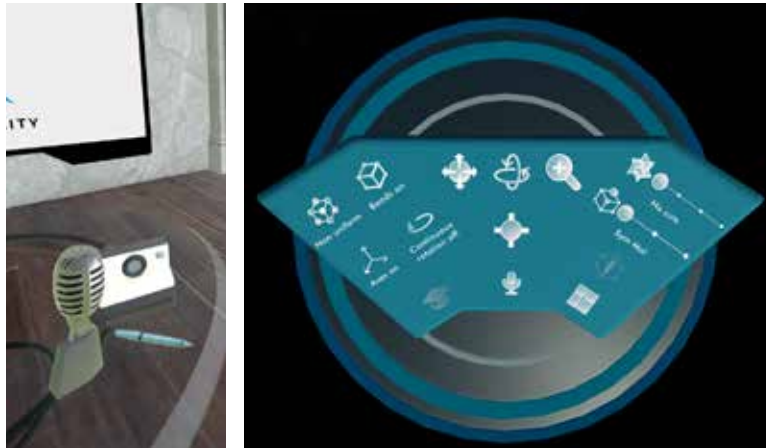


Figure 3.17: *Physical interaction in virtual environment*, Virtual Conference Room (on the left).

Figure 3.18: *Interface of Crystallography Class VR* (on the right).

Loyalty and credibility

Loyalty is understood as the “degree to which the virtual environment simulates the real world.” In other words, it is the level of realism of the application in virtual reality. The manifesto that Mike Alger published in 2015 is a declaration of intent for the research and design of user interfaces for ergonomic multitasking in virtual reality, mainly focused on interaction design for operating systems and browsers.

Alger underlines how VR designers must develop web design patterns and become environment designers, for example, using the colors from everyday life instead of artificial environments and basing interactions on different gestures. What catches your eye is that the technology we already possess can be a starting point for the evolution of virtual interfaces. It is important to find the most natural sensory metaphors possible for the human being, therefore inspired by the nature of the environment in which we live, by what we already know, and adapted to the less “natural” characteristics of virtual reality, which already exist and which we know thanks to our daily experiences with web, computer and digital interfaces.

☆ *Suggestions and feedback*

It is important to design feedback for the user. For example, an active element can be highlighted or animated or change color when the user points to it. In this way, the user knows what they can and cannot use. But what is important, is to give rules to the user that they can intuitively understand. The user needs to understand the norm of the application without any difficulty, and they must be able to access all types of information and suggestions at any time, independently.

For example, UI is a key element when you want the user to be able to make use of information constantly throughout the experience. One of the adopted solutions is that of anchoring the UI to the user's head. This solution is possible but problematic in virtual environments. It is very difficult to define one correctly at a comfortable UI distance for the user. If the user will have to move their head often, if there are a lot of anchored UI interface objects, they might be annoying and overwhelm the experience. One of the effective solutions can be to anchor the UI to a secondary part of the user, such as the arm. The UI, in this case, can be used when needed, at the discretion of the user, and prevent straining the user's eyes. Another solution can place the UI at a precise point in the scene, such as a table, a wall or a virtual screen, and leave the user free to look at and use the interface when needed.



Figure 3.17: *Physical interaction in virtual environment , Virtual Conference Room (on the left).*

Figure 3.18: *Interface of Crystallography Class VR (on the right).*



Locomotion

Motion sickness is one of the most popular problem in Motion sickness is one of the biggest problems in VR. This disorder is related to a conflict between the eyes, which can register changes in slope during the simulation in virtual reality, and the vestibular system within the ear, which does not record any slope because maybe you are still in reality, possibly because you are sitting on a chair. It can cause symptoms such as headache, nausea, discomfort, vomiting. It can be caused by acceleration, speed and direction of movements.

Acceleration is any change in velocity in any direction; it can refer to decreasing the speed of movement, rotating or turning, and moving sideways or vertically. Acceleration conveyed visually but not to the vestibular organs constitutes a sensory conflict that can cause discomfort [45]. Allowing user control over the motion they experience can minimize discomfort. Allowing users to initiate the movement they experience, that is allowing users to move themselves around the virtual world instead of taking them for a ride, appears to reduce discomfort. Direction of locomotion impacts the comfort of users in VR. To minimize sickness in VR, it is important to consciously design the experience. Avoid rapid movement; it makes people sick. If there is a horizon line, keep it steady. A rolling horizon in virtual reality is like a rolling horizon when you are on a ship. Avoid rapid or abrupt transitions to the world space; they are very disorientating. Do not require the user to move their head or body too much. Not only is this disorienting, but the user may be wearing their headset in an environment they cannot turn around in, like on a plane.

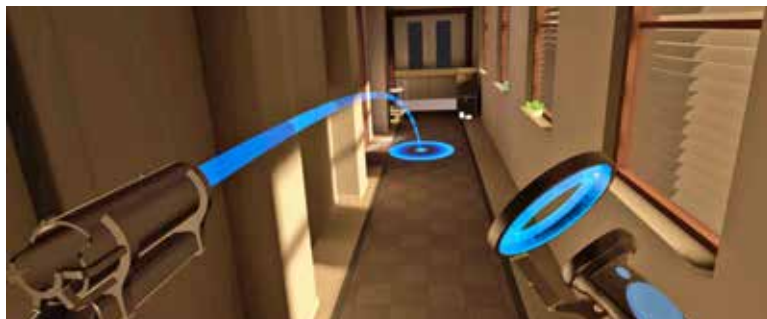


Figure 3.18: *Why 'teleportation' makes sense in virtual reality*, by Engadget

45 Oculus developer, https://developer.oculus.com/design/latest/concepts/bp-locomotion/?locale=it_IT (accessed 1 September, 2019).

There are some methods to reduce locomotion problems, but they have some trade-offs in the user experience, even if the experience will vary from person to person ^[46].

These methods intend to avoid the conflict for the user, by convincing the brain that the user is not in fact moving, that essentially their senses are correct. This means that the more visual cues are presented to reinforce the motion, the less the user will be disturbed.

To reduce locomotion problems, we need to design experiences with the least amount of physical movements as possible. It is really common to replace walk and run with teleportation, which allows users to move around a scene avoiding acceleration. Users can indicate where they want to move in the scene through an input method and they are automatically teleported to the location they indicate, eliminating any issues associated with acceleration in virtual reality. Another trick can be the use of artificial means of transport, such as a train or elevator, or have their view of the world fade to black for story reasons (losing consciousness, being blind folded).



Figure 3.19: *Walk the Plank VR*, sense of vertigo.

Immersion time and long-term adaptation

Malaise problems in a virtual reality application they arise after a certain time threshold. This threshold is subjective and varies according to the individual and the type of application in Virtual Reality. An excellent application will allow a prolonged stay within the scenario. In any case it is possible to improve one's own subjective threshold of malaise, according to some it would be a process of adaptation, just as after many hours on the boat you become resistant to ache sea.

⁴⁶ BBC, <https://www.bbc.com/news/technology-49851798>, (accessed 1 September, 2019).

3.3.2 Ergonomical Principles

Field of View

Field of view (FOV) is the open observable area a person can see through his or her eyes or via an optical device. In human vision, the field of view is composed of two monocular FOVs that our brains stitch together to form one binocular FOV. These rules for VR ergonomics are based on real-life ergonomics, but they are applicable to the VR field too.

If we are sitting in a chair and we look ahead of us, we have a FOV of about 94 degrees. We can rotate our head comfortably 30-degrees and we arrive without any problem to a 55-degree maximum. We even have an up and down comfortable FOV that goes from 20 to -12 degrees and a maximum FOV that goes from 60 to -40 degrees.

If we combine monocular FOV, we have an angle where people can see information and where they have to strain.

The distance from the eyes is also important. If I have something too close to my eyes, I cannot see it; it needs to be from 0.5 meters to 20 meters away from me in order to be readable and understandable.

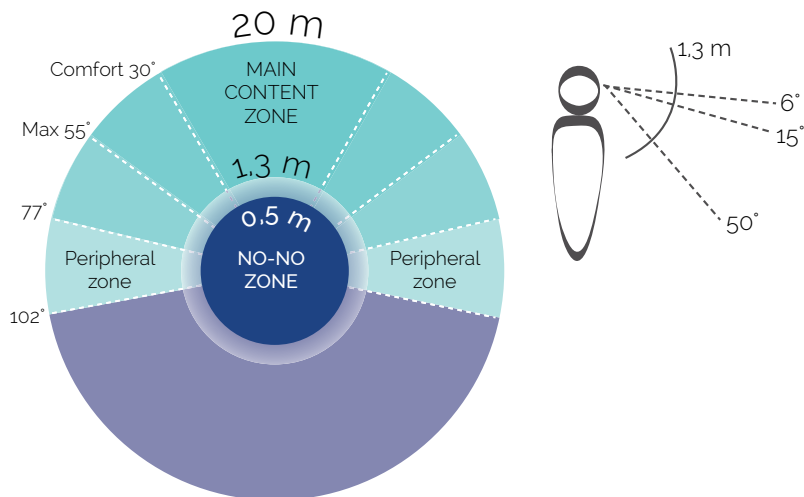


Figure 3.20: *Designing for Virtual Reality*, Reworking of an image by Mike Alger.



Content zone

From these ergonomics rules, Mike Alger extract some guideline zones for types of content. Nuances of the zones' measurements will, however, be variable based on the specifications of the device.

No-No Zone is an area within 0.5m radius from the user. This area should never contain any permanent content to interact with. Note that there can be exceptions, but those should be temporary only and evaluated case by case.

Main Content Zone is an area which is “comfortable” for the user to see and interact with content. User doesn't need to rotate her head too much in order to see items in this area. The comfortable viewing area is 30° from the center to the left or right and max rotation is 55° . Rotation of 30° combined with the device's field of view gives an area in which a user can comfortably rotate their head and see elements, 77° to the side from the centre.

Distance effects also to a human ability to see a stereoscopic separation (3D). The further objects are the more difficult it is to see the separation. Objects appear to be flat if they are more than 20 meters away from the user. If an object is closer than 10 meters, then stereo separation should be clearly visible. This is quite important information when designing UX and scenes for the VR.

Peripheral Zones are areas where user can see stuff if she turns her head. It should be avoided to put any necessary items in that zone.

Curiosity Zone requires that user turns her body to see the area and it shouldn't be used for any permanent items.

Vertical positioning in VR is also important to understand in UX design. Placing objects to vertically to inconvenient positions like too high or too low makes the user feel uncomfortable after some time. The human eye rests naturally approximately 6° below the horizon [5]. Traditional office ergonomic proposes that the most optimal angle for a display is around 15° – 55° below the horizon line. These same guidelines can be applied

for VR when designing vertical positioning of items.

It is important to place items, such as menus, in an easily accessible location where the eyes do not need to do extra work to focus on them, because people spend time in VR. The human eye focuses naturally to approximately 1.3 meters, and this is usually the optimal distance to place text or other items that the user may need to watch for an extended time. According to Oculus Rift documentation, they recommend rendering menu items from 0.75 m to 3.5 m away from a user.

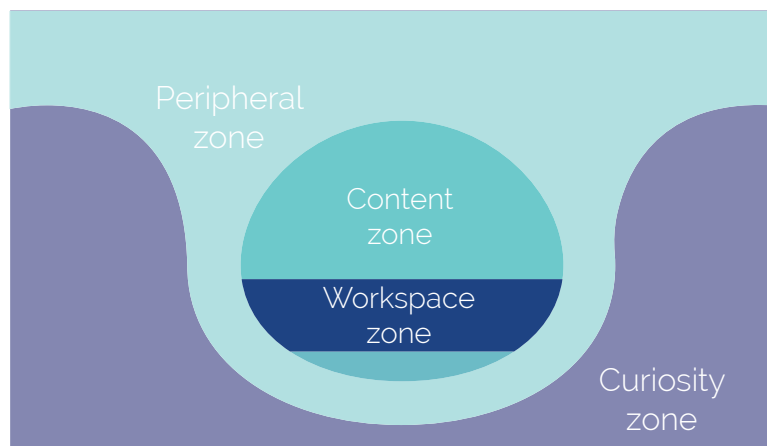


Figure 3.21: *Content Zone*,
Reworking of an image by Mike Alger.



Depth of contents

We can subdivide the environment around us into foreground, midground and background. Like in theatre and films, we need to place a grid over each of these planes and we need to use them as a circle around the camera. We can use each level with different content and different resolution.

Foreground will be the personal workspace and will be in the main content zone. Here, we can put 2D curved UI and 3D interactable objects.

The midground will be the space for the 3D interactable environment, such as whiteboards, shelves and windows. It will stand on the boundary of content, and the user will have the opportunity to reach this area through teleportation, for example.

The background will be the non-interactable environment. It will stay outside the content zone and it might be flat. It is very common to use HDRI maps for the background.

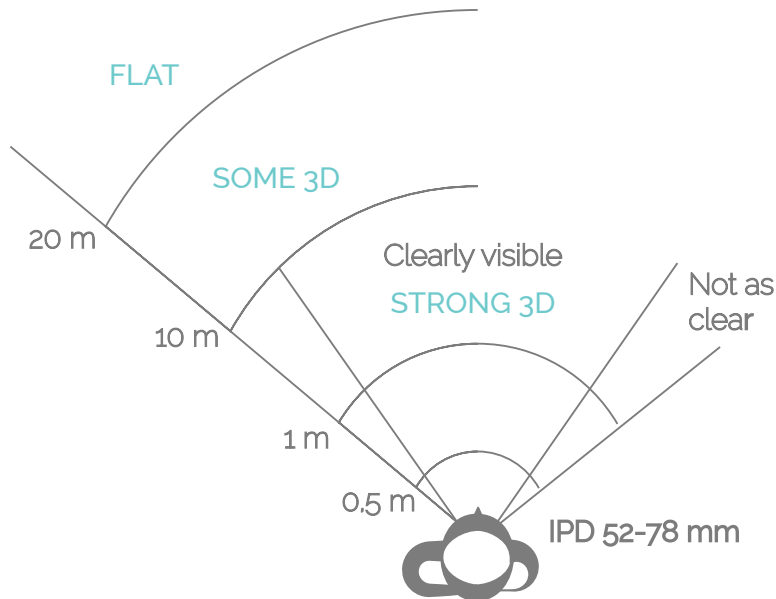


Figure 3.22: *Interface Design, UI for Virtual Reality*, Reworking of an image by Mike Alger.



Curved Design

Traditional user interfaces were built on models designed to have a flat surface. So designing for computer, laptop and mobile screens requires planning different from the realization of an interface in a spherical world in which the user is in the center.

One of the most important aspects in VR is being able to exploit all interfaces via a curved design. This allows you to have every item in view at the same distance from the user. Otherwise, the elements at the edges should have a different focus, which can create confusion for the user and does not allow an easy reading of the image.

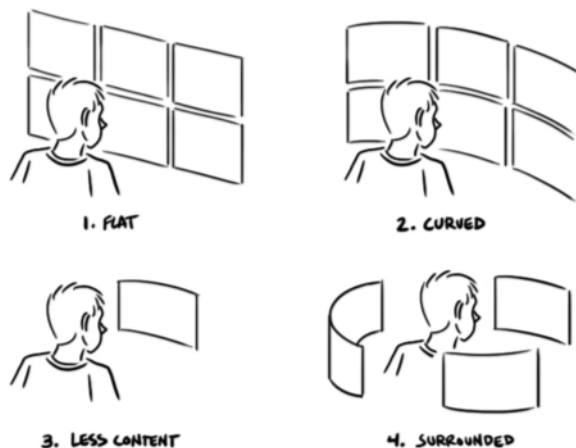


Figure 3.23: *Curved design*, Wired.



Density of information

Keep information density and objects on a low screen. The density must be much lower than the standard screen GUI. Not everything has to be in view. We need to create a pop-up menu and perform most of the time to have the minimum of the essential heads-up display (HUD). Create the HUD so that it is found in a single curved panel (the same sight distance). Keep the density of information and objects on the screen low, much lower than in standard screen design. Not everything has to be in view.



Point of interest

Point of view is really important in VR. The camera is the user's eye. It is important to set the right height of the camera to have the right perspective of the scene. Users can be free to look anywhere inside the scene. At this point, it becomes very important to ask how to structure scenes and how to attract user attention to certain areas. In virtual reality, forcing a user to look at a point by moving or forcing their view is really a bad experience, which will cause sickness and annoyance. What needs to be done instead is to use sound and visual elements to capture the user's attention. The scene must be built to be a guided tour of the content to be transmitted, leaving the user the possibility of being themselves, in reality, the director.



Width Text block

You must avoid having a text block that is difficult for the user to read; it is an uncomfortable experience. The amount of content should be reduced, thus reducing the width of the window display. This will make it easier to read.



Depth and distance

Another feature to take into consideration in the design of an interface is the distance from the user. The ideal distance for reading without discomfort varies from half a meter to 5 meters. The objects farthest from the user must be less clear and tend towards opacity as in Leonardo da Vinci's aerial perspective. Do not put elements too close together within view of the user. Avoid the rapid and frequent change in focus between two objects at different visual depths.

Contrast

We need to create the right contrast to help in reading the UI. It is important to be careful not to overdo the brightness because it could fatigue the user. It takes the right compromise in relation to the environment in which you find yourself and the composition you want to achieve. In general, bright scenes are fatiguing. It is better to use a dark background that doesn't overwhelm the eyes.

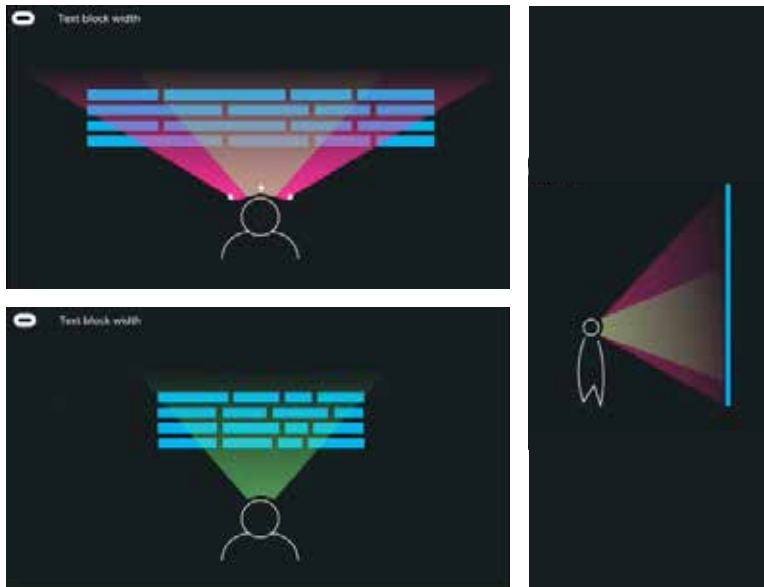


Figure 3.24: *Text block*, Oculus guidelines.

3.3.3 Building a Virtual Environment

When creating a scene in a virtual environment, one must take into account that the user is immediately a part of the environment that has been built. Small details matter, and all content within the scene must allow the user to believe that the placement makes sense. The user can view the scene at 360 degrees. All the space visible must be able to be visited, so it is best to avoid creating parts that cannot be explored. Every object with which one could ideally interact should be able to do so do with the user.

The best virtual environment is where the user can explore all 360 degrees of the environment, interacting with each element. This creates an incredible sense of immersion. Of course, it is not always possible to create a completely interactable scene because of money and time. For this reason, we need to guide our user in exploring what can give them feedback.

3D models

3D modelling for VR is the future of a 3D artist. There are so many rules for designing a 3D virtual object that we could write a book just on this topic. What is fundamental to know is that 3D virtual models must be light. The number of polygons change according to the device, but in any situation, it is better to reduce the complexity of the mesh and leave the normal maps to project the details on the main mesh. All the meshes that present any kind of details and bas-reliefs must be modelled twice, in the low-poly and high-poly version in order to use the lightest model in the virtual scene and add the normal pattern to the texture. The textures can be very detailed, but they also have weight, and it is important not to weigh them down. The importance of the mesh in the experience must be accurately assessed and its design adapted accordingly. If the object will be taken in hand by the user, you can afford to add details and polygons, always trying to be spare. If the object will be a piece of furniture for the environment, you must be able to minimize its heaviness. For this reason, the background of the scene is often an HDRI map.

Normal Maps

In 3D graphics, normal mapping is a technique used to simulate the complexity of the survey of surfaces without having to model them in detail. A normal map is generally an RGB (red, green, blue) image generated by projection from a detailed object, which is done corresponding to the x, y and z coordinates of a less detailed normal surface representing the same object. This technique allows you to improve the appearance and details of a simple polygonal model by creating a normal map from a detailed polygonal model. In video games and in realistic 3D graphics applications in real-time, it is used to improve the appearance of objects without losing performance, usually rendering a low poly mesh. Normal maps can break VR immersion in some cases. This is because the eye is very good at gathering information about depth, and with VR images, they are already stereoscopic by default and what happens is that we see normal flat maps, that is without any depth information. It is a good idea to use only normal maps on objects that will be far away from the reader since the parallax effect will be negligible beyond a certain distance. We should find other solutions for objects closer to the user; otherwise, you could risk having immersion problems.

Icon

An icon must be simple, clear and without details. It may seem obvious, but in VR, more than on screen, icons must be elementary. Avoid the use of fine lines. Use at least 4 points for lines, in favor of a full background. It is better if the icon is supported by a label, as it will be clearest, more understandable and will not require intuition from the user. Highlight and animate icons when they are selected. This type of feedback is really important for the user.

Text

Text in VR is difficult to see clearly, and the user will tend to ignore it unless it is animated or highlighted and attention is placed on it. Using text in VR does not make the best use of the technology. A VR designer should try to avoid text or reduce it as much as possible, placing it in front of the user or near the point of attention, like a label beside a work of art at a museum.

Sound and Music

Audio must help in the perception of experience. Elements of the GUI must be from audio sources to signal the right feedback to the user. One of the important aspects of audio in the context of virtual reality is to drive the user to perceive an important event at the right time and in the right place for the virtual reality application. Not having full control over the user, you need to attract their attention through spatialized sound inputs that indicate the affected area at a certain time.

When in doubt; test, test, test!

Chapter 4

**DESIGN PROCESS FOR VIRTUAL
EDUCATIONAL EXPERIENCES**

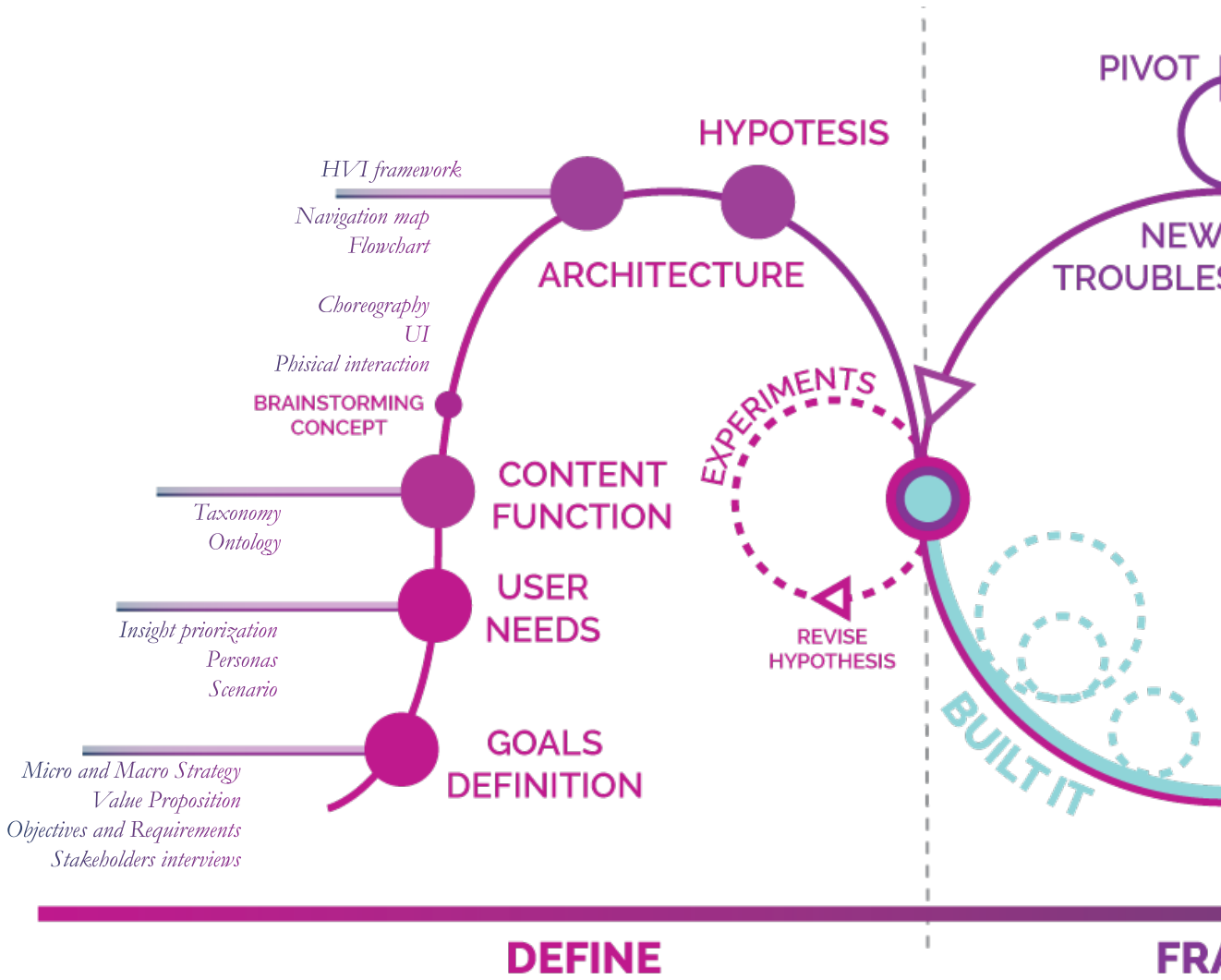
4.1 Introduction to the Design Process

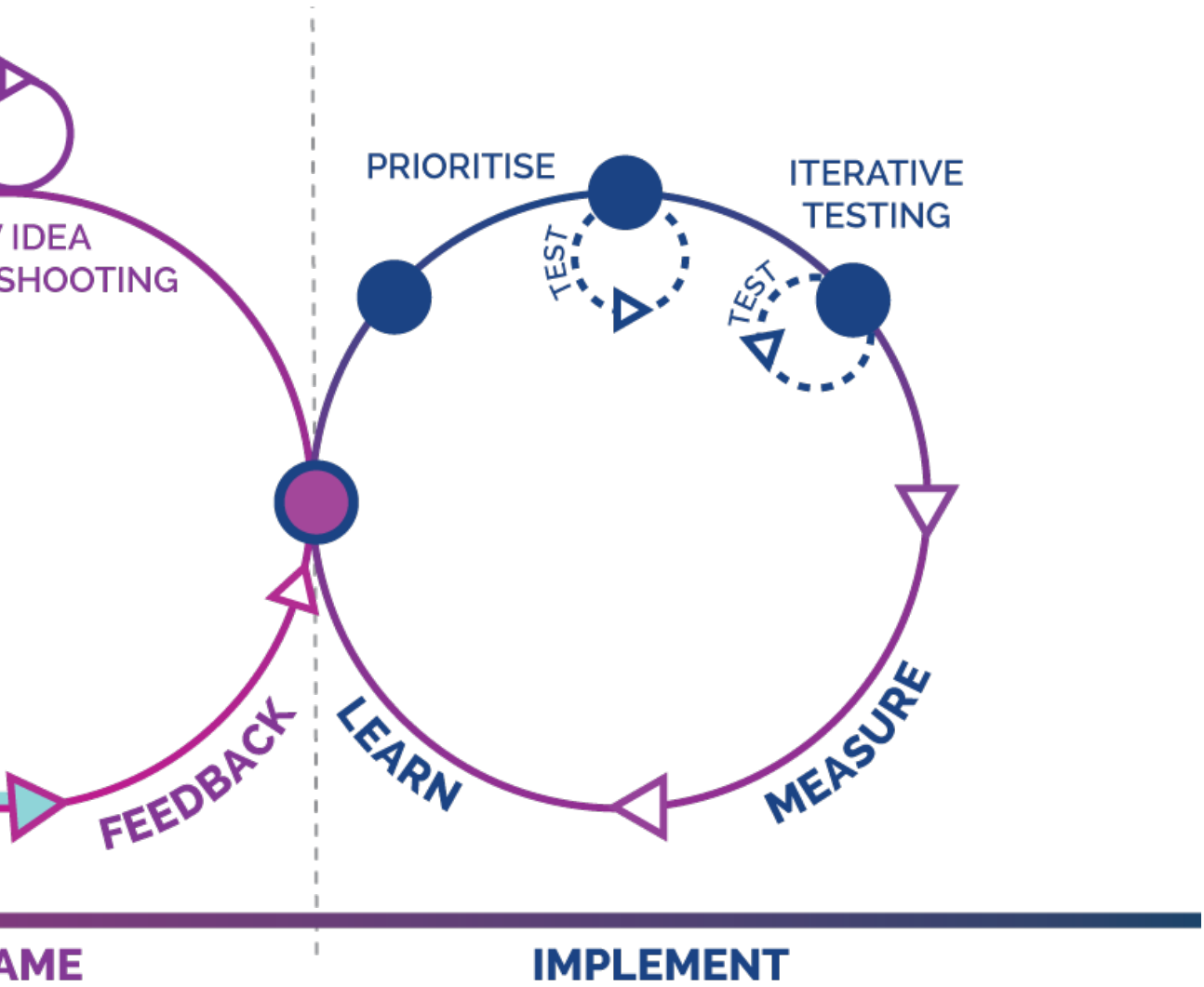
The design of educational virtual experiences follows the interaction design process and the “instructional design theoretical framework of VR based learning environment” of Chen, Toh & Wan ^[47].

To design an educational virtual lesson, it is important to think on paper and devote a lot of time to reflection on virtual spaces. Testing and prototyping are fundamental to understanding whether what we have conceptualized on paper is the right design. The traditional design process is not enough; it is important to use virtual tools to design virtual spaces.

In the following chapters, we are going to explain the methodology followed by two practical case studies, Space Debris VR experience and Crystallography Virtual Class, developed in collaboration DEIB – Electronics, Computer and Bioengineering Department – of the Politecnico of Milan,

47 Kee Man Chuah and Chwen Jen Chen , “*Unleashing the Potentials of Desktop Virtual Reality as an Educational Tool: A Look into the Design and Development Process of ViSTREET*” Faculty of Cognitive Sciences and Human Development, Universiti Malaysia Sarawak, 2008.





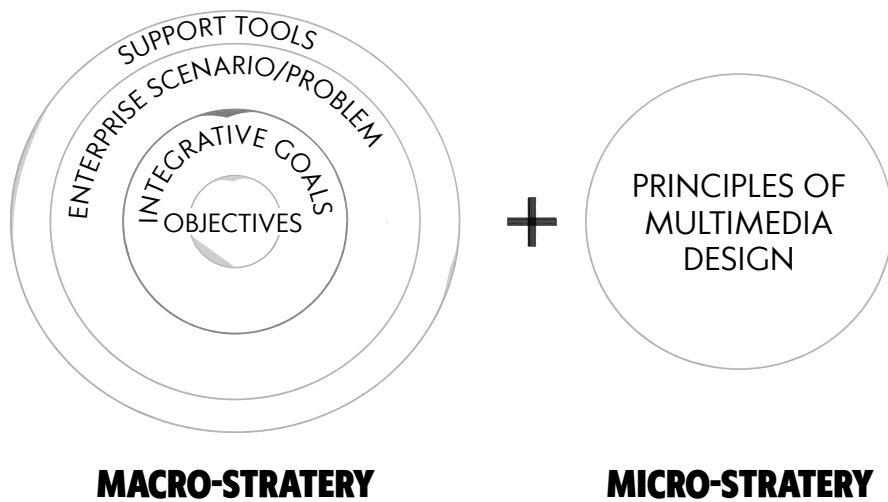


Figure 4.2: *Instructional design theoretical framework of VR based learning environment*, Reworking of an image by Chen, Toh & Wan, 2004.

4.2 Project Pipeline

“Listen, build, test and repeat! Adopt a prototyping mindset and associated skills to empower teams and individuals in the development of new products and services” [48]

This is the work pipeline and the expertise needed that were required to develop Space Debris VR experience and Crystallography Virtual Class for Oculus Go. This entire chapter is based on my personal experiment and my experience at AnotheReality s.r.l. and DEIB.

An interaction designer, game designer or instructional designer defines the objectives, actions and values of the story, user needs and workflow of the experience. It is a process that needs to be supported by prototyping and virtual tools. When requirements, UX, interactions and micro-interactions are defined, the 3D artist can model environments, interactable objects, characters and design the UI. In the meantime, the project is developed by the engineer and comes alive through scripts.

DEFINE and FRAME			
1. GOALS DEFINITION	2. USER NEEDS	3. CONTENT FUNCTION	4. ARCHITECTURE
<p>Definition of project <i>objectives, requirements</i> and <i>Value Proposition</i> through research and <i>stakeholders interviews</i>.</p>	<p>Definition of activities that the user will perform, actions he will act through <i>insight prioritization, personas</i> and <i>scenario</i>.</p>	<p>Analysis of action and interaction, <i>ontology, taxonomy</i> and <i>user relation</i> with the <i>interface</i>.</p> <p><i>Brainstorming</i> and concept sketches in virtual space.</p>	<p>Organization, prioritization and syntesis of the elements. Definition of <i>physical interaction, navigation map, interaction map</i> and <i>flowchart</i>.</p> <p><i>Choreography, UI design</i> and final revision with <i>HVI framework</i>.</p>

After all of this step is important PROTOTYPE the idea in a VIRTUAL SPACE, it does not matter the level of development, even a quick virtual sketch can help visualize the idea and understand if the correct direction has been taken.

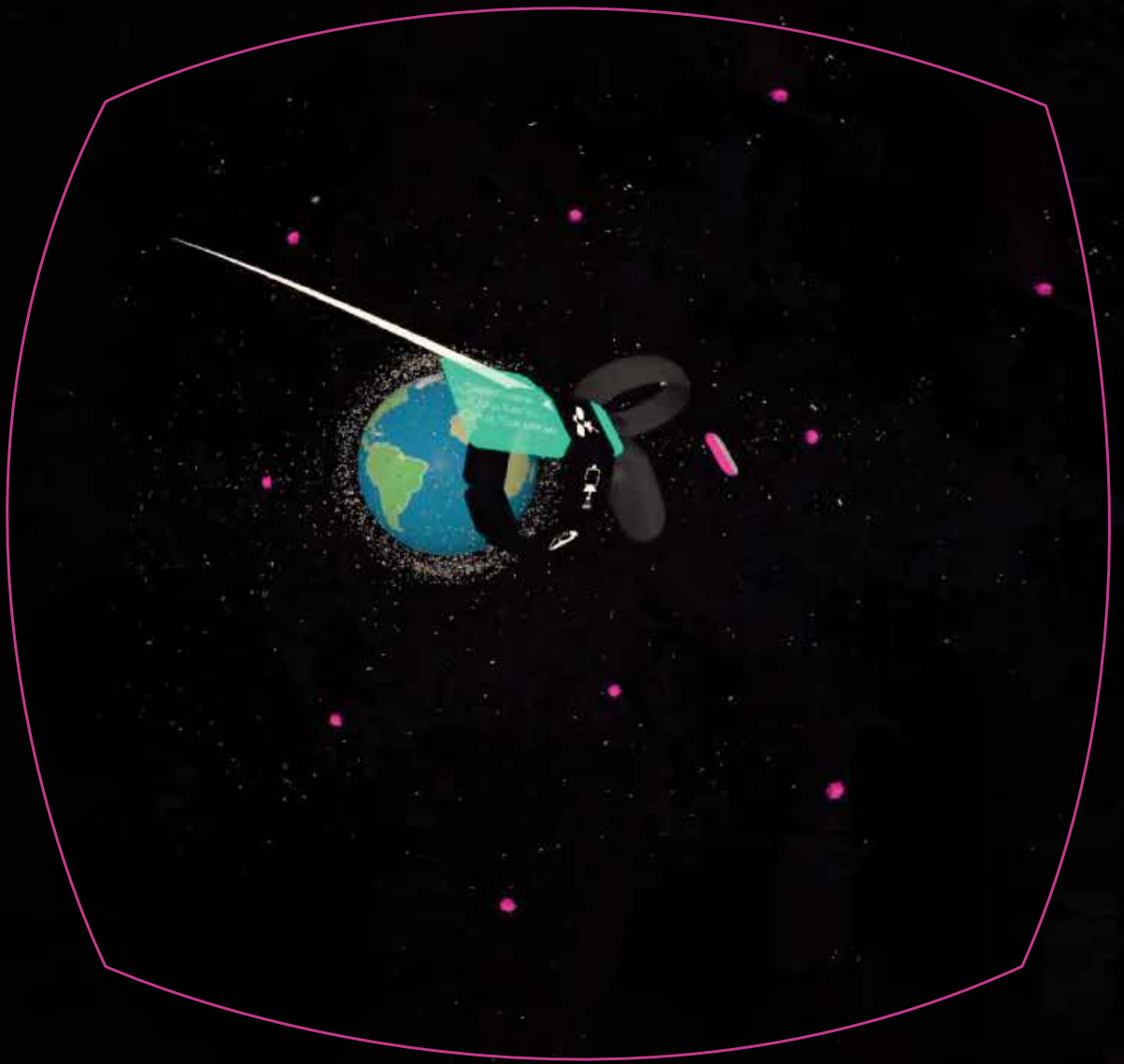
Design and develop for Virtual Reality without build the scene is really complex.

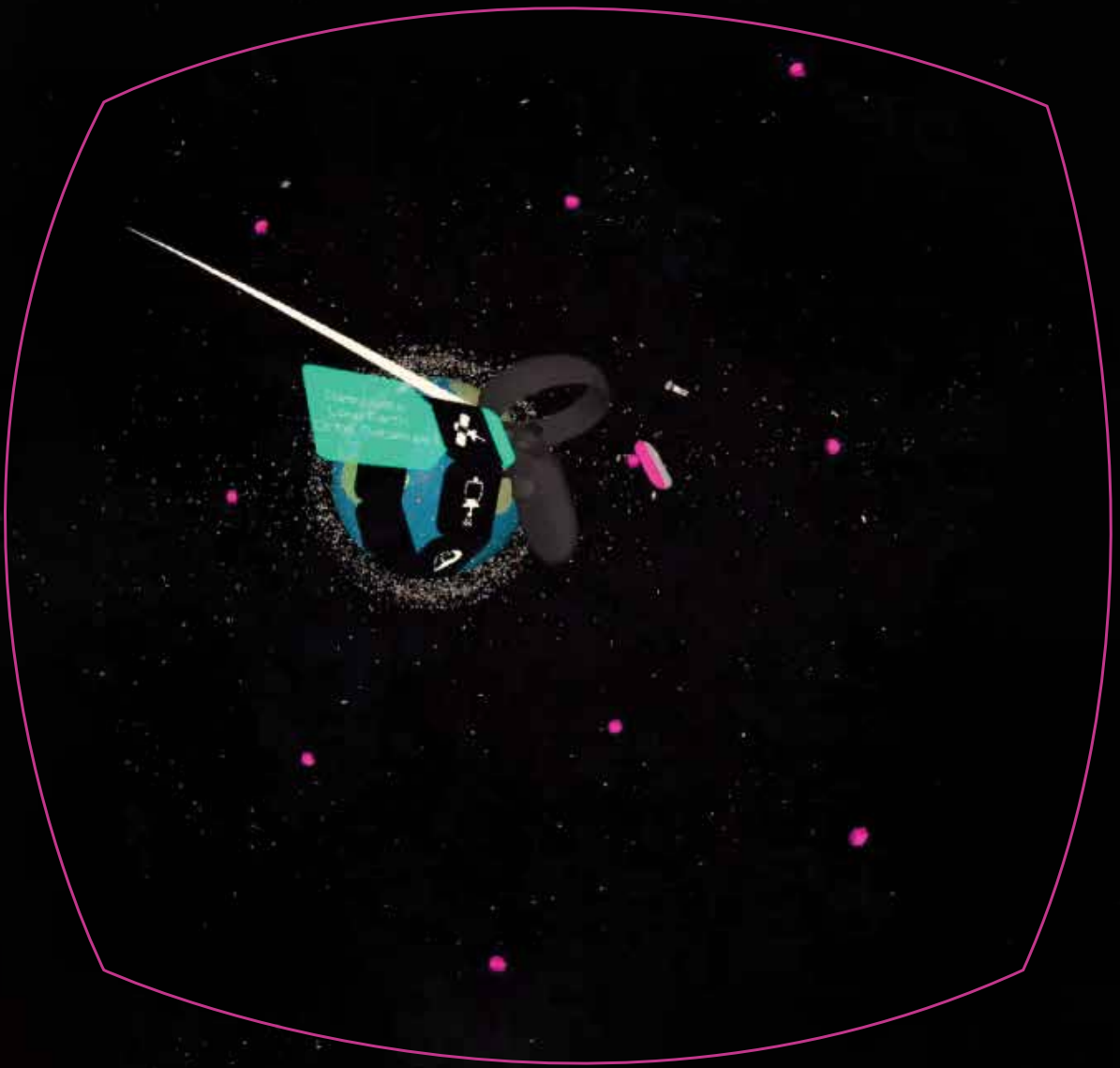
Tests and raw prototype provide a lot of findings and suggestions to improve the quality of the experience.

IMPLEMENT			
5. MODELING	6. TEXTURING and UI	7. IMPORT and 1st BUILD	8. LIGHTING and SHADING
<p>3D artist releases the environment of interactive objects and of the avatar. Two versions of models are created: Low Poly (LP), in which the principal shapes of the models are defined, and High Poly (HP), with all the details for normal map baking.</p>	<p>3D artist bakes a High Poly UV map on Low Poly models, creates materials and applies the texture on the models, exports textures of albedo, normal map, ambient occlusion and metallic smoothness. In this phase, 2D UI is designed.</p>	<p>3D artist imports 3D models for the first time in Unity, applies shader, checks and corrects all the mistakes and imperfections of the meshes and enforces UI on canvas. When everything is correct, it is time for the first build for the headset.</p>	<p>Shader artist codes shaders and sets up the lighting for the entire scene. If necessary, the artist applies the HDRI map and tries to create the most appropriate mood and environment possible.</p>
9. ANIMATION	10. POLISHING	11. CODING	12. VALIDATION
<p>3D artist and designer animate 3D objects, characters' movements and UI.</p>	<p>Final validation from the creative team with mock-up and apk testing, adjustment and optimization of the scene and improvement of the render set up. Time cost can be really high.</p>	<p>Coding starts in parallel with the modelling phase, engineers start to code with temporary 3D models. From a design point of view, the programming phase is really important because it is the final validation.</p>	<p>This is the final part of the project. It is really important to choose the best sample for the user to have good insights and to understand the pros and cons of the experience.</p>
Final APP			

4.3 Design Process for Virtual Educational Experiences

In the following chapter, we are going to present two virtual educational projects. These applications have been developed in collaboration with DEIB for Vodafone Italia, who allowed us to use their new 5G technology. The high bandwidth allows a relatively high number of clients to be connected at the same time. Thanks to its low latency, we were able to send data in real-time, to have a smoother experience on the client side, and also run the application simultaneously on multiple devices. The topic of the two virtual classes was discussed with teachers from different departments at Politecnico of Milan. After a brainstorming session, we discovered an opportunity to develop a virtual lesson for Aerospace Engineering Department about space debris and for the Physics Engineering Department about crystallography. According to the teachers of the respective subjects, virtual reality was the perfect technology to help the students understand those concepts because it can give an external point of view of the earth and a three-dimensional perspective of crystals. Both lessons explain a simple concept that is difficult to visualize. For this reason, we accepted the challenge and we started this project with the aim of creating virtual educational tools for university students without a background in virtual space





Chapter 5

SPACE DEBRIS VR

5. Space Debris VR

This experience has been designed in collaboration with GameLab of the Computer Engineering Department of Politecnico of Milan. The implementation of the application was carried out by Erica Stella, researcher at GameLab.

5.1 Introduction to Space Debris VR

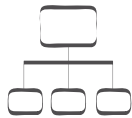
Space debris VR is an educational virtual reality application, an accurate scientific simulation to help people understand the problem of space debris. The aim of the application is to give an educational tool to aerospace engineering students, leave them free to explore through an interactive experience and to provide teachers and students a support lecture. During the experience, the user can float in space and understand the quantity and the behavior of space debris. We are not familiar with this phenomenon, but it is a huge problem and it is a complex topic to explain to aerospace engineering students in the first year. This topic was suggested by the Aerospace Engineering Department at Politecnico of Milan. They helped GamLab identify the requirements and the structure of the overall experience.

The aim of the collaboration of GameLab with an interaction design student was the study of the user experience, the organization of the content and the design of a simple and immediate interface with a lot of information and commands to maintain under control.

5.2 Brief: Objectives and Requirements



Design a *story-driven* experience with free exploration, to give to the student the opportunity to understand through an active experience the space debris problem



Organize and synthesize the concept of space population orbiting of the Earth by activating and studying the movements of all the elements that constitute the space debris

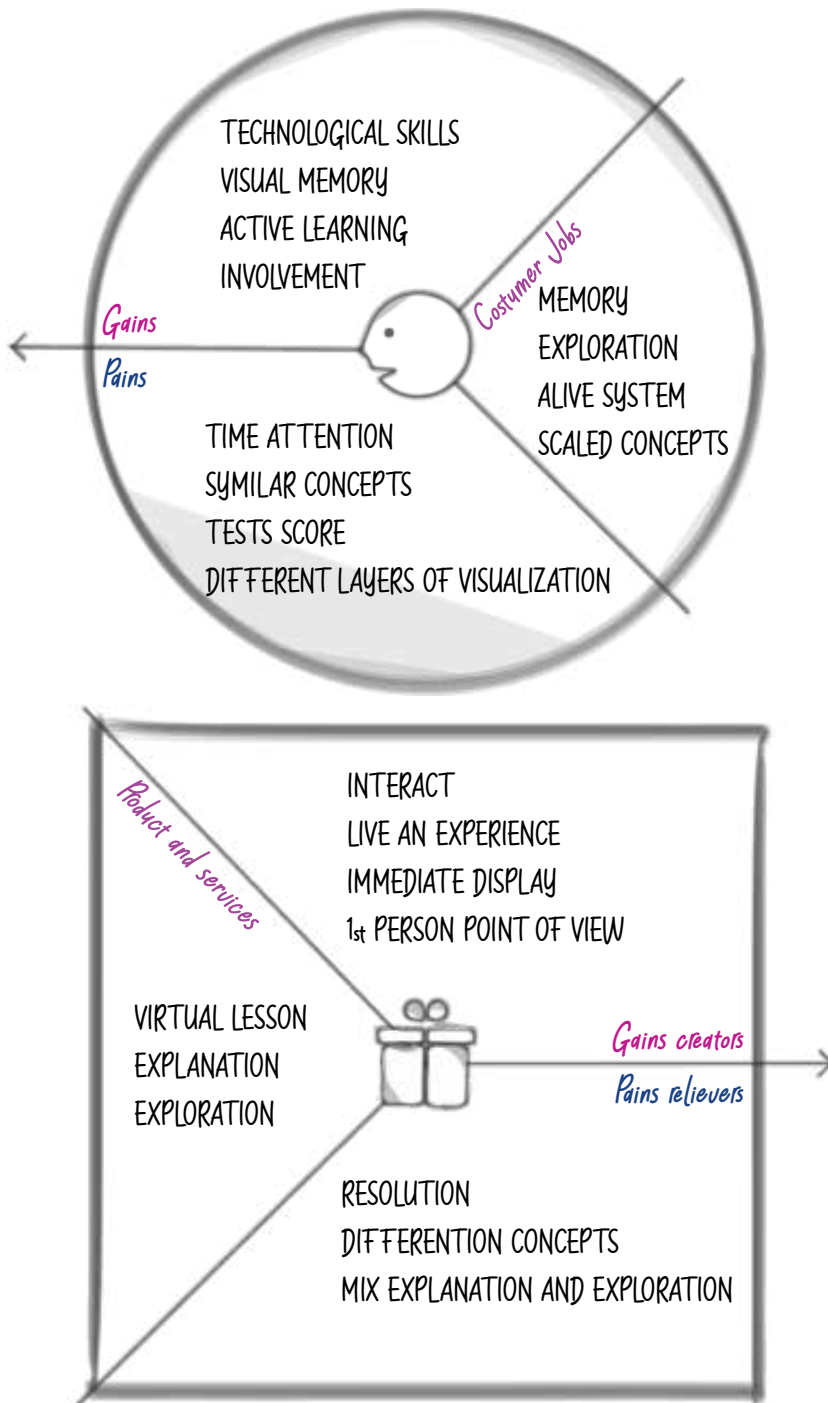


Design a non-invasive and intuitive interface to visualize the different space debris and their trajectories



It had to support different *Virtual Reality headsets*, and it had to runs smoothly on wireless, low-cost hardware with limited processing power

5.3.1 Value Proposition



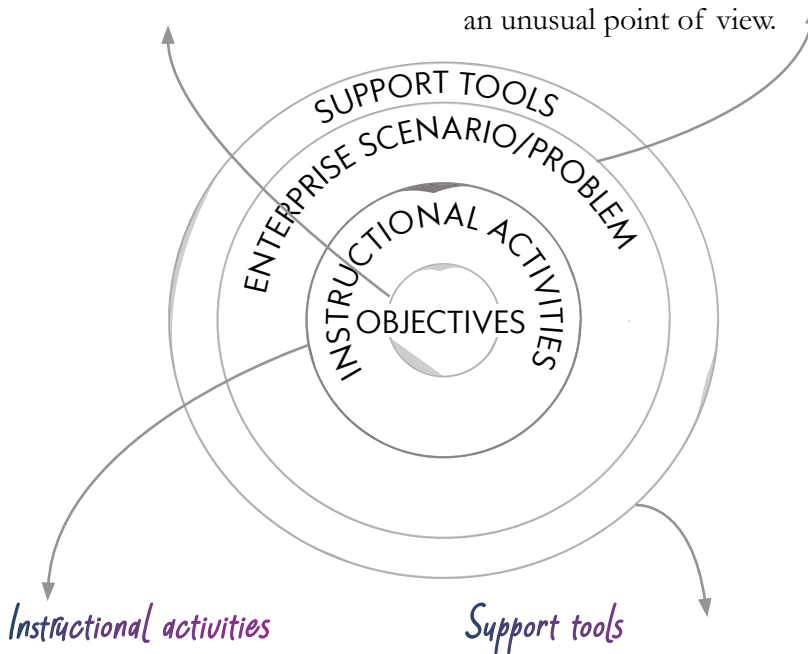
5.3.2 Macro-Strategy

Learning objectives

Knowledge and comprehension of space debris satellites and trajectory through an explorative story-lesson.

Enterprise scenario or problem

The difficulty for the teacher to explain scaled phenomena and for the student to visualize and memorize similar concepts from an unusual point of view.



Instructional activities

With a story-lesson student can listen and understand the concept and with a first-person exploration, they can activate and deactivate satellites and their trajectory to memorize their behaviour.

Support tools

Teachers and students would like to have a virtual interactive lesson on this topic, a visual tool to explore, understand and memorize in the easiest way the different types of debris and their behaviour around the earth.



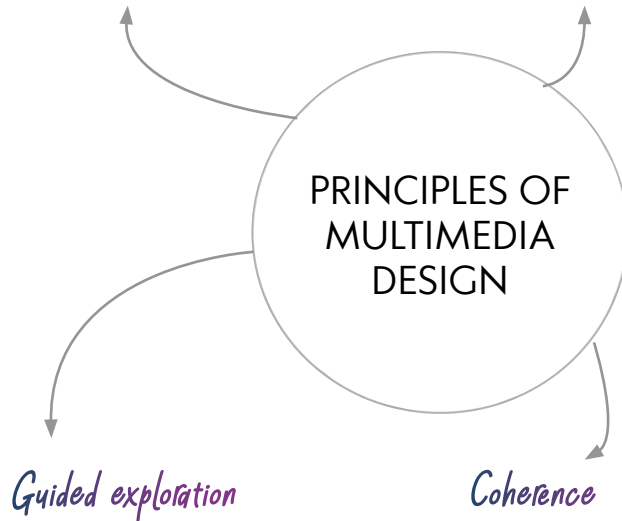
5.3.3 Micro-Strategy

Spatial contiguity

Imagine being on a spaceship. Students can follow the story-lesson, seeing what happens around the earth from space.

Modality

Lesson has been transformed into a tutorial for exploration. Watching the tutorial, students listen to a short lesson that they can create with a personal exploration of the earth.



Guided exploration

The interface has been transformed into a wearable bracelet that they can easily control through the controller. They can turn satellites around the earth on and off and see how they behave.

Coherence

Satellites and trajectories are not a concept to learn but a phenomenon to watch, discover and enjoy.

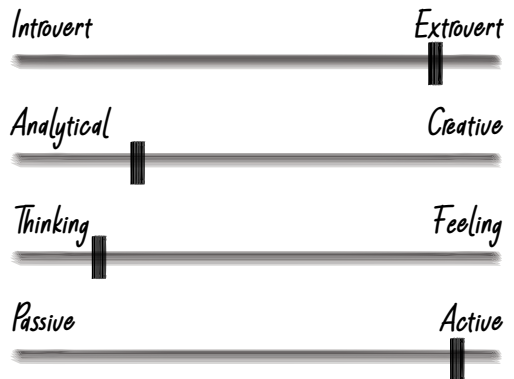


*"Studing Galaxy
it's like a dream for me!"*

ABOUT

Sam is an **Aerospace engineering** student in the first year at university. He is an extrovert guy, he spends a lot of time with his friends and **he likes a lot of technology**. He spends his free time with his friends and **playing a videogame** with them. He has problems in studying for a long time, he has a **practical intelligence**, when he reads he remembers 30% for the first time. He likes a lot of aerospace topic but he is afraid that he will not be able to graduate himself because engineering at Politecnico is really complex and **require a lot of ours sitting on a desk**.

PERSONALITY



NEEDS

- He prefers active learning
- Stay with friends and share experiences
- Understand if an aerospace engineer is the university for him
- Visualize concept

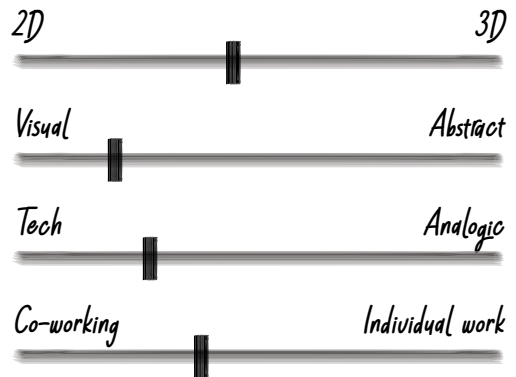
PAIN

- He is not able to study for a long time
- Fear of choosing the wrong university
- Display scale phenomena

FAVORITE SOFTWARE



WORK DESCRIPTION



PREFERRED CHANNEL





Figure 5.1 : Sketch scenario *Aerospatial lesson*

5.4 Scenario

For aerospace engineering teachers, it is difficult to explain the concept of space debris because it is a huge phenomenon with a lot of different but similar elements. Students like Sam have a hard time imagining this kind of phenomenon which has a different scale from our reality and asks them to change their point of view.

Teachers and students would like to have an interactive lesson on this topic, a visual tool to understand the concept and to give the students the opportunity to easily learn about the different types of debris and how each one behaves around the earth. For people with no background in aerospace, it is hard to visualize the movements of satellites around the earth, to imagine eleven different elements floating with different trajectories at the same time.

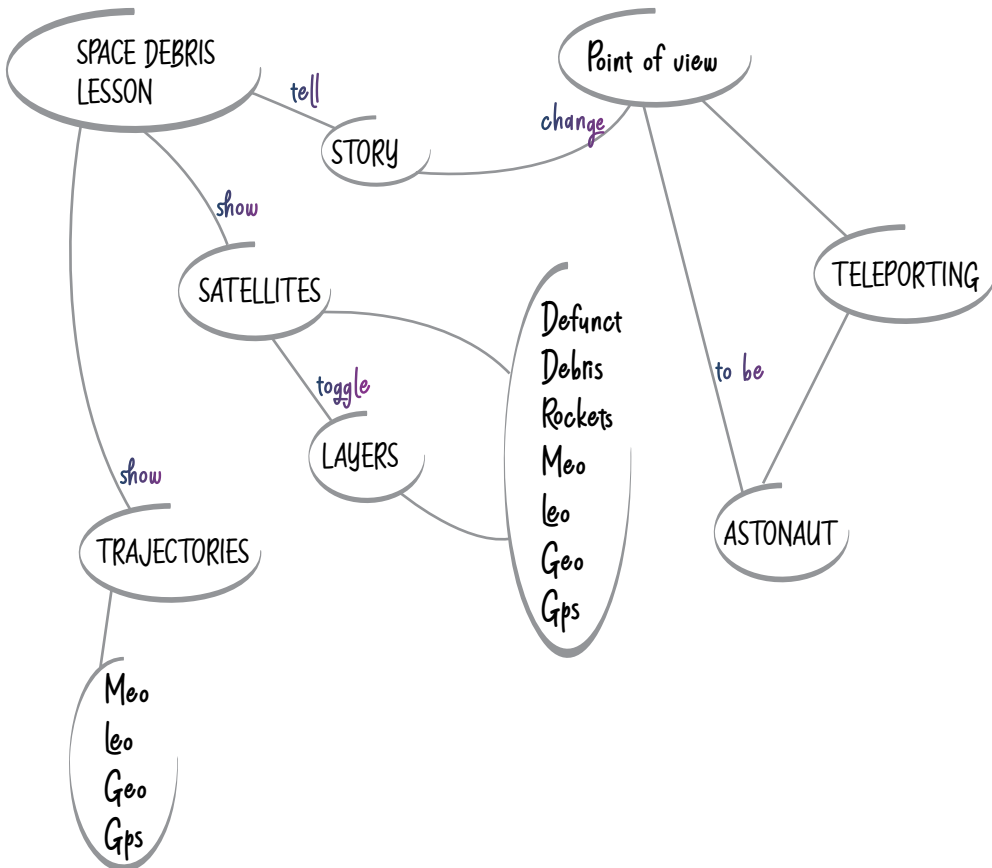
For a teacher, it is hard to explain the difference between these objects and it is harder to help student visualize their trajectories.

5.5.1 Ontology

Topic and concept of the experience were been decided in collaboration with Aerospace Engineering teachers. They suggested the elements of the experience and the type of visualization. They asked a complete visualization of all the space debris pointing out that was fundamental to have the opportunity differentiate visualization.

They said that could be useful to have the opportunity to change the point of view during the experience.

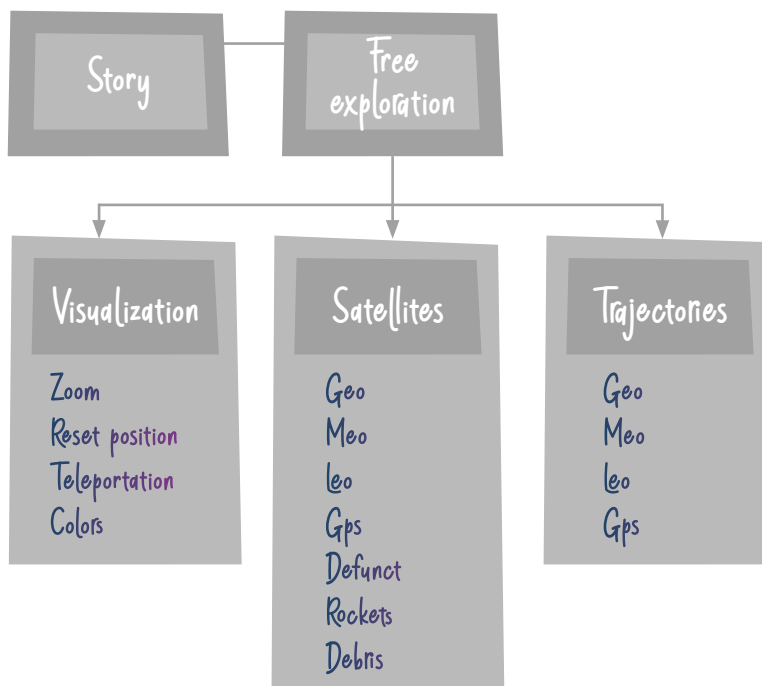
They specified that all the elements have the same level of importance and that they want to give to their student the opportunity to understand and experiment the visualization of these satellites and their trajectories around the Earth.



5.5.2 Taxonomy

The experience is divided into two phases: tutorial and exploration. The most important is the exploration mode in which the student has the opportunity to visualize the satellites and their trajectories all together and one by one. The student can change the point of view, approaching and moving away from the earth and moving around it.

Considering the problem of locomotion and vertigo in virtual reality, since from the first brainstorming it was clear that the user should not have the opportunity to float freely in the space, we created some defined points of teleportation that the student can point to with the controller to change the point of view in that precise position. Exploration mode is perfect for visualizing the elements, but it was difficult to understand the difference in the elements. For this reason, exploration mode is accompanied by a story mode, which consists of a tutorial that explains the origin and properties of the satellites.



5.6 Physical Interaction

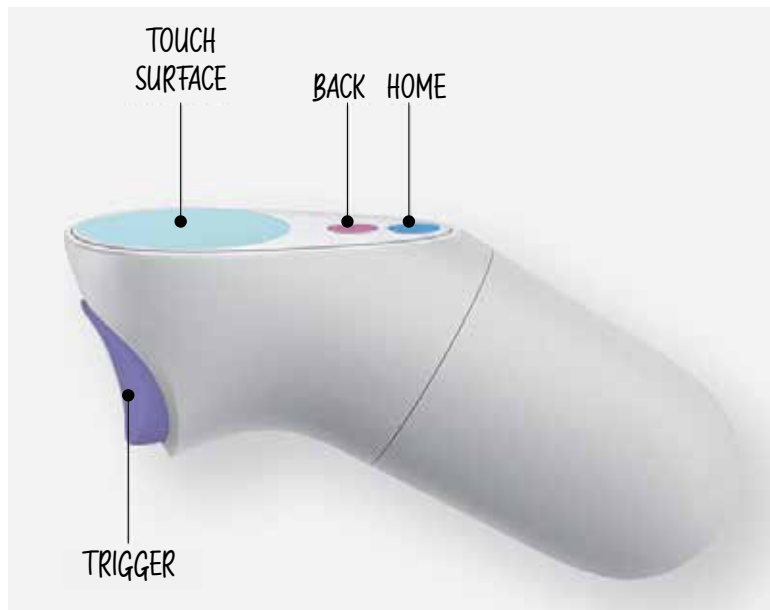
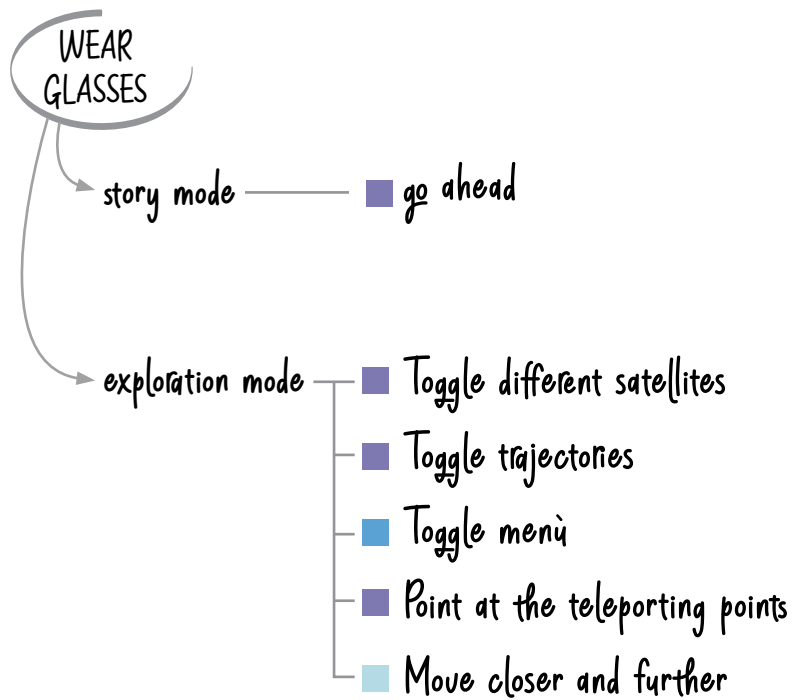


Figure 5.2: Oculus Go controller



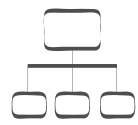
From problems to new goals

This is the diagram of the interaction flow of the first prototype. The aim of this prototype was to validate the coding, which was almost defined and working, and to identify interaction problems.

We moved from the initial objectives and requirements extrapolated from the brief and we defined 4 different objectives focused on the interaction to improve the user experience.



The user should feel like an astronaut



length of the menu and number of commands. The difficulty lay in the fact that all the objects to be selected through the trigger had to be at the same navigation level. We tried to reduce them by combining satellites and trajectories, but the display was not clear.



Differentiation and characterization of the icons.



Users were disoriented, moving from one teleporting point to the other. It would be useful to have a center point in the scene to come back to when lost in space.

5.7 Design Evolution

The first prototype was working from a coding point of view but was the earlier version from a design point of view. Step by step interface and interaction were implemented and refined.



Figure 5.3, 5.4, 5.5, 5.6 : *Space Debris VR*, first version by Erica Stella

In the first iteration all the elements were organized by type of visualization and function, in this way we could solve the differentiation between satellites and trajectors of GPS, GEO, MEO, LEO, the menu was less length but still too invasive. User had the chance to reset the position and move manually the visualization. Again this could not be the final architecture of the application. Was needed a non-invasive interface to collapse all the button and give to the user the opportunity to navigate in the menù in an easy way. After different proposal and tests, the solution arrived: the icons were disposed on a ferrule divided into satellites and trajectory visualization option. At first, we proposed to create a Spacesuit but after some tests were clear that this solution should be too elaborated, with all this button and command would have been better to create a clock or a simple rotating ferrule to simplify the visualization. The ferrule solution seemed to convince teachers and students.

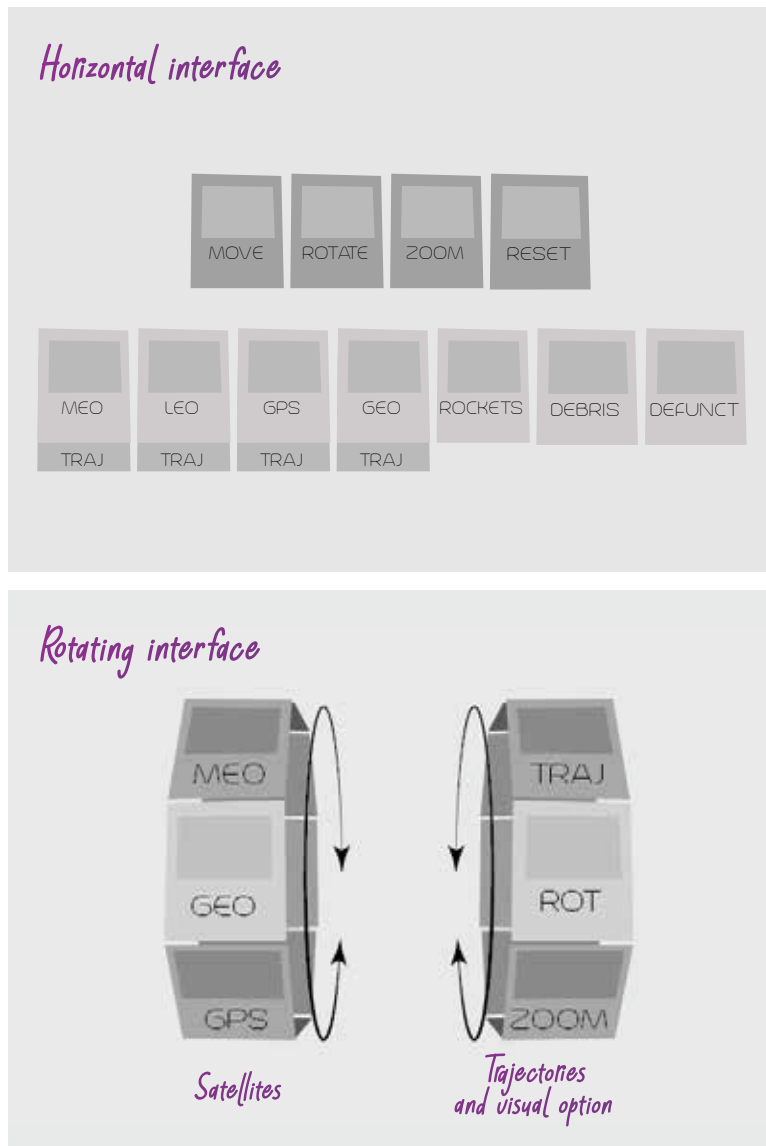


Figure 5.7 (above): *First interface concept.*
Figure 5.8 (down): *Second interface concept.*

There were three options but after the build of a prototype was clear that the third was the best because it allows the expansion of the menu both on the right and on the left and this could be helpful for an intuitive navigation of the interface.

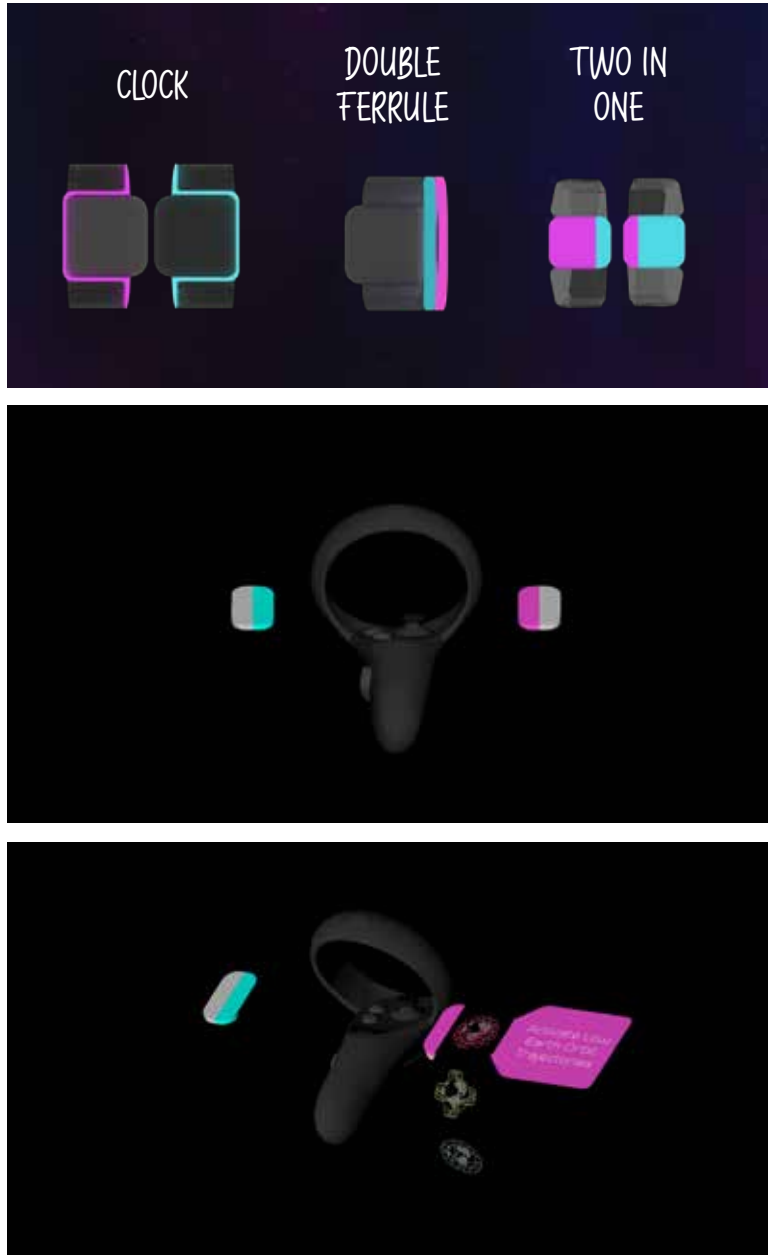


Figure 5.9 (above) : *Ferrule concepts proposal*
Figure 5.10, 5.11 (down) : *Ferrule final version*

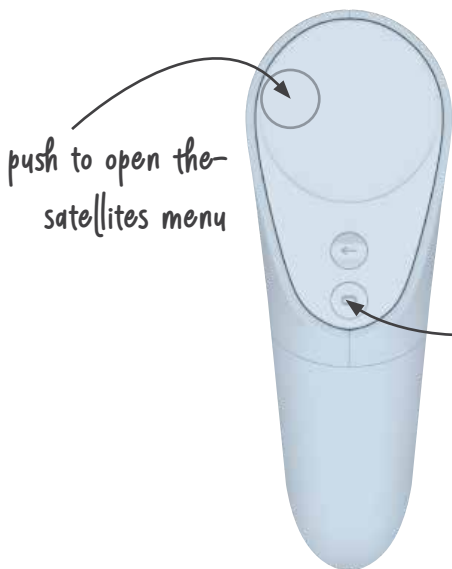
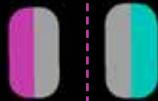
Figure 5.12 (next page, above) : *Space Debris interface*
Figure 5.13 (next page, down) : *Oculus Go controller*

-  SPACE DEBRIS
-  GEO
-  DEFUNCT
-  GPS
-  ROCKETS
-  MEO
-  LEO

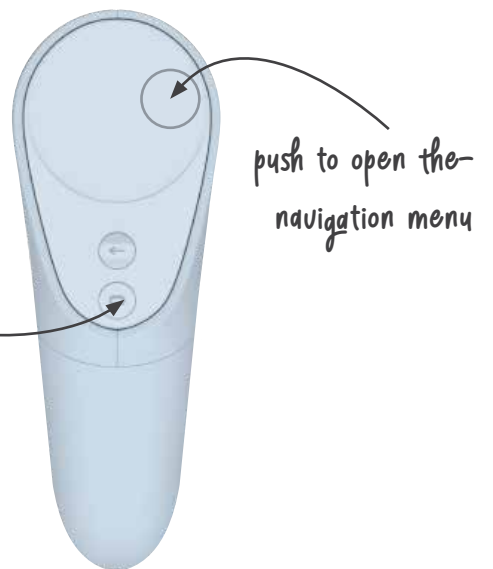
SATELLITES

-  MOVE
-  RESET POSITION
-  ZOOM
-  COLORS
-  GEO TRAJ
-  GPS TRAJ
-  MEO TRAJ
-  LEO TRAJ

VISUALIZATION



TOGGLE MENU

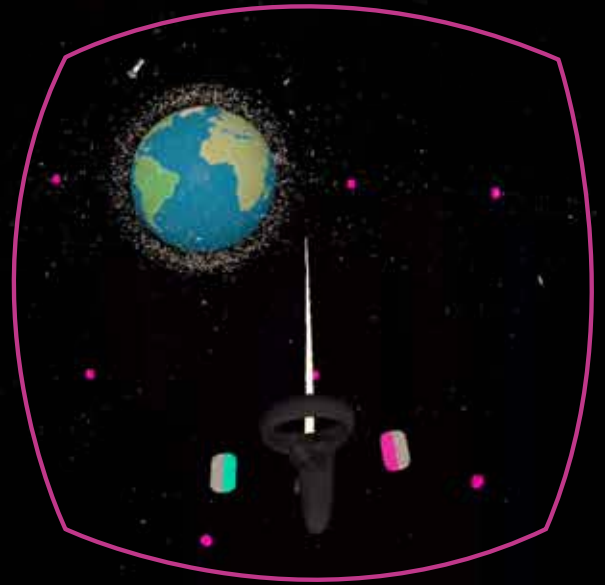


This design solution was working and was approved by students and teachers. The only persistent problem was on icon, texture and text resolution, they were too thin and detailed for Oculus Go resolution. The last version of the application has more clear icons, thick text and simplified texture. It was tested and validated during MeetMeTonight; the sample of users was non-homogeneous but all the participant taken into consideration were young guys in between 15 and 30 years old without knowledge in Aerospace Engineering according to the user target of the application.

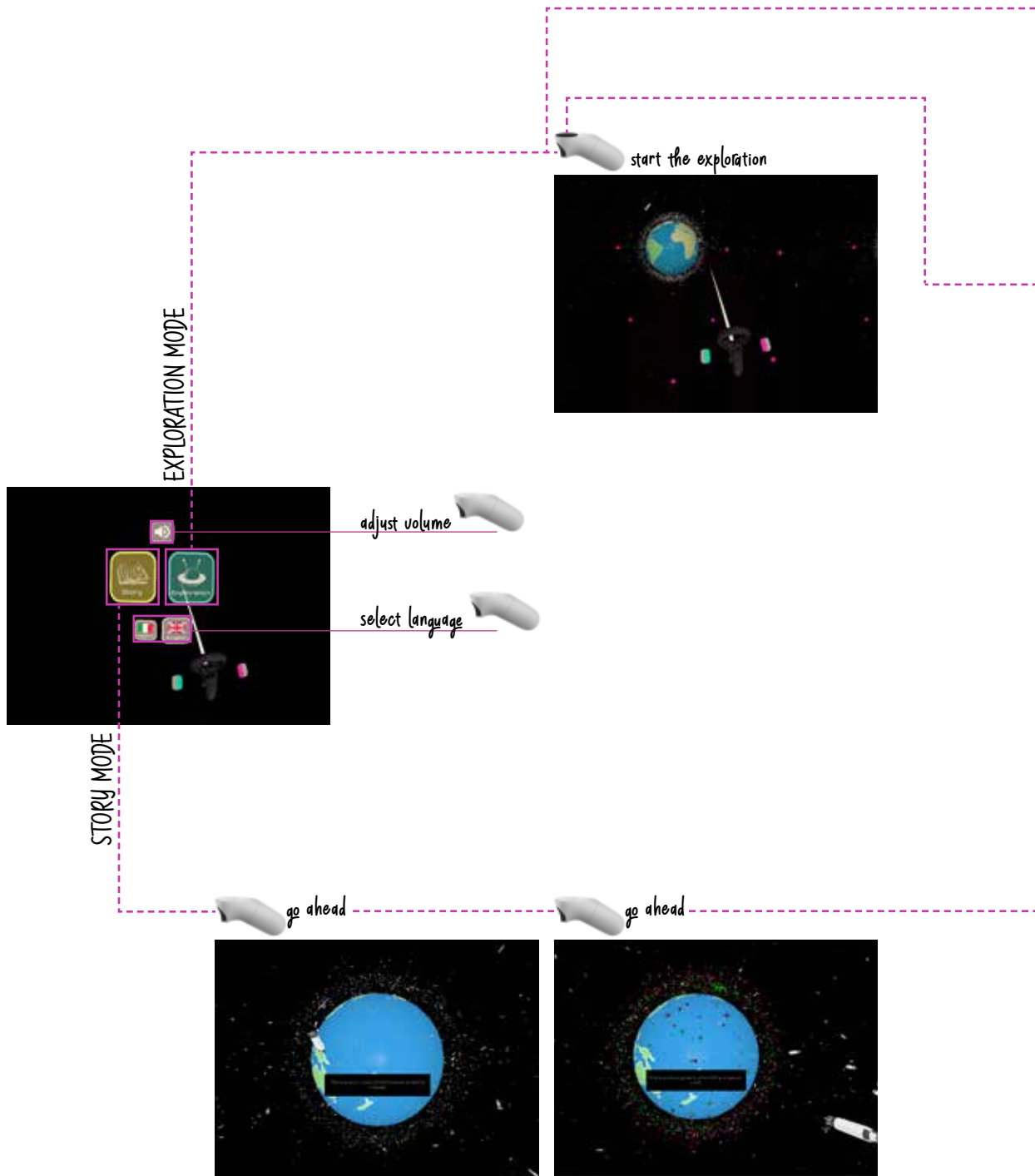


Figure 5.14 (above) : *Icon evolution*

Figure 5.15 (next page) : *Final version of Space Debris VR*



5.8 Flowchart

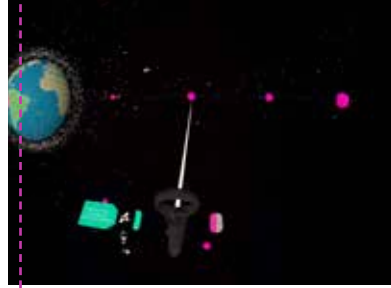




toggle satellites



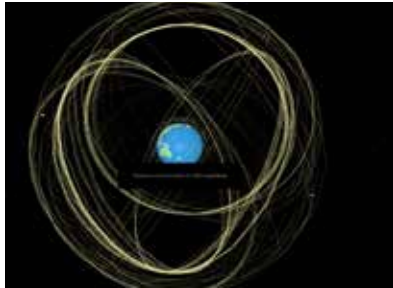
teleportation



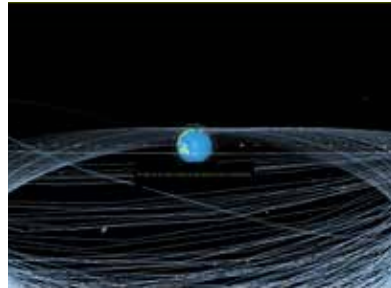
change visualization



go ahead



go ahead



5.9 Principle of Human Virtual Interaction

As explained the development of Space Debris followed the double diamond design process and the project has undergone many iterations.

The difficulty in designing in virtual experience is that what you can imagine or sketch is always different when you build the scene, prototyping in VR is fundamental to understand dimension, position and contrast of elements. Every version of the app is the result of a lot of test and discussion.

This process provides reflections and awareness that were explained in the fourth chapter.

The fundamentals of User Experience in Virtual Reality applied in Space Debris are:



Meaningful interface

To solve the problem about menu dimension was fundamental find a simple and intuitive way, to sum up, all the information needed from the user to complete the exploration. The ferrule ideas comes from image research on space exploration. Starting from the idea to integrate a spacesuit and the need to compress the menu the rotating gear was the most functional and meaningful solution.



Intuitive tools

Almost all the elements of the experience are satellites, it does not consist of a simple visual differentiation, it needs to help the user to the identification and to distinguish their function and trajectory.

We shape them differently and we organise the interface in the simplest and non invasive way to simplify the identification and the interaction during the experience with a wearable system.



Gesture consistency

Oculus Go controller has few buttons and it is fundamental to give a precise meaning to every type of action of the user. Having three types of a button - trigger, touch surface and back button - it is not a problem because in 2019 user are not skilled with VR controller and a huge number of gesture, in

general, provide confusion. It is better to reduce the number of interaction and give consistency to each one. For this reason, to interact with Space Debris scene it is enough to push the touch surface up and down to rotate the ferrule and use the trigger to select and object, activate and deactivate object and teleporting.

Motion sickness



To avoid the problem of locomotion and vertigo in virtual reality, we created some defined points of teleportation that the student can point to with the controller to move the point of view to that precise position. Free-floating navigation in the scene was eliminated to reduce the possibility of losing the user in the scene and was essential to prevent motion sickness.

Field of vision



The user has an external point of view of the earth, and the rotating menu is in the content zone. The user does not have to rotate their head or physically move their body. They can enjoy the experience standing or sitting. All the elements of the experience were designed following the ergonomic rules for virtual reality. In this way, the user will find all the information they need to follow the story and to explore space at their fingertips.

Width text block



As already described in detail, we faced a lot of problems with the width of the menu. This was the biggest problem encountered in the design phase and it provided the opportunity to find a different solution for the interface of a virtual experience.

Density of information



This problem has already been addressed in the design process description and in the previous point. The double ferrule was the solution for the app architecture to help the user in the interface navigation.



Contrast

Icons and texts have been tested and designed a lot of time because of the contrast problem. This problem was amplified because of the Oculus Go resolution but at the end, all the people that tested the experience were satisfied by their efficiency and clarity.

5.10 Validations

The preliminary evaluation of Space Debris VR was performed during MeetMeTonight 2018, a dissemination event open to the public, and the second was done during a closed event for journalists, start-up companies and people from the Italian Ministry of Economic Development (MiSE).

The two qualitative evaluation sessions were conducted by developers. At this point, interactions and interfaces had not been designed. Visitors tested the application for around 10 minutes. The problems encountered were all related in user orientation inside the application. People tended to pay almost no attention to interactive elements. They skipped the tutorial part, moving directly to the exploration. Menu navigation provided a lot of problems, and the menu buttons were unclear to people with no background knowledge of space debris. The teams of developers understood that people with little experience in virtual reality (VR), or gaming in general, had problems using the controller and the laser pointer.

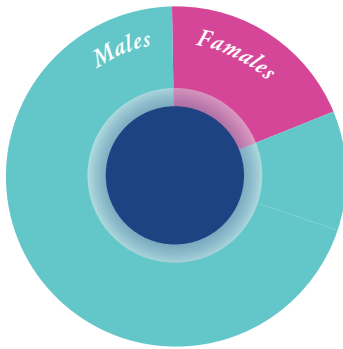


Figure 5.16 : *Space Debris first version*, developed by Erica Stella.

The second evaluation was performed at GameLab with Computer Engineering and Design Master students attending the Video Game Design and Programming course at Politecnico of Milano. Here the sample was familiar with game controllers and some of them already had experienced Virtual Reality. The experience lasted for around 15 minutes and the users evaluated the application through an online form survey.

Questionnaire results

Gender



Was easy moving in the virtual environment?



Was easy activate commands in the virtual environment was easy?

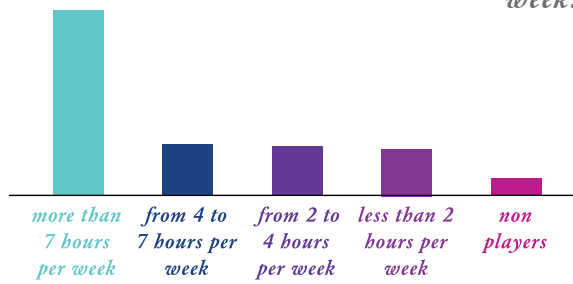


Age
19-32 y.o.

I understood immediatly what I could do in the virtual environment?



How many hours do you play video games every week?



No previous knowledge about Space debris

Usability

Users need few minutes to understand how to interact with the scene

Usability of the device



Usability of the 3D environment



UI



Tutorial is needed before exploration

Problems with

teleportation

This kind of experience enrich traditional university!



Suggestions

navigation status informations

introduce free navigation mode

increase contrast

insert more technical information

The third evaluation was proposed during Digital Week in March 2019, in collaboration with Vodafone Italia and aimed to show the benefits of 5G through the use of virtual devices. The sample of user was not uniform. They filled out the same online survey given to the design and programming students. The application was evaluated positively, but no relevant suggestions or criticisms emerged. We considered the results of this evaluation session not relevant for the development of the application.

The final evaluation was carried out during MeetMeTonight. During this event, users were younger, between 13 and 30 years old. This was considered really positive because the application was tested by the real target audience: the Alpha generation. Users interacted with the final version of the application. Between March and September, the ferrule menu navigation was designed and developed. The questionnaires reported really positive result. Space Debris VR was clear and simple to use for people with different backgrounds. The navigation was considered simple and the UI clear. People were involved and pleasantly affected by the application. Some users suggested to increase the text size and found some bugs in the ferrule's rotation.

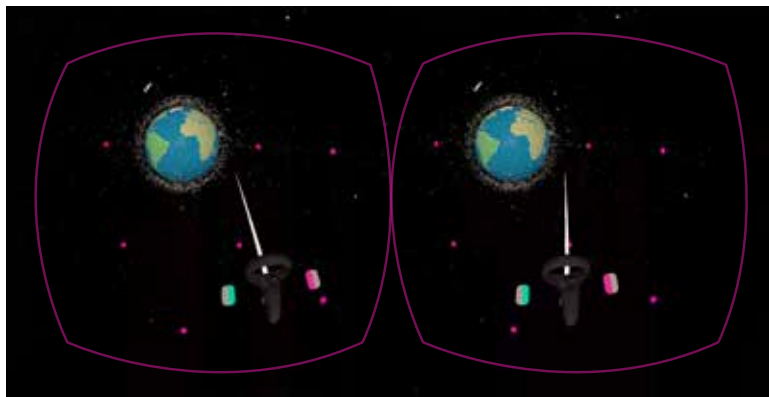


Figure 5.17 : *Space Debris VR*, screen final version

5.11 Space Debris VR Conclusion

Space Debris VR is an educational exploration of the earth for Oculus Go to help students in the first year of aerospace engineering understand the quantity and the behavior of space debris.

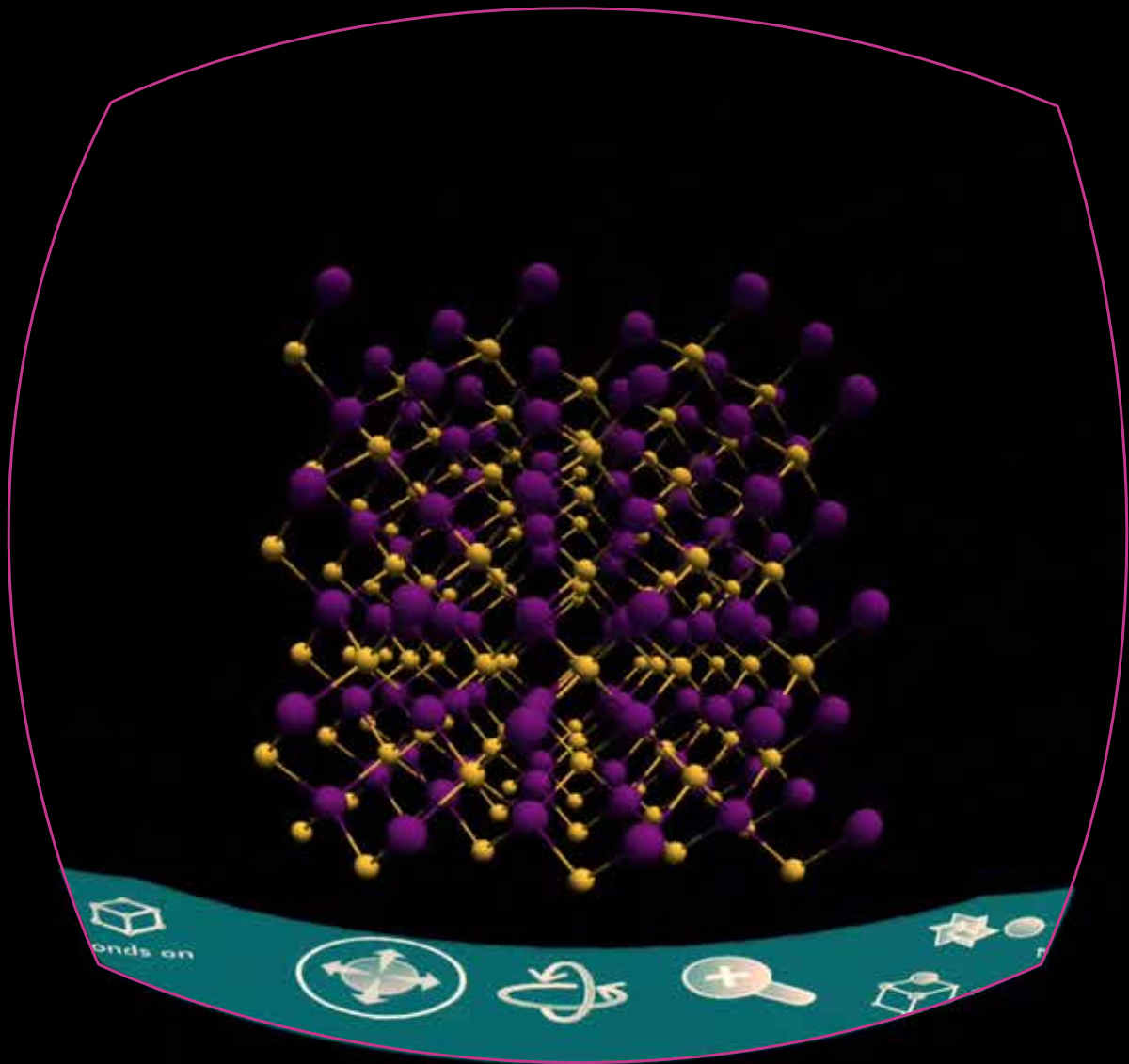
It was a very interesting process. All the decisions were made as a group, following the design process and the “Instructional design theoretical framework of VR based learning environment” of Chen, Toh & Wan. After the design challenge evaluation, the development of the value proposition and the analysis of the user target and scenario, we were able to overcome one engineering and one design challenge.

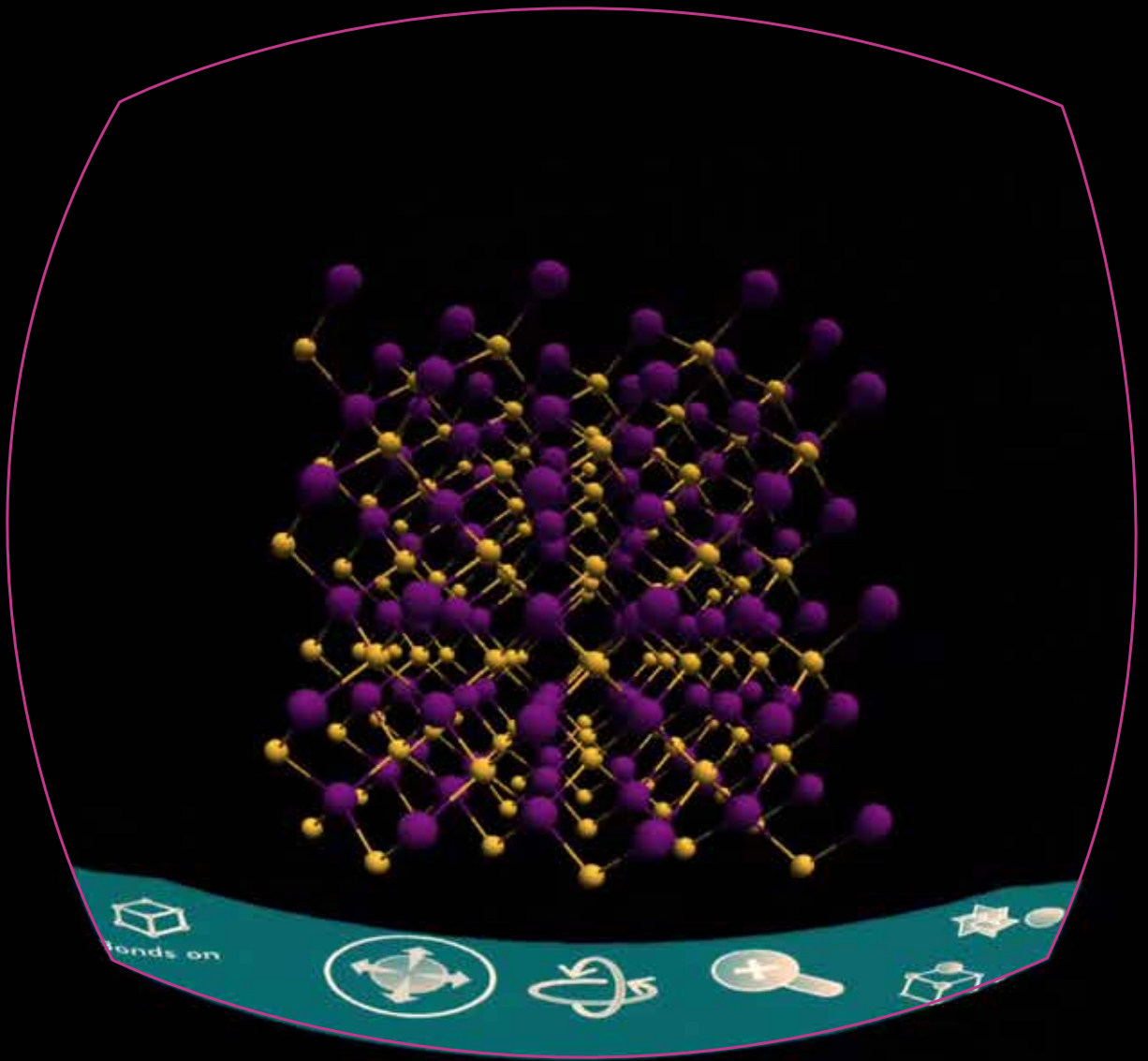
From a design point of view, the most interesting challenges concerned the informational architecture and the design of the interface. Through the development of a lot of virtual prototypes tested and validated by users with different backgrounds that, in some events, were precisely selected by our team and in others were random, we arrived at the final solution.

It was an interesting experiment that led to the design of a rotating interface that synthesizes clearly all the elements of navigation, helping the user to orient themselves with the menu and not to get lost in the immense space of the virtual scene. The application, designed and developed in collaboration with DEIB, was an important opportunity to evaluate, test and validate the fundamentals of user experience in virtual reality described in this thesis.

Virtual reality means involving people in an immersive experience, stimulating memory, senses and reactions impossible to reach with traditional learning tools.

Future research directions include the opportunity to translate the project on Oculus Quest - 6 DOF, stand-alone device, changing the headset from 3 DOF to 6 DOF will provide different constraints, a different interface and different interaction possibilities. This will completely change the user experience.





Chapter 6

CRISTALLOGRAPHY VR

6. Crystallography VR

This experience has been designed in collaboration with GameLab of the Computer Engineering Department of Politecnico of Milan. The implementation of the application was carried out by Isabella Agosti, graduated student of Computer Engineering and Erica Stella, researcher at GameLab.

6.1 Introduction to Crystallography VR

Crystallography VR is an educational virtual reality application for physical engineering. It is an aid for teachers in class and for students to visualize three-dimensional crystals, study their shape and understand their morphology, seeing and manipulating them closely. The interactive lesson can be used by students and teachers locally in class and remotely at home with the option to choose free exploration or to watch a recorded lesson on the molecules.

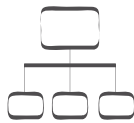
This topic was suggested by the department of Physics Engineering at Politecnico of Milan. Teachers helped us to identify the topic, the requirements and the structure of the overall experience and they followed us in the validation phase to understand the potential, as well as the shortcomings, of the application.

The aim of the collaboration of GameLab with an interaction design student was the study of the user experience, the organization of the content and the design of a simple and immediate interface with a lot of information and commands to maintain under control.

6.2 Brief: Objectives and Requirements



Design interaction and User Experience of a lesson available in different modes, shared class lesson, recorded lesson and crystals free manipulation



Organize a library of crystals and synthesize in a control panel all the different visualization and the inherent characteristics of all of 16 different molecules

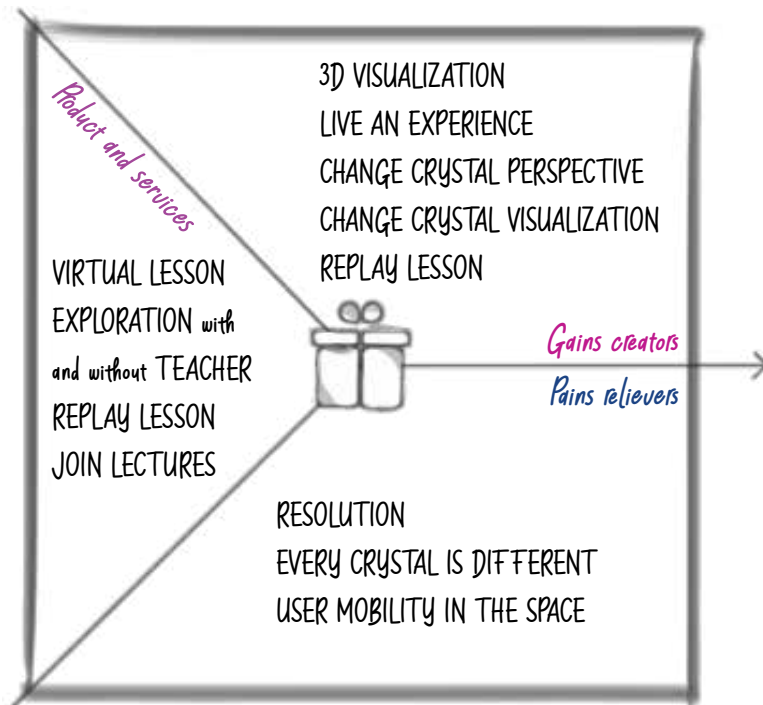
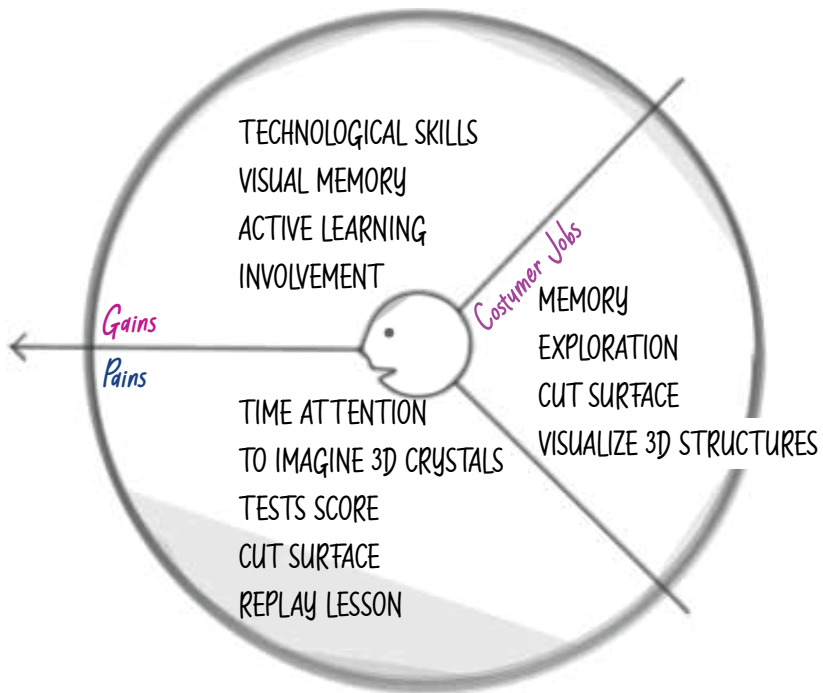


Design a diegetic and intuitive interface to allow students and teacher to experience at the same time and in the same room a completely immersive experience

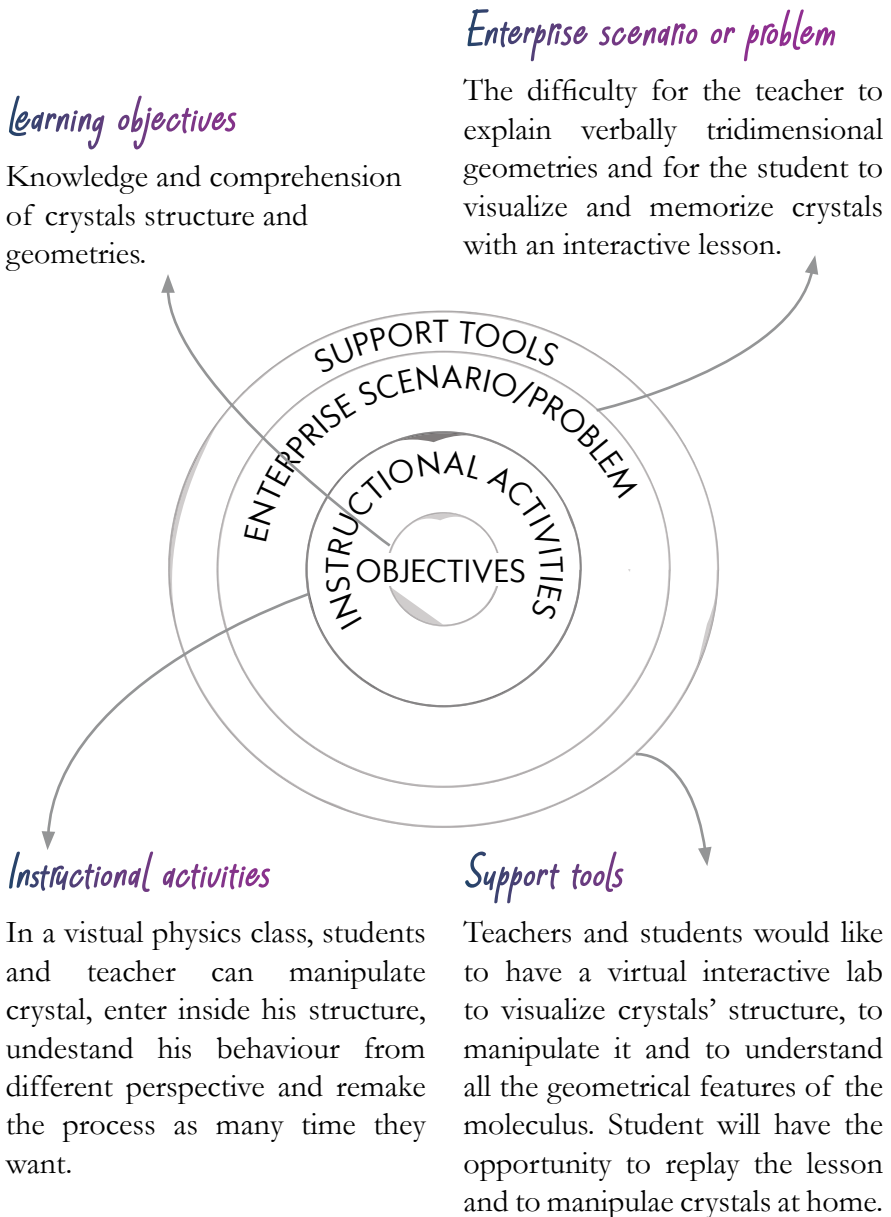


It had to support different *Virtual Reality headsets*, and it had to runs smoothly on wireless, low-cost hardware with limited processing power. The possibility of being able to carry out the experience also in Augmented Reality, is not excluded

6.3.1 Value Proposition



6.3.2 Macro-Strategy



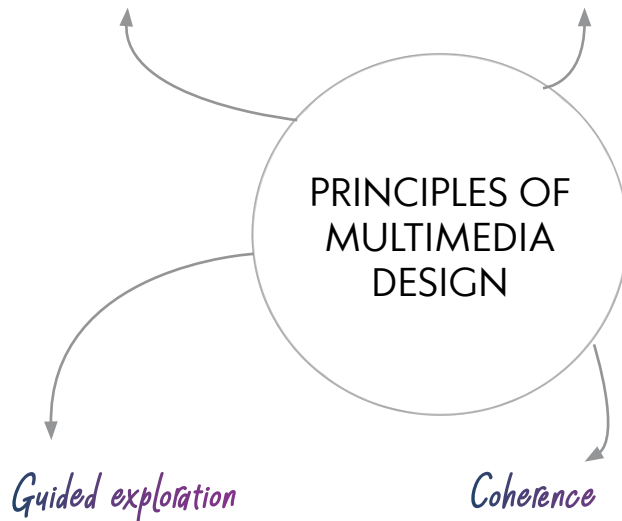
6.3.3 Micro-Strategy

Spatial contiguity

Imagine to become smaller and smaller until you have the chance to see the molecular structure of the objects you use every day. Would you like to hold crystals in your hand and manipulate them?

Modality

Lesson has been transformed in a crystallography lab where you can choose crystals and analyze them as you are in a shop.



Guided exploration

Crystals characteristics are feature that they can activate and deactivate as many time they want until they are sure that they have understood the concept, testing all types of visualization means verifying that they have fully understood the three-dimensional structure of the molecule.

Coherence

Imagine crystals as colored geometrical structure that you can hold in hand, cut and visualize with different characteristics and details.



William Teach

*47 y.o. / Milan
Physics Engineering teacher*

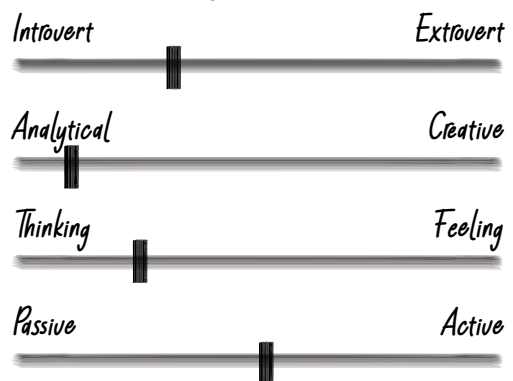
*"We are immerse in physics,
why is so complex imagine it?"*

ABOUT

William Teach is a teacher of Physics engineering at Politecnico of Milano. He needs an easy way to **explain** to his students' **crystals structures**, he has been teaching for 20 years and the concept of crystals **tridimensional visualization** is always the most complex to explain to his students.

He invested time every year to prepare a different lesson on this topic but every year **students failed** question on this topic.

PERSONALITY



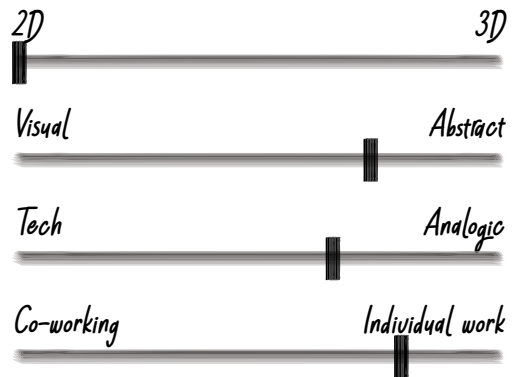
NEEDS

- Help student in visualize crystals
- Show crystals' properties and cuts
- Record lessons and crystals manipulation
- Help students to imagine the structure of objects around them

PAIN

- Represent tridimensional crystals on slides and blackboards
- Low results of his students in the testes
- Every crystals have different structures and behaviour
- The complexity of web application for crystals visualization

WORK DESCRIPTION



PREFERRED CHANNEL





Hannah See

*20 y.o. | Milan
Students of Physics Engineering*

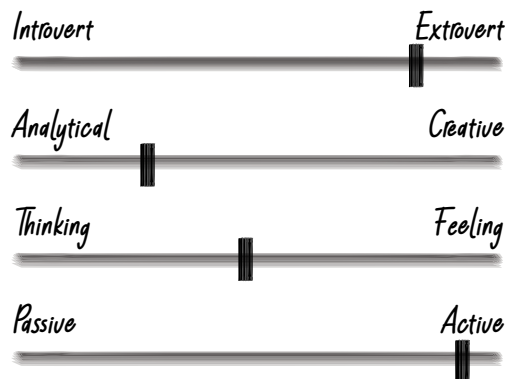
"The best way to remember a concept is to see it."

ABOUT

Hannah is a Physics Engineering student, she is one of the best of his course. She spends every afternoon at the library of the university studying with his colleagues. She has a **visual intelligence**, a **photographers memory** and is really good in study theory with the support of **mind map**

She failed the exam of Physics with professor Teach because he asked to draw crystals cuts even if he did not explain this topic.

PERSONALITY



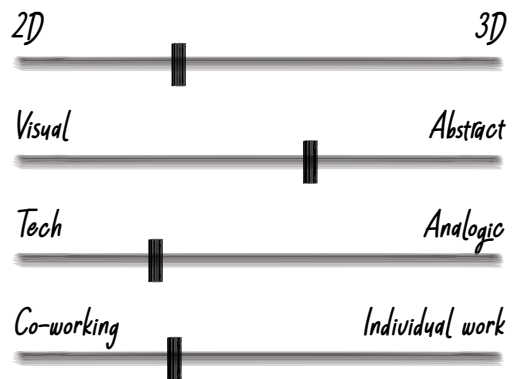
NEEDS

- Visualize abstract concepts
- Had the possibility to slice objects and see structures of different materials
- Keeps its school media

PAIN

- Remember all the characteristics of every crystals
- Memorize teacher's manipulation of crystal
- Web application suggested from his teacher is uncomprehensible

WORK DESCRIPTION



PREFERRED CHANNEL



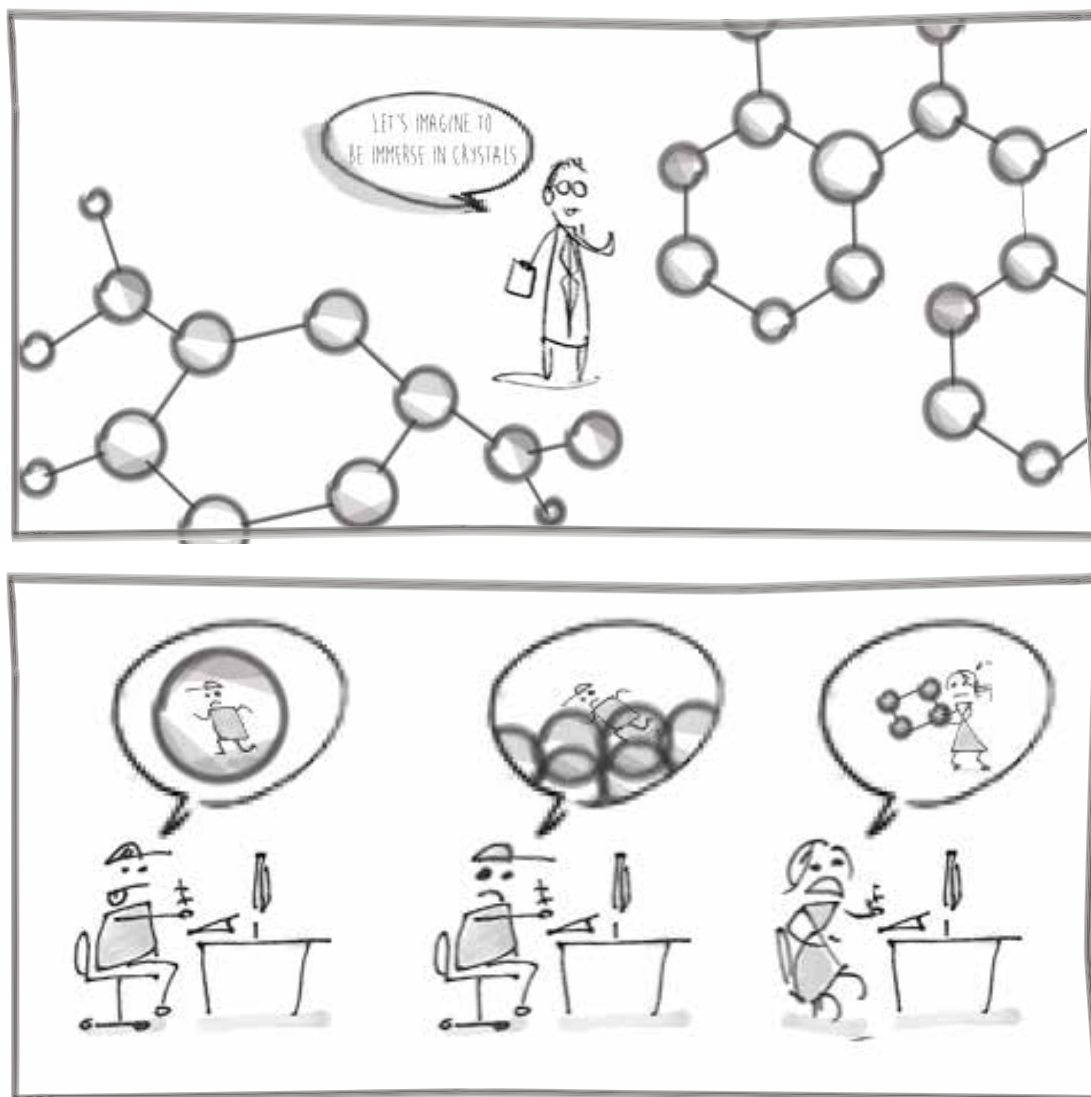


Figure 6.1 : Sketch scenario Crystallography lesson

6.4.2 Scenario

For physics engineering teachers, it is difficult to explain crystals because it is important to visualize them from different perspectives to understand their structure. Students have a hard time imagining crystals because there are a lot of small details to remember.

Teachers and students would like to have an interactive lesson on this topic. Students would like to see the lessons more than one time to remember the teacher's manipulation of the crystals, and the teacher would like to give to the students the possibility to freely manipulate crystals.

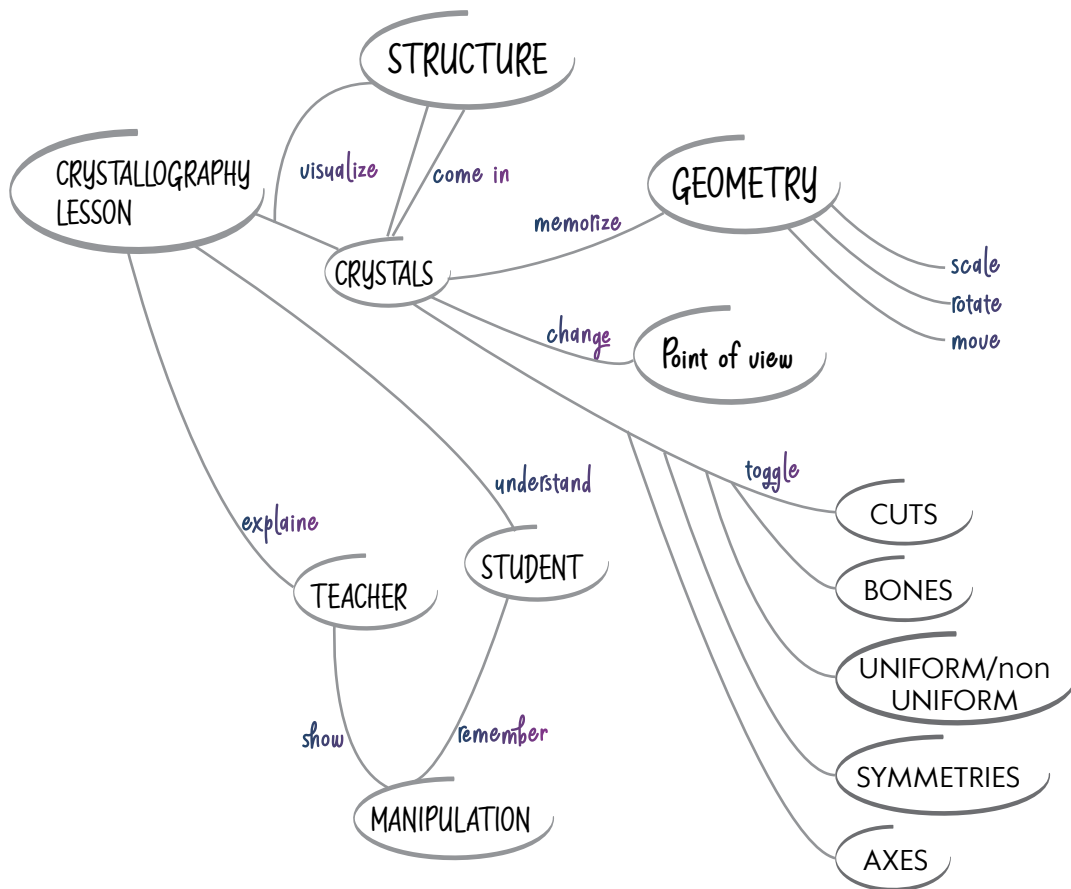
To imagine entering an object and seeing its crystalline structure around us is the objective of crystalline physics. It is really complex, but really helpful to visualize substances from a different perspective.

6.5.1 Ontology

Topic and concept of the experience were been decided in collaboration with “Solid State Physics” course teachers’. They suggested the topic for the lesson and the type of manipulations. They listed 16 crystals and suggested us to refer to the Crystallography Open Database (COD).

They asked the possibility to have a support for their lessons and a tool for student to manipulate crystals.

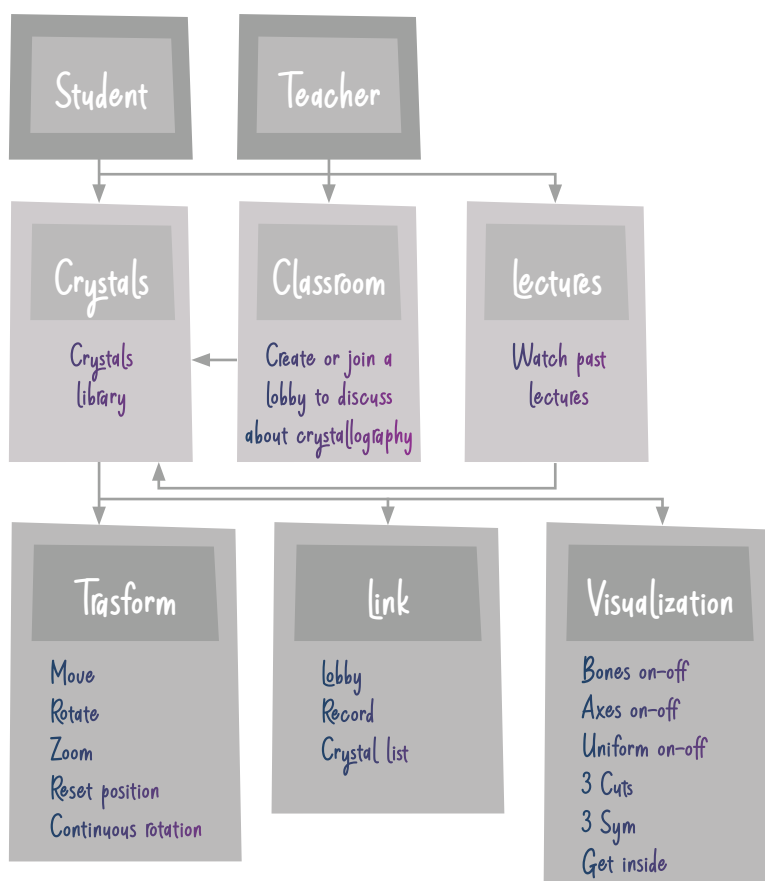
Jokingly, they expressed a desire: to be able to enter crystals structures.



6.5.2 Taxonomy

The experience is available in three different modes. Classroom mode allows professors to take crystallography lectures to a virtual environment and students to follow live teacher explanations. Lecture mode provides tools for professors to record lessons in class or at home so that students can review explanations remotely at any time. Free exploration mode allows students to interact with crystal molecules. In this way, they can have the opportunity to reproduce teacher manipulations.

All the modes place the user in front of a control panel with a lot of commands to change crystal visualizations. The design of this control panel was the most important and challenging point from an interaction point of view. For this reason, we are going to explain the evolution of these elements to demonstrate how the use of the fundamentals of user experience in virtual reality can simplify the design of a virtual interface.



6.6 Physical Interaction

We decided to maintain the experience as much simple as possible. Since the first meeting was clear that design this interface would have been challenging. Physics teachers listed a lot of visualization and this immediately established a medium-high level of interaction for a user without virtual background. Potentially, this experience will be part of a set of lectures for Politecnico of Milano, for this reason, we decided to maintain the same interaction of Space Debrice VR, to reduce the level of learning and maintain all the interactions on the visual interface into the virtual environment.

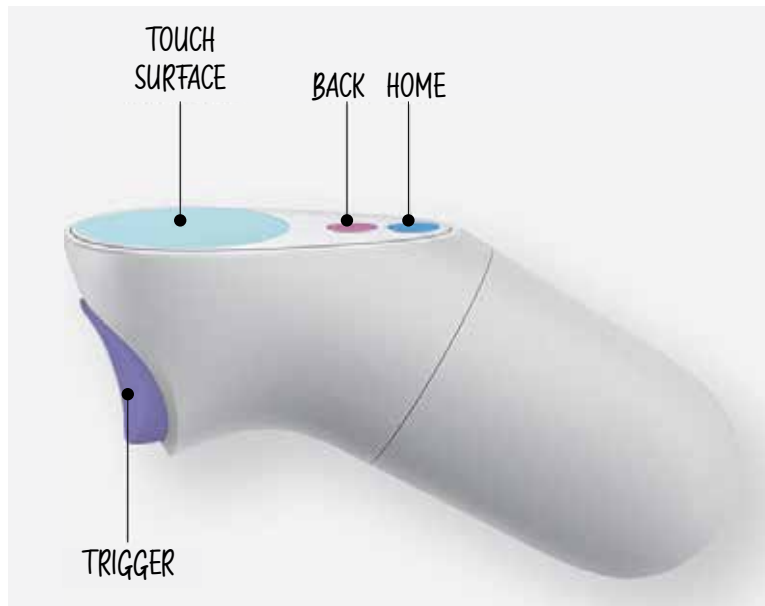


Figure 6.2 : Oculus Go controller

- Select
- Increase/decrease
- Exit the "into the crystal" mode

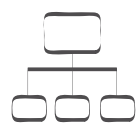
From problems to new goals

The project started with a first prototype that aimed to have a working scene with a list of buttons. When the coding part was almost developed and working, the identification of interaction problems began.

We moved away from the initial objectives and requirements extrapolated from the brief and we defined 4 different objectives focused on interaction to improve the user experience.



Give the user the impression of becoming smaller and smaller until they have the chance to see the molecular structure of the objects, holding crystals in their hands and manipulating them.



Length of the menu and number of commands. The difficulty lay in the fact that all the objects to be selected through the trigger had to be at the same navigation level.



Coherent organization of the UI to manage buttons with different types of interactions. With a virtual interface, it is helpful to align gestures (gesture consistency).



Find a way to avoid movements in the space. Imagine having a class full of students who are completely blind because of the glasses

6.7 Design Evolution

The first prototype was working from a coding point of view but was the earlier version from a design point of view. The aim of this build was to have a working scene with a list of buttons. Step by step interface and interaction were implemented and refined. In the first iteration, all the elements were included to try visualization, functions and to begin to become aware of the actions to be carried in the virtual space. In this way, we could start to design in a working environment and we could try step by step every type of improvement. We were conscious about the fact that the first image was completely against every type of virtual UX rules and the number meshes were voluntarily low to have the lightest scene possible.

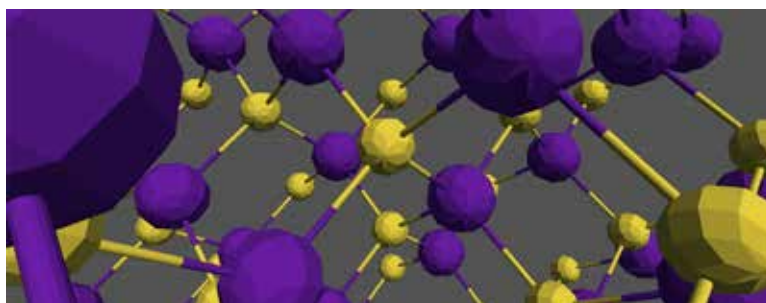
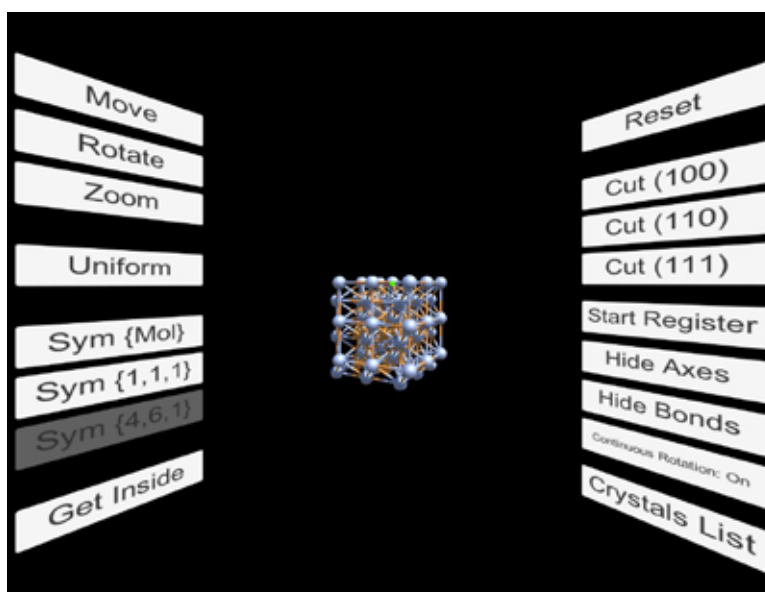


Figure 6.3 : *Crystallography VR interface*, developed by Isabella Agosti
Figure 6.4 : *Crystallography VR Get Inside*, developed by Isabella Agosti

What was clear from the beginning was the rounded platform behind the user (4th image). This was the solution to prevent the user from moving around the scene. We used a principle of UX for virtual reality in an opposite way. We placed the user in the middle of black space on a platform, in this way they would never go outside this confined space and it was working to avoid collisions of students who were blind in the real world due to glasses. We rode this concept by positioning a desk in front of the student in order to have a diegetic interface, a sort of space control panel with all the command buttons on it. This type of interface was the best solution to place all the buttons in a confined space in order to create a hierarchy and to keep the interaction through the controller as simple as possible.

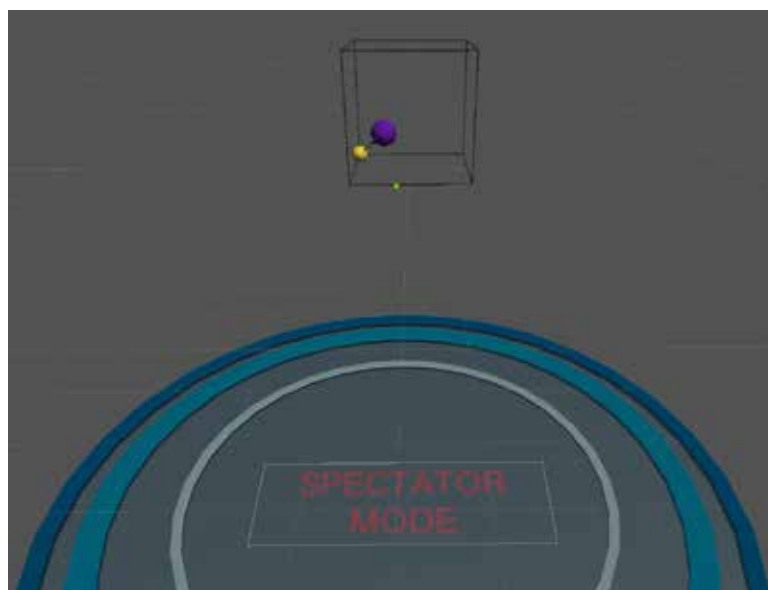


Figure 6.5 : *Crystallography VR user position*

With the second prototype, we arrived at a good level of interaction, but the UI coherence and the choreography of the application were not satisfying. We had problems with the size of the desk. It needed to contain a lot of buttons in a reasonable space. In all the different proposals either the desk was too big and invasive or the icons were too small and unreadable through Oculus Go. Another problem concerned the types of micro-interactions. There was a slider, a switch and buttons, each with a different importance.

Whit the second prototype we arrived at a good level of interaction but the UI coherence and the choreography of the application were not satisfying as. We had problems with the dimension of the desk, it should contain a lot of buttons in a reasonable space. In all the different proposal or the desk was too big and invasive or the icons were too small and unreadable through Oculus Go. Another problem was about the type of micro-interactions, there were a slider, switch and buttons with different importance.

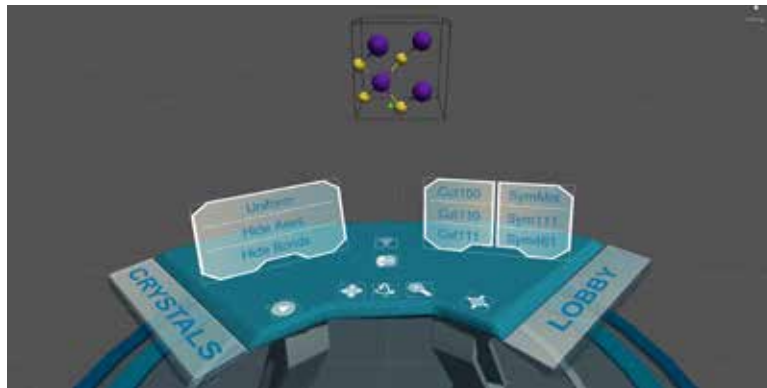


Figure 6.6 : *Crystallography VR second version*

This version has been build May 2019, it was working and was validated from Physics teachers but we were not satisfied with it. The image 5 is in the first point of view. All the action were clearly organized but the dimension of the desk was too invasive, the icons were not labelled and it was clear only for Physics and people already aware of the concept of crystallography. It was not the best solution for a student in the first year.

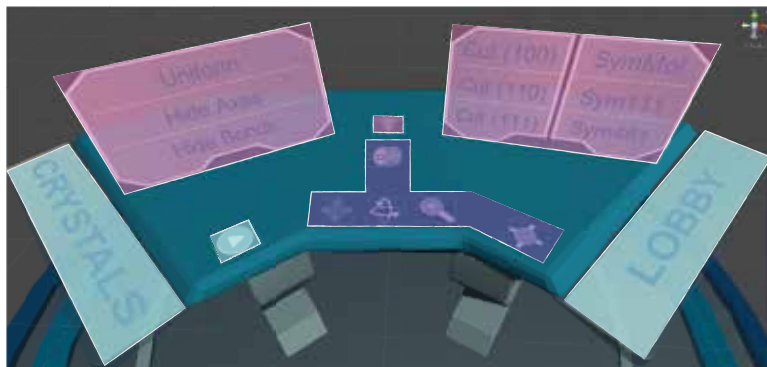


Figure 6.6 : *Crystallography VR interface*

■ Visualizations
 ■ Transformations
 ■ Links

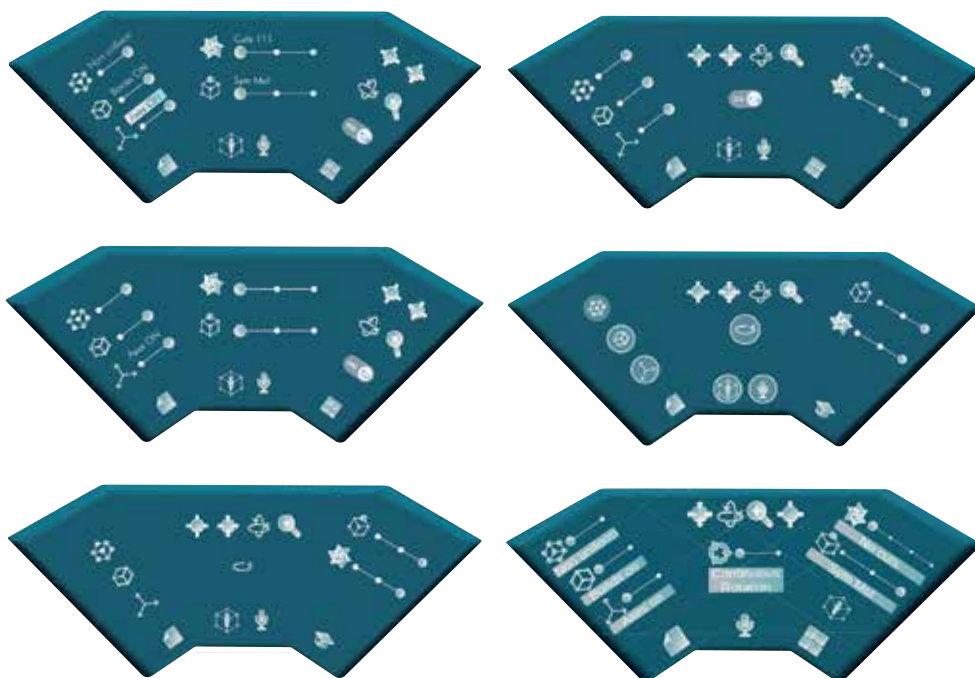


Figure 6.7 : *Crystallography VR interface evolution*

These are different versions of the desk. They appear similar on paper. It seemed to be a problem of aesthetics. But in virtual environment, every small change has repercussions on technical details, such as resolution and field of view, and on perception. The last desk (image 6) technically was perfect for Oculus Go, but the working space was too chaotic, and this was a problem because it could confuse the user. We needed to imagine this interface as a desk. Let's imagine the first day in a new office, being greeted by a messy desk. It is certainly not pleasant or comfortable. On the other side, the penultimate version (image 5) is clear and in order, but it is hard to understand the function of some buttons and feedback was not clear.

Anyway, all those versions were really helpful in arriving at the final solution that is clear for physical engineers and for people completely outside of this field. It is simple to use, and the UI is consistent with the initial requirements.

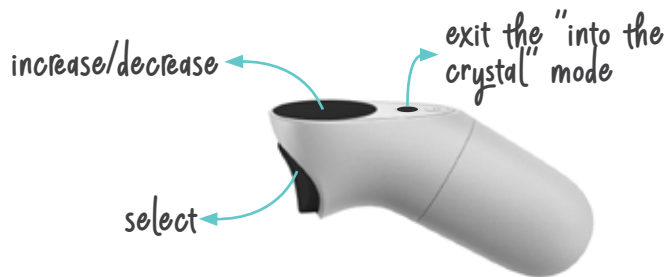
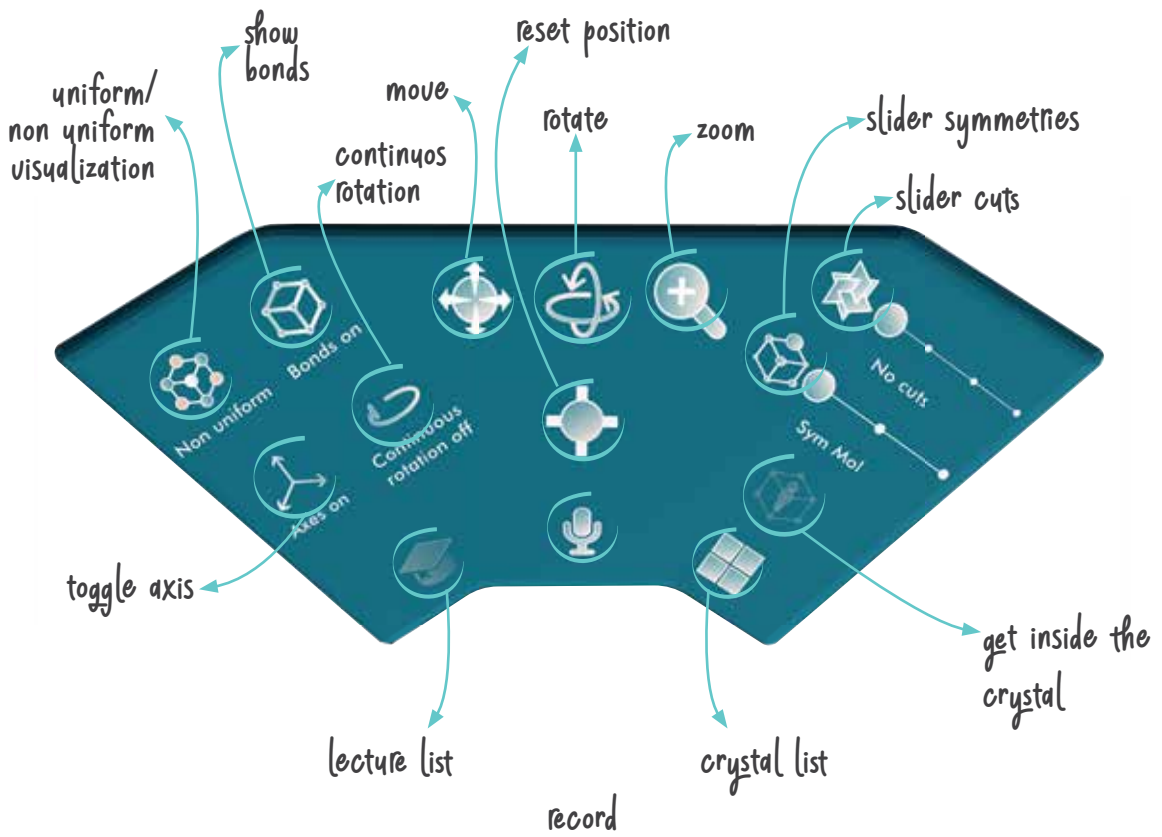
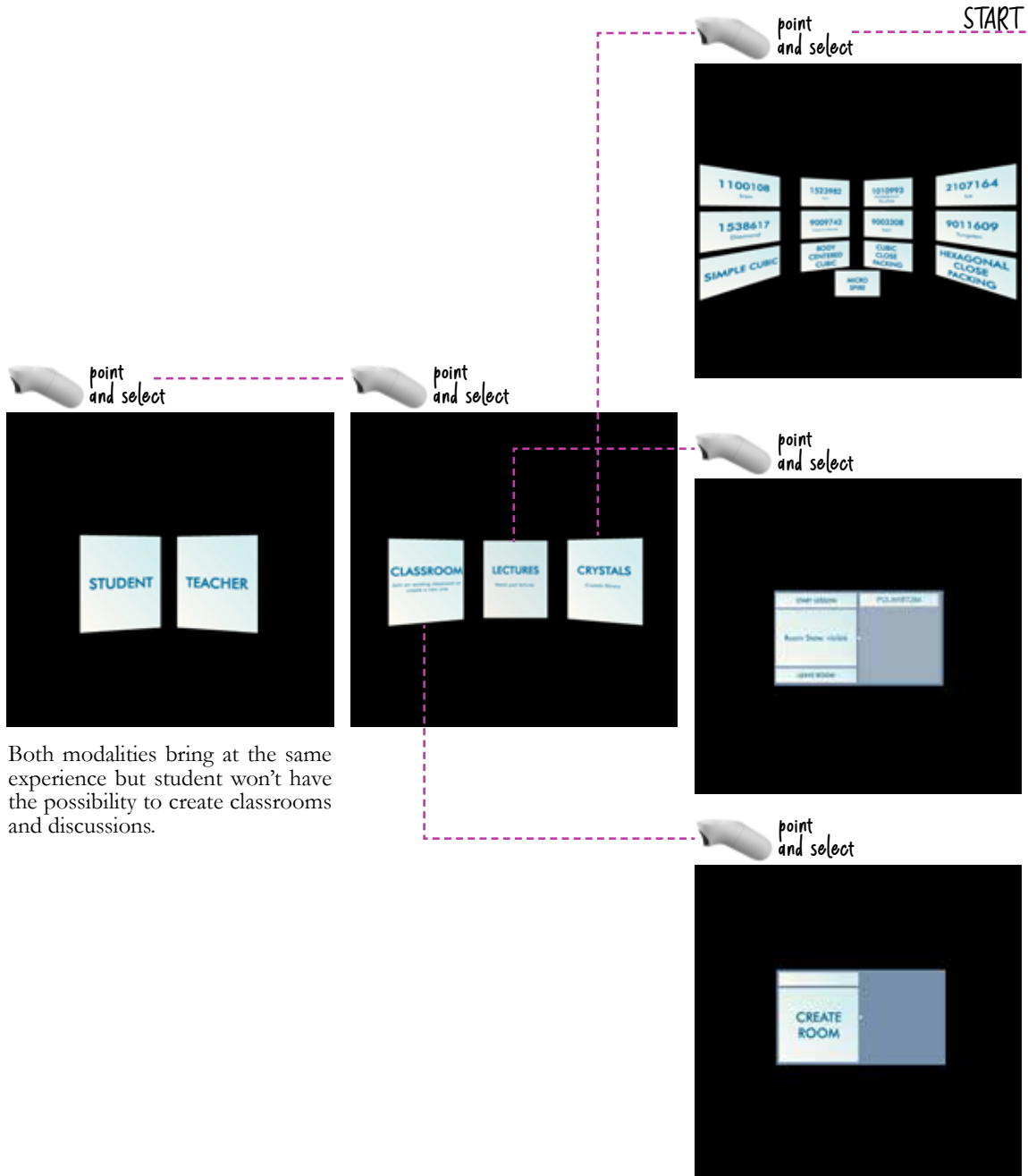


Figure 6.8 (above) : *Crystallography VR buttons description*

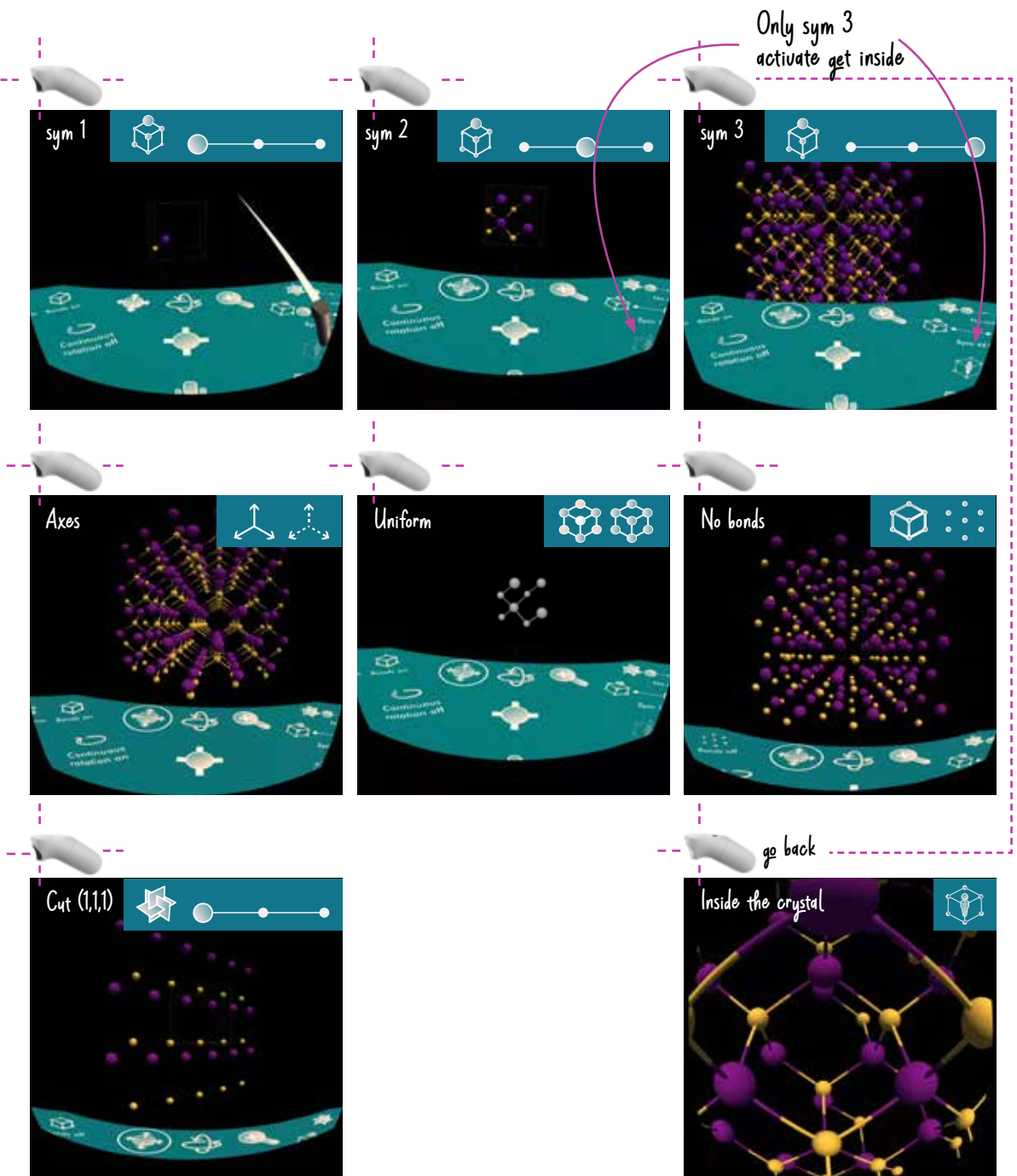
Figure 6.9 (next page) : *Crystallography VR interface final version*



6.8 Flowchart



Both modalities bring at the same experience but student won't have the possibility to create classrooms and discussions.



Exept **GET INSIDE**, all the visualization and manipulation buttons are goggled in every moment of the experience.
User has the opportunity to combine different commands.

6.9 Principle of Human Virtual Interaction

As explained the development of Space Debris followed the double diamond design process and the project has undergone many iterations with particular attention on the UI of the diegetic interface: the desk.

Crystallography lesson VR was a perfect challenge from a design point of view. There are a lot of elements to maintain under control and we faced a lot of contradictions that we tried to manage through compromise. Every version of the app is the result of a lot of test and discussion.

The fundamentals of User Experience in Virtual Reality applied in Space Debris are:



Virtual Body

The first problem regarding the design of the experience was the fact that a group of people will use glasses for virtual reality in the same room. For this reason, was important to avoid movements of the users. The solution was the use of a round platform and a desk to block user movements. In this way standing in front of the table the user will be suspended on a platform in the middle of the dark scene. We used in a positive way the fear of falling to block the user. However, this solution does not provide fear or sense of vertigo in the user.



Gesture consistency

As explained for Space Debris VR, we reduce as much as possible the touch interaction because during some test people were not comfortable in using a lot of buttons without seeing them. For this reason, to interact in Crystallography class it is enough to push the trigger to select buttons and slider and to push the touch surface to regulate transformations. For the same reason we reduced to slider and buttons all the micro-interactions.

Meaningful interface



We spent a lot of time on the icon design. The types of actions are really specific to this subject and, for this reason, it was not easy to find the most intuitive language of communication that kept in consideration resolution constraints. After different iterations, we arrived at a compromise, and the final design was successfully evaluated by physicists and students from other departments.

Suggestion (feedback)



As already explained, one of the most challenging parts of the UI was the choice of micro-interactions and the differentiation between active and inactive commands. In the end, we decided to use different icons for every state and visualization instead of highlighting the icons. It was disturbing and unclear because the only on/off button was for continuous rotation. For the other commands it was just confusing.

Curved design



This principle was used for the design of the initial menu and the crystals library to maintain the same distance from the user and the interface from every point of view.

Field of vision



This principle was important to establish the desk dimensions and position. The focus of the experience is the crystal, its properties and its visualization. The desk is an indispensable interface for manipulating the molecules and, for this reason, is positioned in the workspace and not in the content zone.



Distance

This principle, partially included in the FOV point, defined the distance of the elements of the scene according to human ergonomics. Following the same guidelines, the distance of the desk and the icons were placed to help the user to point the controller in a natural way and select the different buttons without difficulties.



Density of information

As widely described there was a huge study to define the quantity and the typology of information to place on the interface, to help the user in understanding intuitively at the UI.

6.10 Validation

The first prototype of Crystallography Class VR was proposed at Digital Week in March 2019 in collaboration with Vodafone Italia. This version of the app included only the Student Mode. Testers were able to move, rotate, and zoom the crystal in the scene and see its different representations based on the various symmetries. Interactions with the crystal were done through buttons placed in the environment

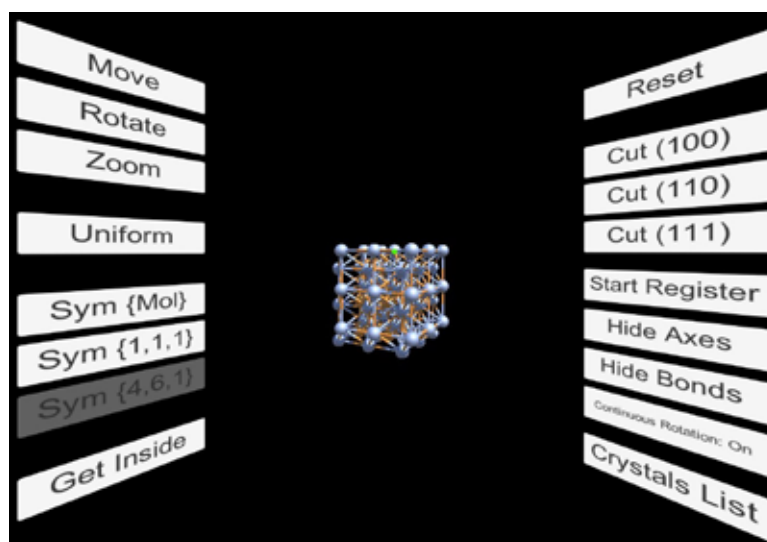


Figure 6.10 : *Crystallography VR*, First interface, developed by I. Agosti

The focus of this evaluation was the functionality of the app. The aim of this test was to understand if this application could be a real support for physics lessons. In the initial phase, the most important feedback was about the three-dimensional representation of the crystals, and the experience in general. This evaluation was purely qualitative. Testers did not complete a questionnaire. At this point, interactions were not designed at all. Testers were interviewed by developers. The interface was declared too invasive. Moving and zooming the crystal caused an overlap with the buttons in the scene and users were not able to click on them anymore.

The second prototype of Crystallography Class VR was proposed to teachers from the Department of Physics at Politecnico of Milan. We interviewed two professors about functionality and usability of the virtual experience. They requested some additional functionalities and asked for the possibility of standardizing the size and color of the crystal visualizations, hiding the axes and bonds and inspecting the

crystal from the inside.

Moreover, they wanted to be able to apply three different types of cuts on the molecule. Finally, they proposed twelve crystals they considered the most interesting to be presented in a virtual reality lesson on crystallography.

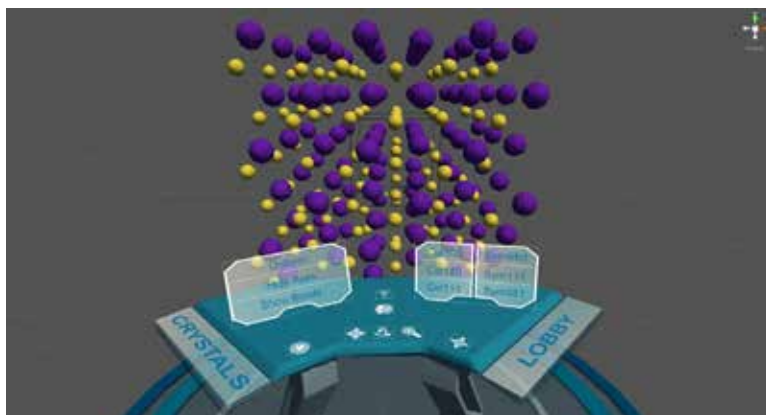


Figure 6.11 : *Crystallography VR , second version*

The third prototype was modified by adding all the functionalities requested during the initial evaluations.

It was proposed to some computer science students. After a brief explanation of the overall experience, describing its purpose and how to use the controller, they wore the headset and started the experience, simulating a lecture by showing them all the available functionalities.

Visitors used the application for about 15 minutes and, at the end, they were asked to fill out an online form to evaluate their experience.

The questionnaire results will be reported subsequently.

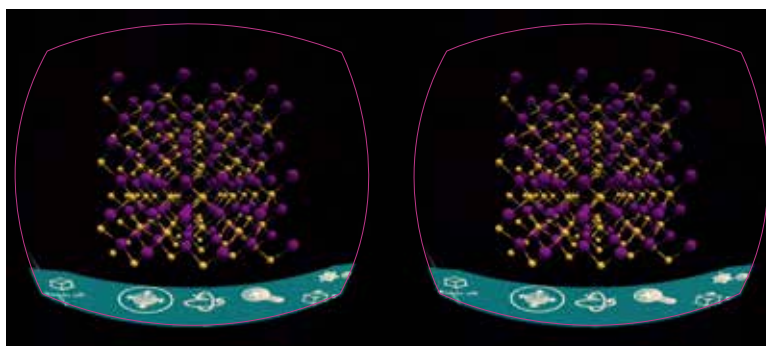
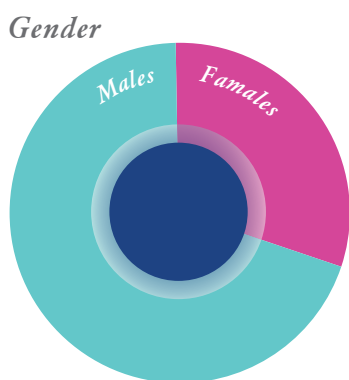


Figure 6.12 : *Crystallography VR , final version*

The validation of the final version of the app was proposed at MeetMeTonight in September 2019 with a qualitative purpose. At this event, the sample was not uniform. During the previous validation, the functionality of the experience was confirmed by students and teachers, so the non-uniformity of the testers was not a problem. In some cases, it was an added value because people with no expertise in physics understood all the interactions and the meaning of the UI.

The focus of the evaluation was the interaction of the application. The users criticized the size and the contrast of text, the desk was declared clear and simple to use, the experience was deemed pleasant, and the navigation was considered intuitive. No particular criticism emerged during the interviews

Questionnaire results of the third validation.



Age
18-30 y.o.

Was easy WMoving in the virtual environment?



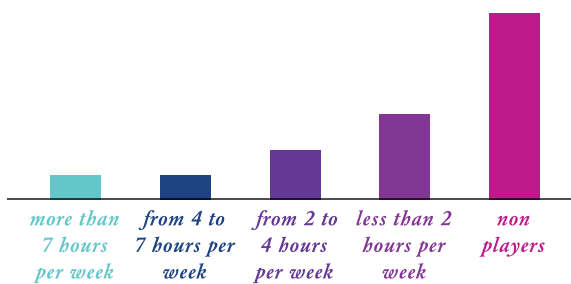
Was easy activate commands in the virtual environment was easy?



I understood immediatly what I could do in the virtual environment?



How many hours do you play video games every week?



No previous knowledge about cristallography

Usability

Very intuitive and comfortable

Usability of the device



Usability of the 3D environment



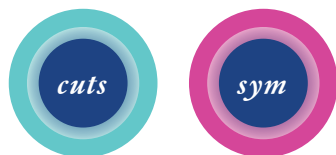
UI



Desk interface is easy to understand



Not clear



This kind of experience enrich traditional university!



*Problems
controller's trackpad
button to enter in the crystal
decrease light
insert crystals name on the desk*

6.11 Crystallography AR

The same app was developed in an Augmented Reality version for Hololens in order to eliminate the problem of movements in the space and to facilitate the fruition of a shared experience between teachers and a group of student.

For this reason, Crystallography Class AR has no lecture section and recorded lessons list, it is not possible to review the past lectures but it can help teachers and student during the in-class activity with a more powerful shared reflection on crystals. The design of the experience follows the Microsoft Hololens guidelines and was a translation of the Virtual experience. The interface is a panel with all the visualization buttons, manipulation is managed with the common bounding box of Hololens and the “get inside” function has been eliminated.

The user can positionate crystals and panel interface in the space in order to have the best fruition of the augmented object on the real environment.

This redesign was a really interesting experiment, it demonstrate how the level of immersion and the quantity of computer-generated elements could change the fruition of the same lesson on the same subject.

Figure 6.13: *Crystallography AR, Crystals menu*

Figure 6.14: *Crystallography AR, Symmetry 1*

Figure 6.15: *Crystallography AR, Symmetry 2*

Figure 6.16: *Crystallography AR, Symmetry 3*

Figure 6.17: *Crystallography AR, Without bones*

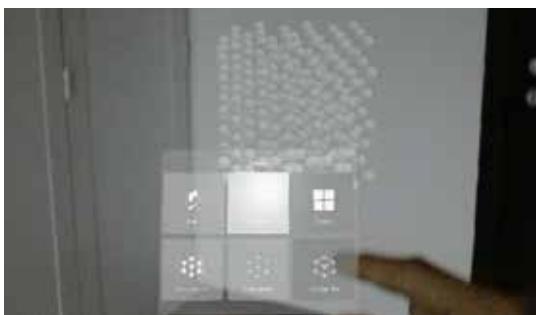
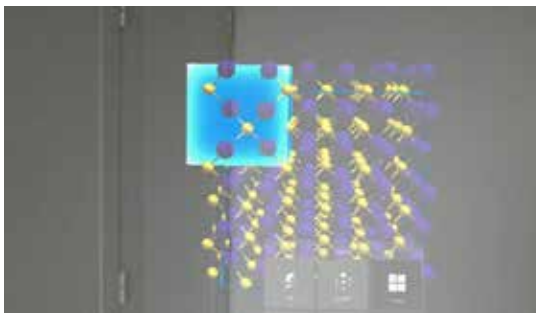
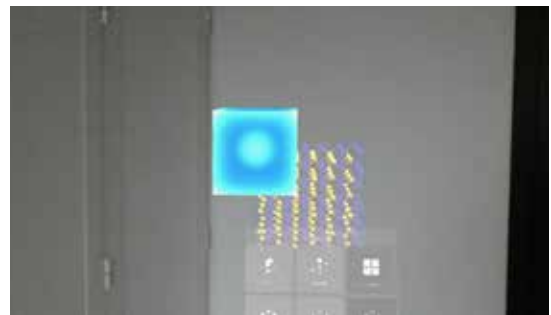
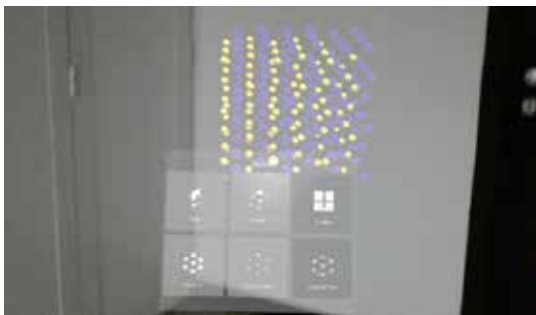
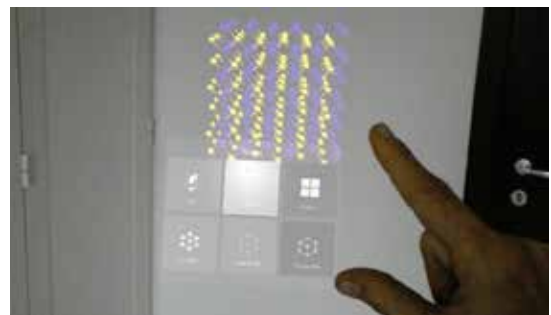
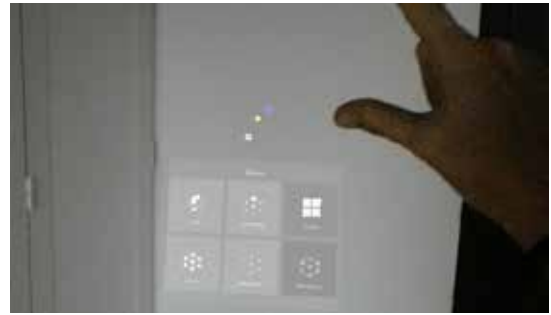
Figure 6.18: *Crystallography AR, Manipulation throught bounding box, scale 1*

Figure 6.19: *Crystallography AR, Manipulation throught bounding box, scale 2*

Figure 6.20: *Crystallography AR, Manipulation throught bounding rotate*

Figure 6.21: *Crystallography AR, Uniform, symmetry 3*

Figure 6.22: *Crystallography AR, Uniform, symmetry 2*



6.12 Crystallography VR Conclusion

Crystallography class VR is an educational experience for Oculus Go, to that allows student at the first year of Physics Engineering to explore the internal structure of solid crystals. The brief was defined in collaborations with teacher of the “Solid State Physics” course of Engineering Physics at Politecnico of Milan.

It was a very interesting process, all the decision have been taken in group following the design process and the “Instructional design theoretical framework of VR based learning environment” of Chen, Toh & Wan, (2004). After the design challenge evaluation, the definition of the value proposition and the analysis of the user target and the scenario we were able to face up one engineering and one design challenge.

The design challenge of this project was the organization of the interaction flow and the design of the interface. It was fundamental a deep study of the informational architecture of the experience and a lot of virtual prototypes to arrive at the final solution. It was an interesting experiment that led us to the design of a diegetic desk with all the micro-interactions useful to manipulate crystals.

The application, designed and developed in collaboration with the GameLab, was an interesting opportunity that led to the design of a diegetic interface for the manipulation of Crystals of the physic state. It was designed, tested and validated followed the fundamentals of user experience in Virtual Reality described in this thesis.

The experience Crystallography VR allows the user to imagine to become smaller and smaller until he has the chance to see the molecular structure of the material he use every day.

Reality mean involving people in an immersive experience, stimulate memory, senses and reaction impossible to reach with traditional learning tools.

The experience has been translated into augmented reality to allow teachers and students to enjoy the experience in the same room without problems of movement. Future research directions include the opportunity to translate the project on Oculus Quest - 6 DOF, stand-alone devices. Changing from a 3 DOF to 6 DOF headset will provide different constraints, a different interface and different interaction possibilities. This will completely change the user experience.

Conclusion

This thesis is aimed at the study of the design principle for virtual environments, the design of a conceptual framework to support the development of educational applications and the application of it to two real scenarios involving educational experiences.

There are several design rules to develop credible virtual experiences. In this thesis, we studied the design principle for virtual environments that have been suggested over the years focused on user experience (UX), interaction and microinteractions.

We focused on the most relevant ones and designed a conceptual framework to support the development of educational applications. It synthesized the principles, organizing them on a scale from physiological to ergonomic, having as extremes sense of presence, that is a feeling perceived by the user, and measurement of the human field of view.

Following the “Double Diamond Design Process”, the “Instructional design theoretical framework of VR based learning environment” and applying our conceptual framework we designed and developed two educational virtual experiences - one of these has been translated into augmented reality - involving real scenarios for the course of Orbital Mechanics and Solid State Physics of Politecnico di Milano.

During all the design and development processes, we used virtual tools. It helped us to become confident with immersive environments. We tried to understand how we behave in immersive spaces and it helped us to change our point of view.

The design evolution was based on team reflections and user suggestions. Validation sessions were conducted with different samples of users and it helped us to understand how to improve the interfaces of Space Debris VR and Crystallography VR. We can consider ourselves satisfied with the final versions of these applications.

Every iteration helped us in becoming confident with the principles involved in our framework and in discovering details and facets of user experience (UX) and user interface (UI) for virtual reality.

Considering our observations and user feedback, we can declare that virtual reality has huge potentiality in an educational context. We worked with university students, but during the Digital Week and MeetMeTonight events, we met younger students who were really interested and fascinated by this type of teaching method.

We think that extended reality could be an important support for the future of education. Of course, the personal relationships between teachers and students will remain the basis of teaching, but immersive tools will help the student in comprehension and learning visual and theoretical concepts.

Currently, the weakness of this type of technology is the time of immersion, which cannot be too long, and the time of development. Other disadvantages are the lack of user expertise. We faced a problem in proposing this technology to people with no previous background on virtual tools. We designed our experience for unskilled people. Increasing the number of interactions is possible and could be really useful, but at the moment could be too complex for lay users. Of course, with the passing of the time, this type of problem will be solved by hardware and software development and with the diffusion of the user, which will increase skills and expertise.

Future research directions include a complete guide with all the rules of human virtual interaction, a project with the design and development of the same experience for a skilled target. Use by users like virtual gamers, virtual developers and people who use virtual reality daily could give the possibility of envisioning future scenarios of human virtual interaction.

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