**DOKUZ EYLÜL UNIVERSITY**
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

# SOLVING AND VISUALIZING THE MECHANICAL PROBLEMS IN PHYSICS BY COMPUTER

**by**
**Ayşe Betül CENGİZ**

**August, 2020**
**İZMİR**

# SOLVING AND VISUALIZING THE MECHANICAL PROBLEMS IN PHYSICS BY COMPUTER

**A Thesis Submitted to the**
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**In Partial Fulfillment of the Requirements for the Master of**
**Science in Computer Engineering**

**by**
**Ayşe Betül CENGİZ**

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## M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"SOLVING AND VISUALIZING THE MECHANICAL PROBLEMS IN PHYSICS BY COMPUTER"** completed by **AYŞE BETÜL CENGİZ** under the supervision of **ASSIST. PROF. DR. KÖKTEN ULAŞ BİRANT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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**SOLVING AND VISUALIZING THE MECHANICAL PROBLEMS IN PHYSICS BY COMPUTER**

## ABSTRACT

In this thesis, we describe the creation and formative evaluation of a virtual environment for investigating the kinematics and dynamics of two-dimensional motion. Our study goals to help students learn physics concepts easily. To do this, we aimed to compute and simulate physics equations in the computer environment. For the application phase, we limited the physics equations to projectile motion. As known, projectile motion is the combination of all other motions. The second step after modeling the equations with the computer is aimed to visualize them. And care has been taken to ensure that these simulations are interactive. The ability to change values such as angle, mass, vector sizes, the position is added in line with this care. On the other hand, the main purpose of this study is to model not only these motions but also neglected factors in experimental environments to obtain more realistic observations and results. Accordingly, the equations were implemented in the computer environment not only for insulated environment equations but also for uninsulated environment equations such as air friction. At the end of our experiments, we can say that we achieve our goals. Also, we propose some additions to advance our study at the end of the thesis.

**Keywords:** Computational physics, simulation, physics engine, virtual laboratory

**FİZİKTEKİ MEKANİK PROBLEMLERİNİN BİLGİSAYAR YARDIMIYLA ÇÖZÜLMESİ VE GÖRSELLEŞTİRİLMESİ**

# ÖZ

Bu tezde, iki boyutlu hareketin kinematiği ve dinamiğini araştırmak için sanal bir ortamın oluşturulması ve biçimlendirici değerlendirmesini tarif ediyoruz. Çalışmamızın ana hedefi öğrencilerin fizik kavramlarını kolayca öğrenmelerine yardımcı olmaktır. Bunu yapmak için bilgisayar ortamında fizik denklemlerini hesaplamayı ve simüle etmeyi amaçladık. Uygulama aşaması için fizik denklemlerini eğik atış hareketi ile sınırladık. Bilindiği gibi, eğik atış hareketi diğer tüm hareketlerin birleşimidir. Denklemlerin bilgisayarla modellenmesinden sonraki ikinci adım, onları görselleştirmeyi amaçlamaktadır. Ayrıca bu simülasyonların etkileşimli olması sağlanıldı. Açı, kütle, vektör boyutları, konum gibi değerleri değiştirme gibi özellikler etkileşimli bir ortam sağlamak maksadıyla eklenmiştir. Öte yandan, bu çalışmanın temel amacı daha gerçekçi gözlemler ve sonuçlar elde etmek için sadece bu hareketleri değil, deney ortamlarındaki ihmal edilmiş faktörleri de modellemektir. Buna göre, denklemler bilgisayar ortamında sadece yalıtılmış ortam denklemleri için değil, aynı zamanda hava sürtünmesi gibi yalıtımsız ortam denklemleri için de uygulanmıştır. Deneylerimizin sonunda hedeflerimize ulaştığımızı söyleyebiliriz. Ayrıca tezin sonunda çalışmamızı ilerletmek için bazı eklemeler de önermekteyiz.

**Keywords:** Hesaplamalı fizik, simülasyon, fizik motoru, sanal laboratuvar

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# CHAPTER 1
# INTRODUCTION

In this period when the digital world is rising and entering every stage of our lives, the new generation has become increasingly compatible with the technology. This situation made it obligatory to change our traditional approaches to many points. For example; thanks to internet technologies, we can easily find any information that we learned by reading the encyclopedia in the past. Environments, where people spend time gradually, have shifted to the virtual world as technology evolves. Therefore, the concepts of the virtual world have emerged. The mathematical universe began to be created in the early 90s. Today, this universe called the virtual universe. This term is very popular but there are many other terms such as virtual reality, artificial reality, etc., however, we prefer to use virtual reality (VR).

In our era when virtual reality is on the rise, traditional school teachings have become outdated. Students who have become compatible with the virtual world have started to slow down their learning from conventional methods. The conventional and also traditional methods are aimed at students learning through printed textbooks. An experiment or application can be made only in cases where there are laboratory facilities. However, this is not possible in science fields where there is no possibility to establish a laboratory for the history science.

The concept of VR allows us to create non-existed or impossible-to-create worlds. This means we can create a virtual laboratory to teach any topic to learners. The standard hardware of a VR environment consists of mainly two parts: a head-mounted display (HMD) and a hand controller. HMD allows us to see the virtual environment and the hand controller allows us to interact with this world.

In this chapter of our dissertation, we point the aim of the thesis. After that, we give the literature review about the simulation, virtual reality, and virtual education. In Chapter 2, technical details and working logic of VR devices are described. Also, in this chapter, the advantages and disadvantages of the technologies we used are discussed. We talk about mechanics' solution methods in Chapter 3. In Chapter 4, we described the methods, which are mentioned in Chapter 3, how we used in our work. Our conclusions are discussed in Chapter 5. Besides, we talk about the additions that can advance this study in this chapter.

## 1.1 The Aim of The Thesis

In this study, we put forward a thesis that students' mechanics (mechanical physics) learning will be easier by creating a virtual reality laboratory.

To proof our assertion, it is aimed to design a simulation environment to help to learn to learners by creating a real-time virtual world for mechanics experiments using VR equipment.

We have two main goals to realize our design: to simulate mechanics physics and to realize the simulation in virtual reality. Physics is all about rates of change. Therefore, first of all, these changes must be simulated and the nature of the motion must be observed. After that, the simulated results should be shown in a proper virtual environment. We also have a sub-goal to decide the target population. The most important expectation from the target population is that they should be familiar with the physics field.

Besides, mathematics has a sub-field named calculus which was created by Newton and Liebnitz, independently. Calculus can be described as "the mathematics of change". It is undeniable that we need calculus when solving problems of mechanics based on the aforementioned knowledge of physics. And also, it can be said that physics is the real-time application area of calculus. For this reason, the target population should have background information about calculus at least the basic level.

As a matter of fact, the Oculus Rift "health and safety warnings" include a recommendation according to which children under 13 should not use the device

(Freina & Ott, 2015). Based on this warning, no matter which VR technology is used, it is decided that the target population would be over the age of 13.

Another issue is the country where the target population is selected. Education systems and methods of countries differ. Our target population is selected from Turkey. 4-year primary, middle, and high school stages are compulsory in Turkey. Optionally, students can continue their education at a university. For this, they should get a score from a central examination and prefer the department according to their scores. In Turkey, students start to study calculus and physics in high school. Then, especially in departments that include mathematics teaching, this learning continues.

In light of our selection criteria, it was decided that our target population would be between 15 and 20 years old from high schools and universities who have at least a basic knowledge of physics and calculus.

## 1.2 Literature Review

In this thesis, it is aimed to facilitate the learning of physics by using a virtual environment. In order to achieve this, it is imperative to have background knowledge in three important fields. First and importantly, a good knowledge of mechanics is required for the proposed system to give correct results. Results must be simulated in a computer environment. Finally, simulation results must be properly visualized in VR. Therefore, in this section, we researched what the researchers did in these areas. As it is known, although the science of physics dates back to ancient times, today's methods can be considered to have started from Sir Isaac Newton in the mid 15th century. As a result of our researches, the first known simulation examples were encountered in the 18th century. Therefore, we investigate the simulation field from the 18th century to see the general framework. Although the first examples were mechanical studies, the history of the concept of VR goes back to the late 17th century. You can find the details of all this research below.

### *1.2.1 Simulation*

For a very long time, there are people who have created works outside the reality they have lived. This aim is sometimes used for estimation and sometimes for entertainment purposes. It can be said that the sum of the assets existing relative to a reference point is the reality of that reference point. There are many ways to realize this desire such as simulations.

Simulation is the imitation of the operation of a real-world process or system over time (Gray & Rumpe, 2016). Baudrillard, one of the philosophers of the postmodern era, also explained the concept of simulation with "Whoever fakes an illness can simply stay in bed and make everyone believe he is ill. Whoever simulates an illness produces in himself some of the symptoms" sentences (Baudrillard, 1994). Simulations are used to show the possible effects of situations before real-time events. They are used in many contexts, such as engineering, testing, training, education, and video games, etc. It has been observed that people have been using the simulation method since the pre-computer periods in order to understand the behavior of a system or evaluate different strategies.

The needle problem introduced by the French mathematician and naturalist Buffon in the 18th century is the oldest known simulation example (Remesan, 2017). Buffon aimed to find the probability that the needle would coincide with the line when a short needle was randomly thrown on a lined paper. The remarkable result was that the probability was directly related to the pi value. And this experiment is the oldest example of using a simulation's independent parameters to achieve a physical constant $\pi$. In addition, Buffon's needle test is considered the early variant of the Monte Carlo method that aims to make predictive solutions for problems where it is difficult to make a definitive solution (Goldsman, Nance, & Wilson, 2010). In other words, it is a simulation system based on probability theory. In the Monte Carlo method, it is essential to simulate and solve an experiment or a physical event that needs to be solved by using random numbers repeatedly with statistical and mathematical techniques.

In 1876, Gosset derived a new estimation method where the sample size is small and the population standard deviation is unknown. This method is known as t-distribution (Boland, 2011; Zabell, 2008). The t-distribution is a more general form of Pearson Type IV distribution (Pearson, 1901). Gosset developed this method to simulate the evaluation of the price/performance ratio of the beers produced in the brewery where he worked.

This technique got its present name by Jon Von Neumann and Stanislaw Ulam during World War II. These two mathematicians were working on "neutron diffusion in fissionable material" with nuclear weapons physicists at Los Alamos Scientific Laboratory (Eckhardt, 1987). Although scientists had some of the necessary data, they realized that this study would not progress with traditional mathematical methods due to the enigmatic behaviors of the neutron Therefore, Stanislaw Ulam proposed the Monte Carlo method, a simulation technique, rather than deterministic mathematical methods. After Ulam's breakthrough, John Von Neumann programmed the ENIAC computer to carry out Monte Carlo calculations (Metropolis, 1987). Despite limited technology, this method had become an indispensable part of many projects by offering simulation opportunities against costly and complex calculations.

In 1960, the GSP (General Simulation Program) was introduced by Keith Douglas Tocher and his teammates (Gordon, 1961). Prior to this development, the Tocher was in the OR department of the United Steels and was working on the simulation of the steel plant that was already being studied. It was suggested that the work called general steel plant simulation at that time could be used not only for steel plants but as a general simulation tool, and its name was changed to the General simulation program. GSP is of great importance as it offers an approach from the combination of discrete and continuous simulation types.

As can be done in different ways, we can divide the computer simulation into two models: discrete, and continuous. Discrete models analyze the system at specific times or cases. Continuous models handle situation changes continuously over time.

Although GSP was developed for steel production estimation, it was a benchmark for simulation studies. Works on simulation environments have started around the 60s. The discovery of GSP was followed by the development of Simscript that is a simulation programming language in 1962, by H. M. Markovitz and others (Markowitz, Hausner, & Karr, 1962). This programming language was designed especially for stock management and manufacturing system simulation and could be used in non-simulation problems. Kiviat produced a FORTRAN-based simulation language as a basis for addressing a steel plant problem (Hollocks, 2008). But, this language was originally developed for general purposes. At IBM, Gordon produced another language named GPSS to address problems within computer systems design (Gordon, 1961).

In 1963, the Art of Simulation is published. With this book, it can be said that Tocher wrote the first book in this field. After this year, Tocher continued his works and he evolved GSP to PLUS (Programming Language United Steel) (Hollocks, 2008).

Dahl and Nygaard developed a new simulation language named SIMULA at the Norwegian Computing Center in Oslo (Dahl & Nygaard, 1966). They released the first version in the 60s. Their main purpose is to provide a systems analyst with unified concepts that facilitate the concise description of discrete event systems. SIMULA is an extension of the programming language ALGOL 60.

Today, due to the advancement of computer graphics and hardware parts, some simulations can be created virtually and visually easily. Especially, the increase in computer games has inspired the works in this area. Experimental environments or direct implementations of many operations, which are difficult to perform in real life, using computers can be created.

It was observed that training pilots during the First World War were costly and dangerous. Also, it was not possible to use real planes for training while the war was going on. Based on this requirement, pilot training instruments began to be developed in the late 1920s. One of these instruments is the simulator that trains pilots to fly the Antoinette monoplane in France. In America, in 1929, Ed Link, a pilot, invented the first flight training simulator (Page, 2000). Although this invention did not attract much attention at first, it would later attract the attention of the Army Air Corps and this invention would be improved to train pilots in bad weather conditions.

Before World War II, with the introduction of analog computers in the field of simulation, some important developments in designs for radio navigation, radar, and synthetic radar training occurred at the Telecommunications Research Organization (TRE) in the UK. During the Second World War, analog computers were developed to perform calculations that can analyze the movements of the aircraft. Thus, a method using calculations was used instead of imitating aircraft movements in simulations that lead to the creation of many flight simulators. This invention, developed for the Boeing 377 Stratocruiser in 1943 and the first simulation of an airline (Pan American Airways), is an example of these creations.

Developments in the field of simulation did not only continue in the aviation field. The entertainment industry was also working in this area. In 1952, A. S. Douglas created the video game OXO (Kaplan, 2017), simulating the noughts and crosses game played with pencil and paper. William Higinbotham introduced Tennis for Two (Baker, 2013), which simulated the game of tennis in 1958. This game allowed two people to play together by connecting two consoles to an analog computer. In addition, an oscilloscope was used as a screen. In 1962 Steve Russell created the Spacewar, which is a flight simulation video game (Yilmaz & Cagiltay, 2005). In 1967, Ralph Baer invented and in 1971 patented a game console prototype that uses television as a screen (Baer, 1971). The Brown Box was the first game console to be used at home. Shortly after the launch of this invention in 1972, the Atari "Pong" games appeared and gained more popularity than the Brown Box (ComputingHistory, 2020). The reason for this was that the Brown Box was compatible with one type of television while the Pong games were compatible with all kinds of televisions.

In addition to these studies in different areas, it was thought that simulations should provide more realistic experiences. In order to provide this realism, a physical terrain model named "model board" was used in the early flight simulations (Allerton, 2009). This model, prepared in a horizontal plane, was illuminated for image quality and the camera was moved on the model according to the movement of the plane. The video prepared in this way was brought to the screen watched by the pilot.

With the transition from analog computers to digital computers, this method used in terms of reality would not be enough. General Electric Company has developed a computer image generation (CGI) system for simulations. This system was more efficient than "model board" because not required a camera or manually created model. This system designed for producing a patterned "ground plane" image.

During the 1970s, laser techniques were started to use for simulations. One of the first example was a navy research engineer Al Marshal’s rifle-mounted laser transmitter and receiver (Marshall, 1975). He put a laser transmitter on a rifle to simulate fire on a retroreflective screen. He also put a receiver on a vest. This was the first laser tag system which was the ancestor to the Multiple Integrated Laser Engagement Systems (MILES).

Computer simulations are called in many areas as “sim”. Since computers give close results during the estimation phase, it helps us to avoid examining extreme and off-topic situations. With the help of the dynamic structure of computer-based designs, the situation to be examined can be diversified for each different case.

Computer simulations are used in a wide range from economy to education, from the military to the entertainment sector. In 2006, M. Fontana suggested a systematization of the relationship between simulations, mathematics, and economics (Fontana, 2006). In 2016, Malgorzata conducted an experimental study on the effect of computer simulations on the economic analysis (Latuszynska, 2016). In 2018, Gaffeo et al. offered a computer simulation-supported proposal to take measures regarding bank debt in times of crisis (Gaffeo, Gobbi, & Molinari, 2018). In 2019, Balaban used a computer simulation to improve the design of military vehicles performing a computer-based crash simulation (Balaban, 2019). Again in 2019, Fox et al. designed a simulation for modeling military decision-making (Fox & Burks, 2019). In 2019, Bertacchini et al. proposed a didactic computer simulation to cover many areas of mathematics (Bertacchini, Bilotta, Caldarola, & Pantano, 2019).

Visualization and graphics have undoubtedly made a huge impact on all simulation companies. Easy-to-use modeling has resulted in low-priced packages that would have been unthinkable just a few years ago. Simulation technology has shot up in value to other related industries. The Simulation industry is coming of age and is no longer just the domain of academics (Donaghey, 2020).

### *1.2.2 Virtual Reality*

Virtual reality (VR) is a term, which denotes a simulation to experience desired things out of the real world. There are different types of definitions about VR, but all of them point to the same spot. The best definition which merges all of them is Zeltzer's definition as in Figure 1.1: VR is an interactive and immersive (with the feeling of presence) experience in a simulated (autonomous) world and this measure we will use to determine the level of the advance of VR systems (Zelter, 1992).

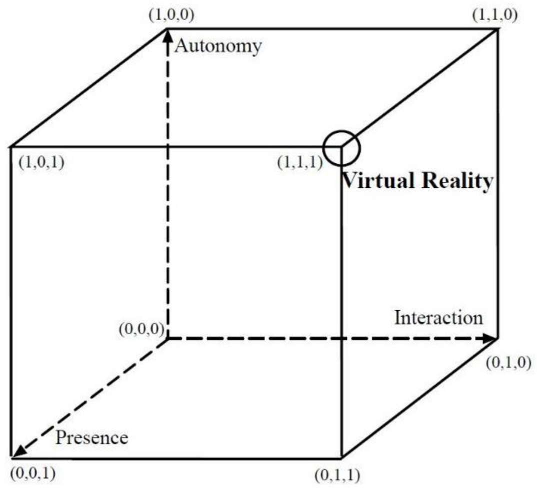



Figure 1.1 Zeltzer's cube for VR definition (Zelter, 1992)

In popular culture, VR is used only for the entertainment industry. But this term is wider than that. Today nearly everything can be modeled in virtual reality. Also, virtual realities can be interconnected. Because of that, multiple universes can be built. The developments in the field of VR from the 17th century can be found in the ongoing parts.

It can be said that early attempts about virtual reality are back to the late 17th and 18th centuries. This era can be called Victorian Virtual Reality (Goldsborough, 2007). There have been many early attempts at reproducing reality in such a way that it can be perceived as real by the user or observer. Charles Wheatstone designed a stereoscope in the 1830s (Wade, 2002). In Figure 1.2, an example of his study can be seen.

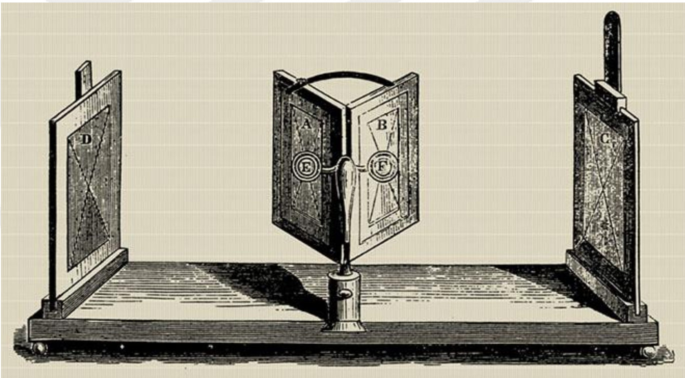


Figure 1.2 Charles Wheatstone’s stereoscope (Barnard, 2019)

In the 19th century, when the realist movement began, artists tried to produce more realistic works of art. Panoramic tables have been created to ensure this without using any device. However, in 1832, English physicist Sir Charles Wheatstone developed a device called stereoscope and modeled the human binocular system. This device explained that the human brain was able to process two different images from each eye into a single image. Later, the stereoscope was upgraded by Sir David Brewster because of its cumbersome. His invention was presented at the 1851 International Exhibition in London.

American science fiction writer Stanley G.Weinbaum wrote a fantastic, science fiction short story named Pygmalion's Spectacles in 1935 (Weinbaum, 1935). He presented a specific fictional model for virtual reality. A character in this story has invented a pair of goggles that create a virtual world and it makes its user feel like s/he is in the movie. With this short story, for the first time, we may have encountered the concept of virtual reality glasses in the modern sense.

View-Master can be count as the early and poor pioneers of these goggles in 1939. By inserting the card with tiny slides lined up in a circle, a small world is observed in the tool by lowering the small arm on the side as in Figure1.3. The images that were watched included a wide range of stories, from the layouts of dolls to Western movies' frames. All these images are in 3D.

Figure 1.3 The early pioneer of VR googles View-Master (Wikipedia, 2020f)

Later from View-Master, in the 50s, a filmmaker Morton Heilig theorizes a mechanical device dubbed Experience Theatre in the paper named The Cinema of the Future (M. Heilig, 1955). His main purpose was to stimulate all the senses of the audience and provide a more impressive movie experience. In 1962, he built a prototype as in Figure 1.4 and called it Sensorama (M. L. Heilig, 1962). This multi-sensor simulator machine allows experiencing the experiences of the interaction of scent, wind, and vibration. The only shortcoming from Experience Theatre of this one-man theatre is the interaction. He also referenced a pair of goggles in the same paper. He dubbed it Telesphere Mask and patented in 1960. This device was the first head-mount display (Flores-Arredondo & Assad-Kottner, 2015).


Figure 1.4 Sensorama, designed by Heilig (Turi, 2014)

In 1961, two engineers Comeau and Bryan created the first head-mounted display (HMD) as in Figure 1.5 which capable of motion tracking (Prema & Roopa, 2018; Tumey, 2018; Żmigrodzka, 2017). It had built-in video screens for each eye and a head-tracking system. They named their invention Until Headsight. However, this wasn't used for virtual reality; it was developed for the military to allow them to remotely look at hazardous situations. A remote camera imitated the head movements so the user could look around the setting.

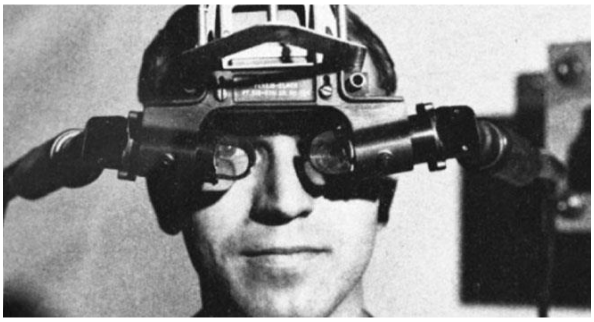


Figure 1.5 The first head-mounted display (Cohen, 2000)

In 1965, a pioneer in the field of computer graphics Sutherland first proposed that a mathematically designed world be visualized with the help of glasses (Sutherland, 1965). He dubbed this world as Ultimate Display (Sutherland, 1965). However, perhaps it is Lanier who first introduced the term VR (TheFranklinInstitute, 2020). Lanier and Thomas G. Zimmerman left Atari in 1985. They found their company VPL Research, Inc. This company is known as the first seller of VR equipment such as gloves and goggles. One of the best-known headsets was the EyePhone (Figure 1.6) that was an HMD. They also created gloves named the DataGlove. The DataGlove was a glove shaped input system. Their other invention was a full bodysuit named the DataSuit. This had multiple sensors to detect users' movements (Zimmerman, Lanier, Blanchard, Bryson, & Harvill, 1987).

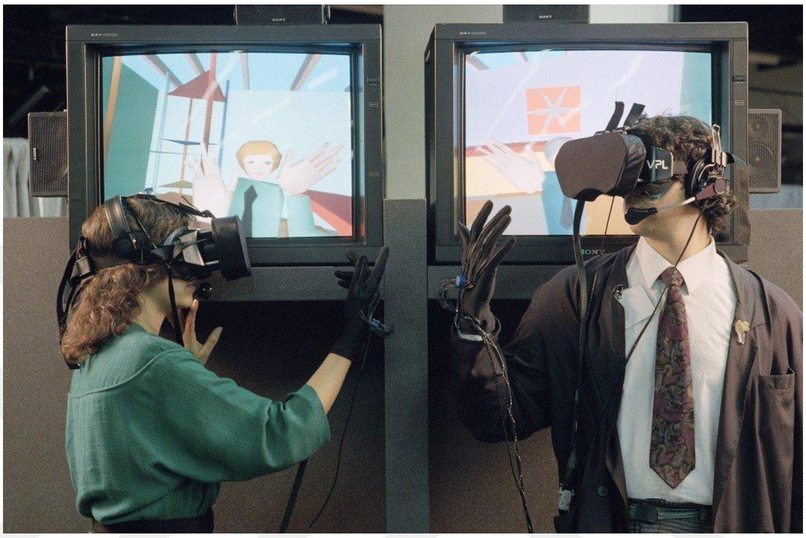



Figure 1.6 Two people demonstrate the EyePhone in 1989 (Sorene, 2014)

Another problem arose when the concept of VR was introduced. This is how to interact with this universe. Therefore, many devices have been invented to solve this problem. While HMDs allow us to enter the virtual world visually, wired gloves help us interact with this world. In 1982, the first sample which is created by Sandin and Defanti is seen. Its name was Sayre gloves (Antonio & Boas, 2013; Gupta, Singh, Pandey, & Solanki, 2015; Sturman & Zeltzer, 1994).

Although Telesphere Mask patented earlier, Sutherland and his student Sproull's The Sword of Damocles became more popular (Figure 1.7). This invention is patented in 1968 and capable of tracking both the position of the user and his eyes and update the image of its stereoscopic view according to the user's position.

Figure 1.7 The Sword of Damocles (Computer History Museum, 2020)

In 1968, an American computer artist Krueger started to develop a series of artificial reality experiences. Viewers enter an interactive space in which they interact with computer-generated visual objects at a remote location. His first work was Glow Flow. Glow Flow is a computer-controlled light and sound environment. The physical space was an empty rectangular room. It allowed successful visual elements but interaction options were limited. The following experience was Metaplay in 1970. Metaplay was the next version of Glow Flow. Interactions were upgraded however they were obtrusive. These two projects were group events, on the other hand, the third experiment Psychic Space was developed for one person in 1971. Also, Psychic Space was more advanced than in previous experiments. His last experiment was Videoplace. The Videoplace had projectors, video cameras, special-purpose hardware, and onscreen silhouettes of the users within an interactive environment (Heim, 1993; Krueger, 1977).

We can see that the 70s and 80s are years when military and aviation researches began to focus on VR. Since 1966, electrical engineer Thomas Furness had been working on visual displays and instrumentation in cockpits for the U.S. Air Force. He started to develop a cockpit in the 1970s. By the early 1980s, he demonstrated the Visually Coupled Airborne Systems Simulator. From 1986 to 1989, Furness directed the air force’s Super Cockpit program (Mertz, 2019). Its system and virtual environment can be seen in Figure 1.8. The American aerospace manufacturing corporation named McDonnell-Douglas created a new type of HMD in 1979. This invention is a kind of helmet and it can be said that this is a helmet-mounted display. The main reason for creating this device, which they called the vital helmet, was military use (Chesher, 2003). This HMD followed the pilots' eye movements to match computer-generated images. Again, in 1980, Jack Thorpe from DARPA created SIMNET which was a wide area network to help train soldiers for the USA military (Miller & Thorpe, 1995). This network also consisted of a virtual battlefield. In the late 1980s and the early 1990s, the USA Navy began to develop the Virtual Environment for Submarine Ship Handling and Piloting Training (VESUB) system (Hays & Vincenzi, 2000). This system included an HMD to access the virtually created training area. A head tracking device attached to the HMD was tracking the movements of the users and creating visuals according to the direction they were looking at. In this way, it was creating a 360-degree virtual universe. In fact, variable conditions such as fog and rain could be added to this virtual environment.

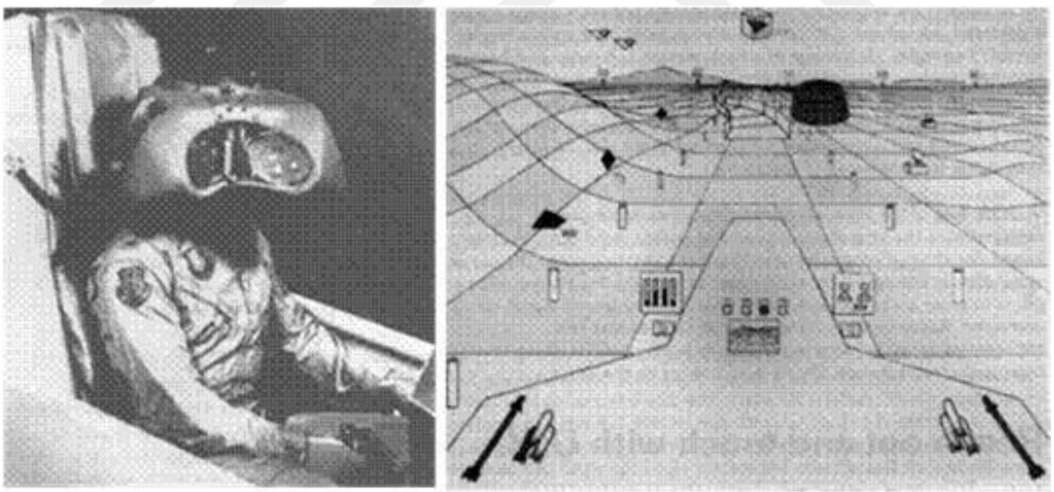


Figure 1.8 System and virtual environment of the "Super Cockpit" (Cohen, 2000)

In 1978, a team with Lippman from MIT developed a hypermedia system named The Aspen Movie Map. This project was supported by The Defense Advanced Research Projects Agency (DARPA), formerly The Advanced Research Projects Agency (ARPA). This early example of a hypermedia project enabled the user to take a virtual tour through the city of Aspen. Later, this project was an inspiration for Google Street View (Anable, 2012; Vincent, 2007).

While mentioning the VR field, it is also necessary to touch on the stereo vision subject. Stereovision is a three-dimensional effect achieved by blending, through special eyepieces, the images of two photographs taken at slightly different points. Although this technique does not create a virtual universe, it creates the illusion of 3D images from 2D images. The process which creates a stereo vision is stereoscopy. In 1980, the company named StereoGraphics created the first representative of a pair of glasses that create stereo vision (Lipton, 1997). The main idea in this technique is to combine a pair of stereoscopic images that depict the left eye and right eye views of the same scene as a single three-dimensional image.

Tron, directed by Steven Lisberger, spread the concept of VR to wider audiences In 1980 (Onyesolu & Eza, 2011). This science-fiction movie examined the VR from a different point of view. According to this movie, people were converted into data with a converter and transferred into a computer game called Tron. After that, some other movies released in the coming years. A director Douglas Trumbull directed Brainstorm. In this movie, a scientist group invents a brain-computer interface that allows sensations to be recorded from a person's brain and converted to tape (Geurts & Guglielmetti, 2015). In 1992, a science-fiction movie The Lawnmower Man, directed by Brett Leonard released. It was the adoption of Stephen King’s 1975 short story of the same name. In this movie, a doctor who works for Virtual Space Industries works on experiments that enhance cognitive performance using psychoactive drugs and virtual reality (Reid, 1995; Wertheim, 1992).

Scott Fisher said, “VR definitely would have happened, starting first in the arcades”. He was in charge of the VR project of the Atari company. The company started to develop VR technologies secretly at its Sunnyvale Research Lab in 1982. During the video game crash of 1983, which was a large-scale recession in the video game industry, their research stopped.

Dr. Michael McGreevy who was an engineer at Nasa released the prototype of the Virtual Visual Environment Display (VIVED) helmet in 1985 (Chang, 2020; Fisher, McGreevy, Humphries, & Robinett, 1987). The design consists of an HMD placed in the visor part of the astronaut helmet, as in Figure 1.9. The main product released in 1986 at Consumer Electronics Show (CES). This helmet employed a wide-angle, stereoscopic display system. Unlike other VR systems, it had an improved voice control mechanism. Besides, it had a glove-like peripheral. A sensor mounted on the helmet was tracking users' head motions and supported with a stereo sound system to create a more realistic 3-dimensional feeling.

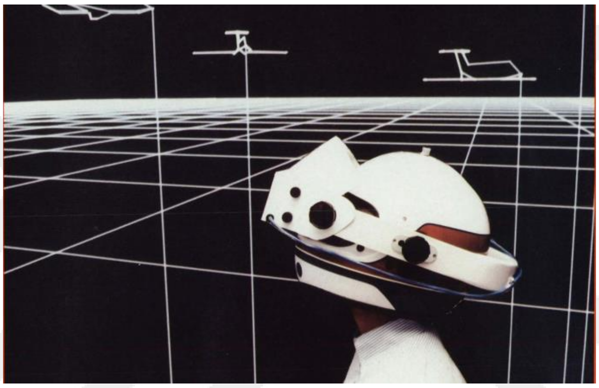


Figure 1.9 NASA's VIVED (Hadro, 1988)

Nintendo announced a new accessory for Nintendo Entertainment System (NES) in 1989. This accessory was an input glove named the Power Glove (Figure 1.10) (Pausch, 1991). This glove was the form of traditional NES controllers attached to the forearm. Beyond the traditional controller, movement commands were provided by the hand's location and shape. Again in 1989, the Fakespace Labs commercialized a VR tool Boom which is a small box, which contains two CRT monitors that can be viewed through the eye holes. A mechanical arm holds this box over the user. The user can grab the box and move wherever s/he wants as long as the mechanical arm allows (Figure 1.11).


Figure 1.10 Power Glove (Wikipedia, 2020d)

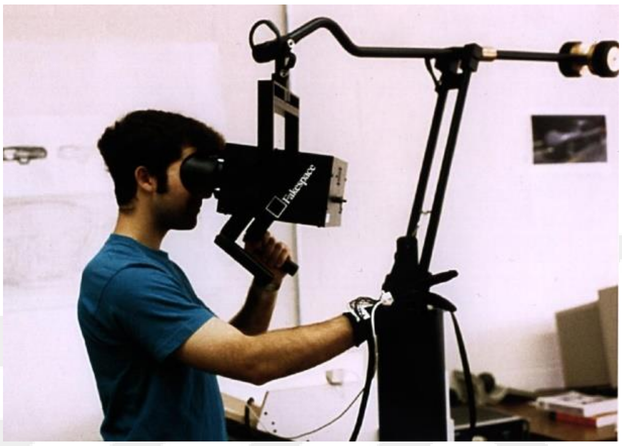



Figure 1.11 The Fakespace Labs' Boom (BEIER, 2000)

In the early 90s, NASA needed a wind tunnel to observe and investigate flow-fields. They decided to design this tunnel in VR. They dubbed is Virtual Wind Tunnel and they used Boom and DataGlove which are technologies mentioned earlier. In Figure 1.12, inside and outside views of the Virtual Wind Tunnel is seen.

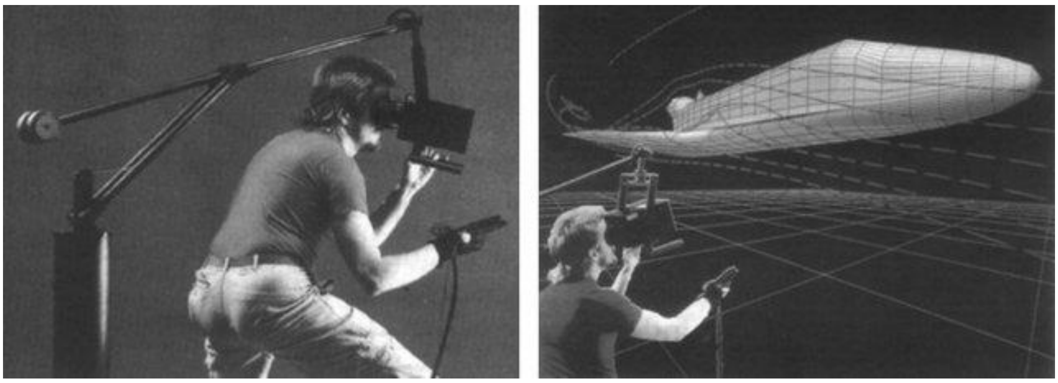


Figure 1.12 Inside and outside views of the Virtual Wind Tunnel (Mazuryk & Gervautz, 1999)

Virtuality, one of the largest dedicated VR Companies in the world, was born in 1987. Their main foundation purpose upon the principle of delivering fully Immersive

Virtual Reality to improve human-computer interaction. In 1991, they developed a VR entertainment system. This system included an HMD that senses head motions using magnets and joystick. In addition, it can be seen in 1991 that Virtuality's efforts for VR systems to work together started. A new product named the Virtuality Group had announced. These machines provided real-time gaming experience with other players as in Figure 1.13. They are generally used in arcades (Virtuality, 2020)..

Figure 1.13 The Virtuality Group (VirtualRealitySociety, 2020)

In the 1990s, the Sega Corporation started to develop an HMD. This product called Sega VR could only be developed for arcades and released in 1993. Its design was similar to recent HMDs as in Figure 1.14. As with other HMDs, this HMD had sensors that track user head motions, an LCD screen in its visor, and stereo headphones.

Figure 1.14 Sega VR (Sega, 2020)

In 1991, Apple Inc. created an image file format, which allows the creation and viewing of VR photography, panoramas, and the exploration of objects through images taken at multiple viewing angles. This file format was dubbed QuickTime VR (QTVR) (Nieder, Scott, & Anderson, 2000).

In 1992, Carolina Cruz-Neira, Daniel J. Sandin, and Thomas A. DeFanti at the University of Illinois, Chicago Electronic Visualization Laboratory are designed the VR environment (Cruz-Neira, Sandin, & DeFanti, 1992). This environment was a representation of the allegory of the Cave (Sauter, 2003). They created a room as in Figure 1.15 where its walls were a video theater. Instead of using an HMD, they designed an LCD shutter glasses.

Figure 1.15 CAVE VR (Wikipedia, 2020a)

As known, VR is a computer-generated environment. Like all computer applications, there needs a programming language to develop VRs. In 1994, at the very first World Wide Web (WWW) conference, Virtual Reality Markup Language was proposed. Its name changed to Virtual Reality Modelling Language after 1995 (Brutzman, 1998). It was a 3D modeling language intended to be, like HTML, a web standard. In 2001, X3D became the successor to the VRML. X3D is an XML based format for representing and communicating 3D information (Wei, Sourin, & Stocker, 2009).

Works for using VR in a group led to the establishment of ideas about virtual communities. In 1993, Howard Rheingold who was an American critic, writer, and teacher, wrote a book named The Virtual Communities and pioneered the first virtual communities. It is not possible to talk about a physical place in virtual communities as in traditional communities. The place of virtual communities is "cyberspace". The term cyberspace describes the virtual reality environment that arises from the communication that computers and people using it establish within the internet and similar networks.

In 1994, we encountered a new term Virtual Reality Therapy (VRET). Max North documented the first known publication about this field (North & North, 1994). This method of therapy is the use of virtual technologies helping to cure psychological illness. One of the projects in this field is a project named Virtual Vietnam: Virtual Reality Exposure Therapy for Post-traumatic Stress Disorder started in 1997. This project is carried out in cooperation with Georgia Tech, Emory University, and the VA Hospital in Atlanta. With the help of this project, the project team tries to help Vietnam veterans (Rothbaum et al., 1999).

While Sega's VR work for the consoles was canceled, Nintendo released a VR for consoles under the name Virtual Boy in 1995. It has a gamepad and HMD as in Figure 1.16 Virtual Boy was working with games designed to be compatible with it. These type of games creates an illusion of depth by using the parallax effect. Perhaps, for this reason, it did not reach the desired sales targets and the project was stopped in 1996.

Figure 1.16 Nintendo’s Virtual Boy (Wikipedia, 2020g)

In 1995, the Forte VFX1 was released by Forte Technologies, Incorporated (Kuusisto, 2015). This HMD comprised a helmet, a handheld, and an interface that was compatible with Industry Standard Architecture (ISA) which is the 16-bit internal bus. The Forte VFX1 offered head tracking, stereoscopic 3D, and stereo audio. Its design is a kind of hybrid of a headphone and an HMD as in Figure 1.17.


Figure 1.17 The Forte VFX1 (Wikipedia, 2020e)

With the beginning of the twenty-first century, there was a drop in interest in VR technologies. One of the most remarkable technology was SAS Cube (also known as SAS3), developed by Z-A Production, Barco, and Clarte in 2001 (Al-Azzawi & Minkov, 2017). This was a first pc-based cubic room as in Figure 1.18. Besides, Google released Street View, which still has an important place in our lives, in 2007. In 2010, they improved Street View by adding the 3D feature (Anguelov et al., 2010).

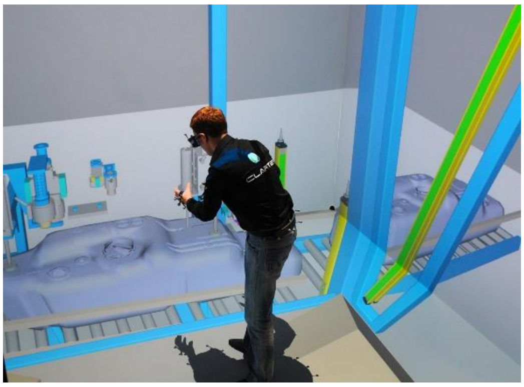


Figure 1.18 SAS Cube with its cubic room (Barco, 2020)

Palmer Luckey who is an American entrepreneur started a campaign in a global crowdfunding platform known as Kickstarter. He announced a prototype named Oculus Rift in 2012 (Bolas et al., 2013; electricTV, 2012; Harley, 2019). To develop the new product, he founded Oculus VR with Brendan Iribe and Micheal Antonov. The main contributions of this device are that it is wireless, has an extreme 270-degree field-of-view, and is relatively smaller. They released the first commercial product in

2016. Oculus Rift is still being developed until today (2020) and is constantly supported by new patches. It has an HMD and at least one hand controller as in Figure 1.19.

Figure 1.19 Oculus Rift VR system (Oculus, 2020b)

Apple Inc. which is an American multinational technology company released a new feature for their smartphones which is known iPhone. This program called VR Viewer provides its users to watch VR photos and videos.

In 2012, a student at the University of Wisconsin–Milwaukee, Bryan Cera, successfully gained donates from the Kickstarter campaign. With this donation, he developed a wearable device, glove. He dubbed it Glove One (Figure 1.20) (Yanbo, 2014). This device is also a mobile communication device.

Figure 1.20 Glove One (Oscillada, 2015)

At this point, it is necessary to talk about a field called haptic technology. Haptic technology is a technology that enables us to feel the surface by getting feedback from the surfaces we touch through devices. The first examples of this technology go back to the 60s. In 2013, the company Tactical Haptics released VR motion controllers which give feedback to the user about the virtual environment.

Like Apple, Google has begun to release VR support for smartphones. In 2014, they developed a platform called Cardboard for Cardboard compatible VR images and videos (Smus, Plagemann, & Coz, 2014). It contains two lenses in a foldable cardboard case, thus providing a VR experience as in Figure 1.21. The platform is intended as a low-cost system to encourage interest and development in VR applications. Besides, Samsung has released VR glasses that smartphones can be mounted in (Samsung, 2020). The first product released in 2015. The main working principle of these devices of Google and Samsung, a smartphone must be placed in these headsets to use them and compatible images should be opened on smartphones.

Figure 1.21 Google Cardboard (Cardboard, 2020)

In 2015, Microsoft announced a pair of mixed reality smartglasses, HoloLens as in Figure 1.22 (Gottmer, 2015). Mixed reality is the reality that includes real and virtual reality together. HoloLens was the first Windows operating system compatible HMD. It is running the Windows Mixed Reality platform. This HMD combines the two realities by providing the user with a virtual world in the real world.

Figure 1.22 Microsoft’s HoloLens (Microsoft, 2020b)

Another smartphone manufacturing company, HTC, introduced its VR system in 2016 (HTC, 2020). This system, which they dubbed Vive as in Figure 1.23, is designed with the room-scale paradigm and reflects the user’s real-world movements to the virtual world. Also, like Oculus Rift, with the help of motion-tracked handheld controllers, the user can interact with the environment.

Figure 1.23 HTC Vive (Wikipedia, 2020c)

With the development of VR technology, VR compatible programs and data have emerged. The game industry has also exhibited many examples in this area. Sony company also released PlayStation VR in 2016 in order to play VR games (El-Ganainy & Hefeeda, 2016). This HMD developed under Project Morpheus. It has futuristic design as in Figure 1.24. The actions of the user are simultaneously displayed on both the headset and the television screen. In this way, other users who do not use the headset can accompany the game (PlayStation, 2020).

Figure 1.24 Project Morpheus's HMD (Teknolog, 2020)

VR possibilities started becoming widely available to the general public. In 2015, The Wall Street Journal announced an emulation which shows the Nasdaq Stock Market data. They modeled Nasdaq's ups and downs of exchanges on the coordinate plane as a roller coaster. The user can take a tour of the financial area. Again in 2015, the BBC created a 360-degree video. This video allows users to view a Syrian migrant camp (Tse et al., 2017). Also, The Washington Post created a VR to show users Oval Office at White House (Martinelli, 2020).

### *1.2.3 VR in Education*

In this section, we will discuss VR applications in education. Basically, education is the process of teaching and learning. Until today, a physical environment such as class and laboratory was needed to provide education. The common features of these environments are that those who will attend the training should be in the same place. Therefore, with the advent of VR devices, these people may be in very different physical places. This situation also eliminates relatively expensive physical environment designs.

With the help of VR, there will be many changes in education. In traditional education methods, learning via printed symbols in textbooks is essential. These symbols sometimes emerge as mathematical expressions, chemical equations, and sometimes letters. This symbolism, which is the necessity of our mental structure, can be moved from printed form to the simulation environment, with VR. Thus, curriculum materials will not be abstract based but will be experiential-based. For example, performing chemical experiments in a virtual laboratory instead of reading from books can provide more permanent learning for the learner. Besides, virtual labs do not have to teach users anything. There may also be an exercise environment to upgrade talent.

In 1999, Bransford et al. developed a framework named HPL (How People Learn) (Bransford, Brown, & Cocking, 1999; Yalvac, Smith, Hirsch, & Birol, 2006)**.** This study was conducted to create a learning environment where all factors affecting people's learning are present and balanced for learning. Their approach is learner-centered. They suggest that the learning process should not only take into account students' abilities, habits, knowledge, etc. According to them, learning should provide the freedom of choosing time and place. While this gives students the ability to make decisions, it also imposes responsibility about own educations.

VR usage in education may vary. Nearly all topics can be given with the help of VR. The dental field and medicine are examples of these topics. As it is known, in order to be a successful operator, it is necessary to practice a lot. In addition, monitoring and examining the previous operations can prevent the repetition of the mistakes made, if any. The advantage of VR laboratories is that it would allow flexible learning with self-teaching not limited to formal training hours, thus increasing students' training time and reducing the overall future costs (Roy, Bakr, & George, 2017).

One of the dental applications is IDEA (Individual Dental Education Assistant) (Gal, Weisis, Gafni, & Ziv, 2011; IDEA, 2020) IDEA provides a 3D animated image on the screen that allows the user to practice with tools while providing haptic feedback. Also, the simulator measures the user's performance by giving scores. Another application of the VR dental simulation is DentSim that helps dental students to improve their skills. Also, this system provides augmented reality support (Welk, Splieth, & Kordaß, 2004). The Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC) also developed another dental VR named PerioSim. Like DentSim, this system has a haptic feedback feature (Kolesnikov, Zefran, Steinberg, & Bashook, 2009).

Voxel-Man is an example of medicine applications. It is a set of computer programs for the creation and visualization of three-dimensional digital models of the human body. The digital models can be obtained from the outputs of systems such as tomography, MR, etc.  It was developed at the University Medical Center Hamburg-Eppendorf (Pflesser et al., 2001).

VR applications in schools can be divided into two sub-categories; those in which teachers use pre-developed applications and those in which students themselves build virtual worlds in order to test hypotheses (Christou, 2010).

To an example of pre-developed applications, the Virtual Gorilla Exhibit application can be given. It is an immersive virtual environment, lets students assume the persona of an adolescent gorilla, enter into one of the gorilla habitats at Zoo Atlanta and interact as part of a gorilla family unit (Allison, Wills, Bowman, Wineman, & Hodges, 1997). In 1996, Dede et al. offered a VR that aims to explore electrostatic forces for students. The project named MaxwellWorld helps students to gain information about the electrical fields by making informative evaluations and increase their experiences such as 3-D demonstrations, interaction, and learning multiple perspectives (C. Dede, Salzman, & Loftin, 1996). Also, Dede et al improved their work in 2005. They designed a virtual world for learning Newtonian mechanics (C. J. Dede, Salzman, & Loftin, 1996). There are also examples such as Cell Biology, Atom World, Newton World, Greek Villa, etc. To an example of student-build applications, Virtual Stage and Wetland Ecology can be given (Christou, 2010).

For educational purposes, VR is highly used in cultural heritage and archaeology. There are numerous applications that create a heritage site in VR. These applications help the learner to explore the corresponding era.

In the late 80s, the University of North Carolina developed an architectural walkthrough application named UNC Walkthrough project. This project included several VR tools such as HMDs, trackers, etc. to help to learn of the architectural stages. In addition, there is a website named “www.learningsites.com”. This website designs and develops interactive 3D digital models that are based on actual archaeological evidence and that are reconstructed with an accuracy and sensitivity to known details that reflect the highest standards of scholarship (LearninngSites, 2020). They started to develop virtual heritages sites until 1989. In their early projects, they designed the mastabas at Giza, the temples at Jebel Barkal, The Sun temple at Meroe, and The Tomb of King Aspelta in Nuri. These projects were relatively smaller than ongoing projects. Today, they can develop a whole heritage site. Likewise, The Institute for the Visualization of History has a website to show archeological sites. They designed Athens Acropolis, Mount Nemrud, Nimrud, Til Basrsib, and Vari.

Besides, VR can be used for showing museums to the learners. The Exploratorium where is a museum of science, technology, and arts in San Francisco (Carrozzino & Bergamasco, 2010). Physicist Frank Oppenheimer opened it in 1969.

As is known, a driving license is required to drive the corresponding vehicle. To get a driving license, it is necessary to receive training from specialists. Today, the training of a vehicle is carried out by driving the vehicle in the real world. But, VR technology reached the transportation area. Nowadays, with the help of VR, every weather condition is created. So, it is provided that drivers can practice in environments that they cannot experience. Several car manufacturers are adopting this technology to test the driving experience of their vehicles.

Like pilot training, medical training is an expensive process. Also, it involves risk to patients. Today, medical education requires students to study on cadaver until they reach a certain level. All of their steps are followed by their supervisors or lecturers. By doing so, it is aimed to gain as much experience as possible before the student starts surging patients. However, the main problem in this training is that there are differences between the live patient and the cadaver. Another problem with this educational approach is the lack of cadaver. VR provides that surgical training has benefited the most from developments in haptic feedback devices which provides a realistic sense of control and manipulation of soft body tissue. To an example, Kuhn et al. presented a VR technique for Minimally Invasive Surgery. Karlsruhe Endoscopic

Surgery Trainer is a graphical real-time simulation environment (Kühnapfel et al., 1997). Also, Izard et al. designed a VR educational tool for human anatomy in 2017. They aimed to illustrate the teaching potential of applying Virtual Reality in the field of human anatomy, where it can be used as a tool for education in medicine (Izard, Méndez, & Palomera, 2017).

In the field of physics, in 2001, Jimoyiannis and Komis developed computer simulations in physics teaching and learning (Jimoyiannis & Komis, 2001). In 2013, Avradinis et al designed a virtual world for the simulation of physics experiments (Avradinis, Panayiotopoulos, & Anastassakis, 2013). In 2019, Park developed a simulation-based formative assessment model and modeled two topics: motion in two-dimension and conversation of energy (Park, 2019). In 2020, Sankaran et al. developed a physics-driven blood-flow simulation (Sankaran et al., 2020).

# CHAPTER 2
# TECHNICAL DETAILS OF VIRTUAL REALITY TECHNOLOGIES

As mentioned before, virtual reality is the use of computer technology to create a simulated environment. Like all computer-based technology, VR consists of two main components: hardware and software. In this section, we will discuss all components of VR.

The operating logic of VR is about presenting a virtual environment designed with a suitable programming language to the user through suitable hardware parts. This creates the illusion that the user is in another world. In order for this illusion to be better, human senses must be stimulated as much and accurately as possible. The most stimulated senses today are sound, image, and haptic senses. However, the sense of smell and taste can be triggered with necessary hardware additions.

Traditional computer programs provide a simple user interface to interact with the user. Generally, we see the interface on a screen and interact with this interface via a traditional input device such as a keyboard and mouse. Unlike traditional computer programs, VR places the user inside a program.

## 2.1 Hardware

In order for the user to be placed in the virtual environment, suitable hardware parts for this situation are required. Like traditional computers, hardware parts of VR can be classified into two classes: input and output devices.

Output devices are responsible for the representation of the virtual environment. These devices are essential components of any VR. The most common device is the Head-Mounted Display (HMD). HMDs have been updated and developed for years. Today, almost all the latest designs of HMD include sound systems, screens, and haptic sensors. HMDs consist of two main parts, a glasses apparatus, and a processor unit. An average HMD is bigger than 180 x 180 x 250 mm and 500 or 600 grams. The average field of view (FOV) is approximately 100 degrees, but some models have 120-degree FOV. The resolution per eye starts from 960 x 1080 and goes up to 3840 x 2160. There are also models with a microphone plug-in for voice communication. It has an accelerometer and gyroscope to measure head and body movements. The processor unit is concerned with the correct and smooth transfer of 3D images. The processor unit is also responsible for the organizing of other units connected to the glasses apparatus. Therefore, powerful processors are required to achieve high resolution. The main purpose of the output devices is to keep real human senses as possible as the user is in the virtual world. A standard HMD can be seen in Figure 2.1.

Figure 2.1 A standard HMD (Wikipedia, 2020b)

The most commonly used input devices are hand controllers (Figure 2.2) and gloves (Figure 2.3). The main difference between them appears in the use of the device. Gloves are designed to spread the entire set of buttons from hand to arm. The hand controllers are designed to have a hand-held joystick-like device and buttons around the device. The models currently on the market are usually in the form of hand controllers and have 4 or 5 keys. The handle of the controller is held in such a way that it is in the palm of the user. There are keys on the finger level that correspond ergonomically to each finger.

Figure 2.2 A hand controller example (Vr-plugin, 2017)

Figure 2.3 A glove example (Noitom, 2020)

Unlike output devices, input devices are not essential components yet. Today's VR designs are still in its infancy. So most of the designs only provide visualization. They do not allow any interaction. As the development of VR increases, the input devices will become more important.

### 2.2 Software

Hardware devices are just a dysfunctional tool unless there is software running on them. VR software ensures the compatibility of hardware parts. Another feature of VR software is to allow users to interact with the virtual environment. Today's VR software can be divided into two categories: virtual environment, virtual program, although not all VR software is in the aforementioned conditions.

A virtual environment is an environment, where the virtual world allows only basic interactions to the user. This is a kind of shell application. In this application, there can be several types of virtual programs such as simulations, games, theaters, etc. We called these types of applications as virtual programs. The best-known example of this system is OpenVR that is a software development kit (SDK) and application programming interface developed by Valve Co (Egger et al., 2017). OpenVR allows the user to be in a virtual home environment. In this way, the user browsing his/her virtual home can run and use the application s/he has purchased before.

### 2.3 Issues Relating to VR

Generally, technological developments enter our lives without the opportunity to measure their losses. The effects of some developments can be understood in the next generation. For this reason, its effects should be considered before researches are conducted. For this purpose, in this section, we will talk about the advantages and disadvantages of VR technologies. Besides, our study concerns VR in education, then we mostly talk about educational advantages and disadvantages.

It can be said that each advantage can be a disadvantage. Thus, we need to examine each issue with a double point of view. The most important advantage of VR is that it can be used in broad areas of application. Nevertheless, this causes VR to require different devices to be set up in different environments. Therefore, there is an increase in price and installation time. VRs provide a more interactive environment but this may cause sickness. To a more realistic VR experience, multiple human sense stimulation is made. On the other hand, this situation can be the cause of the lack of realism.

Issues related to VR can be examined under two titles, which are the performance of VR and its effects on the users. The performance of VR depends on hardware and software. VR performance directly affects user experiences. Hardware, as we mentioned earlier, consists of two main devices: input and output.

The basic expectation from the VR input device is the keypad. Therefore, a good device should have enough keys to meet the user's expectations. The main design problem here concerns the number and place of keys. By human nature, humans want to constantly see the device used directly until they gain experience. When users enter VR, their eyes will be closed by HMD and they will experience blindness until they master the input device. Therefore, the number and place of the keys on the input device should not confuse the user.

HMDs are essential for a good VR experience. HMDs consist of two parts with a processor and eyeglass apparatus. The processor unit has functions such as creating images, processing 3D sound, creating displaying modes. As the processor unit gets powerful, the virtual world to be created is more satisfying, but the size of the unit is growing and heavier. This causes pain since it will put more pressure on the user's head. On the other hand, infants may experience skull disruption due to excessive use of HMD. It is one of the reasons for the use of under 13 age to be inconvenient. Humans' simultaneous visual perception in an area is about 160 degrees, while HMDs have 120 degrees. This creates a feeling of suppression in some users. Images with low resolution create dissatisfaction with users. When these side effects come together, complaints of nausea emerge often.

A well-designed software identifies items to interact with. In order for the VR environment to be more useful to the user, it should be an object that can satisfy every need of its needs. At this point, the performance of VR software can be measured by the number of objects it can interact with. On the other hand, interaction with these objects must be established correctly. Another issue is the complexity of the designed objects. For example, suppose that a home theater system is designed in a VR environment. Users will expect even a simple remote control to be as complex as in real life.

In the field of education, VR software should provide the opportunity to easily transfer the subjects that teachers want to tell to the virtual environment. They should be able to prepare many mechanisms in VR as in real life. It is natural for students in our target population to get bored and distracted from the lessons in the physical world due to their pedagogical age. For this reason, the course environments must become interesting. Thanks to VR software, many objects can be designed to attract students' attention. In this way, course performance can be increased. On the other hand, Today's VE laboratories are redesigned according to the feedbacks of the students. To the more reliable results, at least one supervisor should also be at various steps of the procedure.

Therefore, the most important criterion for the advantages and disadvantages of VR is the effects on students. Systems designed to measure this should be tested in a sufficiently large student population. It also requires an examination of the efficiency, functionality, and capabilities of the VR used. It can be said that VR is a powerful tool to support and facilitate learning and teaching.

## 2.4 Issues Relating to Mechanics

The science of physics deals with matters, energies, and their relationships with each other. Physics has six major areas that are mechanics, thermodynamics, optics, waves, electromagnetism, and modern physics (Young, Freedman, & Ford, 2012). The main concern of this study is the projectile motion of mechanics.

Mechanics is divided into three main branches: statics, kinematics, and dynamics. Static is the sub-branch of mechanics that examines objects in static equilibrium. Static equilibrium is achieved if parts of an object do not move relative to each other. This means there is no acceleration in the system. Kinematics concerns the motion of an object, but, the cause of this motion is out of its concerns. Dynamics concerns with the forces and their effects on motion. Therefore, mechanics deals with topics such as motion, work, energy, collision, rotation, flexion, gravity, etc.

Each of the branches of mechanics is described quantitatively in three fundamental quantities: time, length, and mass. Each object has a mass. Each object or action has physical dimensions. Each movement is completed in a certain time. This can be summarized by saying that each object travels a certain distance at a certain time during a movement. The mass is measured with the kilogram, the length is measured with the meter, and the time is measured with second in the metric system. However, some countries have own measurement system.

Many parameters are ignored in order to make calculations easier in mechanics. This situation will be discussed in detail in the following sections. However, it should be noted that every missing parameter causes us to move away from the reality of the movement. The existence of these parameters requires the use of analytical methods that require a very long solution process. This is not only a problem of mechanics but of physics in general. With the help of simulations, we can achieve more accurate results by making numerical approaches.

# CHAPTER 3
# METHOD

In this thesis, motions in one-dimension and two-dimension are discussed to prove our assertion. While doing this, we performed this study in three stages. Firstly, the equations of mechanics to be used were decided. The steps of using the necessary parameters for the equations were determined. Then, the equations to be used are simulated with the methods that will be mentioned in this chapter. At this point, many unnecessary probabilistic problems were tried due to the fact that to observe all situations. Finally, a virtual world was designed in accordance with the results obtained, and all stages of the solution were displayed.

In the real world, there are so many unpredictable and uncontrollable parameters that affect motions. Generally, to ease computation, nearly all natural parameters are ignored when calculating the result of the motion. Unfortunately, this situation takes us away from the real nature of the motion. However, the calculation of the true nature of motion with all parameters using analytical methods takes too long. Because of the aforementioned problems, in this work, we have used numerical methods to represent and solve the true nature of the motion. Therefore, it should be noted at this point that the experimental setup of our study is the kinematics basis. However, by examining the external forces, dynamics have also been investigated.

As known, two-dimensional motion is the resultant of two one-dimensional motions. The resultant of the Y-axis is affected by gravitational acceleration. The resultant of the X-axis is affected by air friction if there is. When there is air friction in a system, there is also the force in the opposite direction of the motion. Therefore, we have to simulate Newton’s laws of motion.

In the below section, we will discuss these topics. These topics are our main starting point.

## 3.1 Newton's Laws of Motion

Sir Isaac Newton found three fundamental laws about classical mechanics in 1687. The first law says that an object at rest will remain at rest unless acted upon by an external and unbalanced force. An object in motion will remain in motion unless acted upon by an external and unbalanced force. In short, this law says that a force is required to start or stop motion. The second law says that the alteration of motion is ever proportional to the motive force impressed, and is made in the direction of the right line in which that force is impressed. We know this law as $F = ma$. According to the third and last law, all forces occur in pairs, and these two forces are equal in magnitude and opposite in direction (Newton, 1687).

## 3.2 Projectile Motion

Projectile motion is the motion of an object thrown or projected into the air, subject to only the acceleration of gravity as in Figure 3.1. The projectile motion is the combination of two simple shots: vertical and horizontal.

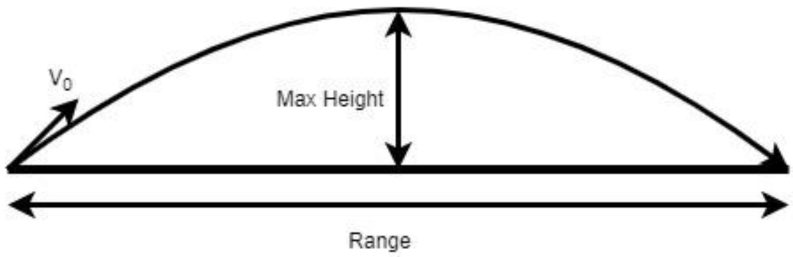



Figure 3.1 An example of projectile motion

We can find two components of any vector using the sine multiplier. For example, the X-axis value of $V_0$ is $V_x = V_0 \sin \Theta$ and the Y-axis value of $V_0$ is $V_x = V_0 \cos \Theta$.

The projectile motion of an object is simple to analyze is we accept that (1) there is no air friction and (2) gravitational acceleration (g) is constant over the range of motion. Using the first acceptance, we can use the calculations and equations of the projectile under constant acceleration to find the horizontal component. The vertical component of the projectile motion turns to the free-fall motion after the peak point. According to our second acceptance, although the value of the gravitational acceleration is nearly 9.80665 m/s$^2$ in Paris, it is accepted as 9.8 m/s$^2$ in order to easily calculation.

Usually, one or two parameters are sufficient when calculating the results of a movement. If we know the displacement and the time tuple, the velocity can be found. If the final velocity, the time, and the initial velocity are known, the acceleration can be found. And so on. The most basic equation is the equation which founds the final velocity as in Equation (3.1). Here, $V_f$, $\Delta x$, and $\Delta t$ indicate the final velocity, the displacement of the particle, and the total time of all motion respectively. As can be seen in Equation (3.2), the average acceleration is defined as the change in velocity divided by the time. Lastly, the last location of the particle ($x_f$) depends on the velocity, the acceleration, and the time as in Equation (3.3). Equation (3.1), (3.2), and (3.3) can be used to calculate the X-axis motion of the projectile.

$$V_f = \frac{\Delta x}{\Delta t} \tag{3.1}$$

$$a = \frac{\Delta V}{\Delta t} = \frac{V_f - V_i}{t_f - t_i} \tag{3.2}$$

$$x_f = x_i + V_i t + {}^1\!/_2\, at \tag{3.3}$$

In the vertical component, the time in which the projectile reaches the peak and the fall time to the initial position are equal. The time at which the projectile reaches its maximum height can be calculated using Equation (3.4) which is derived from Equation (3.2). Here, $t_u$ represents the upward flight time of the motion. We know that if we throw an object to the air, its final velocity will be zero when it reaches the peak. Also, our acceleration is constant, negative, and gravitational. Thus, the acceleration equals the gravitational acceleration. Because the upward flight time equals to the fall time, it can be said that all flight time is two times the upward flight time. And finally, using Equation (3.3), we can find the maximum height of the motion.

$$t_u = \frac{V_y}{g} \tag{3.4}$$

To remind again, the equation systems above are used when the acceleration is constant. Otherwise, in this study, Euler's numerical method can be used.

### 3.3 Euler's Numerical Method

If the acceleration of a particle varies in time, its motion can be complex and difficult to analyze. Changes in acceleration occur when another force comes in the system from outside at different times. The projectile motion gets the information of the $V_0$ initial velocity and the initial angle ($\Theta$). If air friction is included in the system it creates an external force and some other parameters that are air density ($\rho$), the mass of the object (m), the dimensional constant (C), and the cross-sectional area of the projectile (A) are needed to calculate this air friction force ($F_d$) as in Equation (3.5). Equation (3.7) and Equation (3.8) shows that $F_d$'s X-axis and Y-axis values respectively. In Equation (3.6), D is the drag coefficient. The weight of the mass (W) is calculated with multiply the gravitational acceleration (g) and the mass of the object (m) such as $W = gm$. The negation in Equation (3.7) says that air friction force slows the object. Also, the negation in Equation (3.8) shows that the projectile drops.

$$F_d = DV^2 \tag{3.5}$$

$$D = \frac{\rho CA}{2} \tag{3.6}$$

$$F_{dx} = -F_d \cos \Theta \tag{3.7}$$

$$F_{dy} = -W - F_d \sin \Theta \tag{3.8}$$

Physics is all about rates of change. During the motion, the air friction affects the projectile every the smallest time interval. To examine all of these changes, Euler's numerical method can be used. Euler's method is a simple way to approximate the solution of ordinary differential equations numerically. Assuming the Equation (3.9), the solution is $y = f(x)$.

$$\frac{dy}{dx} = f'(x) \tag{3.9}$$

Euler's numerical method can be represented as in Figure 3.2. This figure shows that every change of the motion.

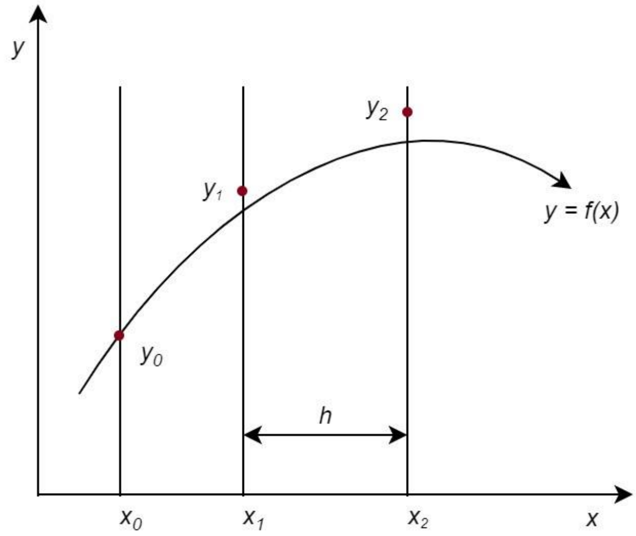



Figure 3.2 Representation of Euler's numerical method

If we combine Figure 2 and Equation (3.9), we can say that Euler's method is numerically examining each Δx interval which means $x_{i+1}$-$x_i$ from a known starting point ($x_0$, $y_0$) as in Equation (3.10). Thus, the solution is $y = f'(x)\Delta x$.

$$\frac{dy}{dx} \cong \frac{\Delta y}{\Delta x} \tag{3.10}$$

Equation (3.10) can be expanded such as in Equation (3.11). As known, the acceleration (a) is the derivation of the velocity (V) and time (t) and the velocity is the derivation of the range (x) and time. Therefore, the system of equations in Equation (3.12) is obtained. Here, Δt represents the smallest possible time interval.

$$
\begin{aligned}
x_n &= x_{n-1} + \mathit{\Delta} x \\
y_n &= y_{n-1} + f'(x_{n-1})\mathit{\Delta} x
\end{aligned} \tag{3.11}
$$

$$
\begin{aligned}
t_n &= t_{n-1} + \mathit{\Delta} t \\
x_n &= x_{n-1} + v_{n-1}\mathit{\Delta} t \\
V_n &= V_{n-1} + a_{n-1}\mathit{\Delta} t \\
a_n &= a
\end{aligned} \tag{3.12}
$$

# CHAPTER 4
# APPLICATION

## 4.1 Model

The developed model offers the user two options asking if there will be air friction. Then, the model offers two more options. One of these options takes the initial velocity and the initial angle. The other option needs the resultant vectors of the initial velocity which are $V_x$ and $V_y$ from the user. Also, if the user has not chosen air friction, the system offers another option that gets the range and the initial vector. A basic scheme of the model is seen in Figure 4.1.

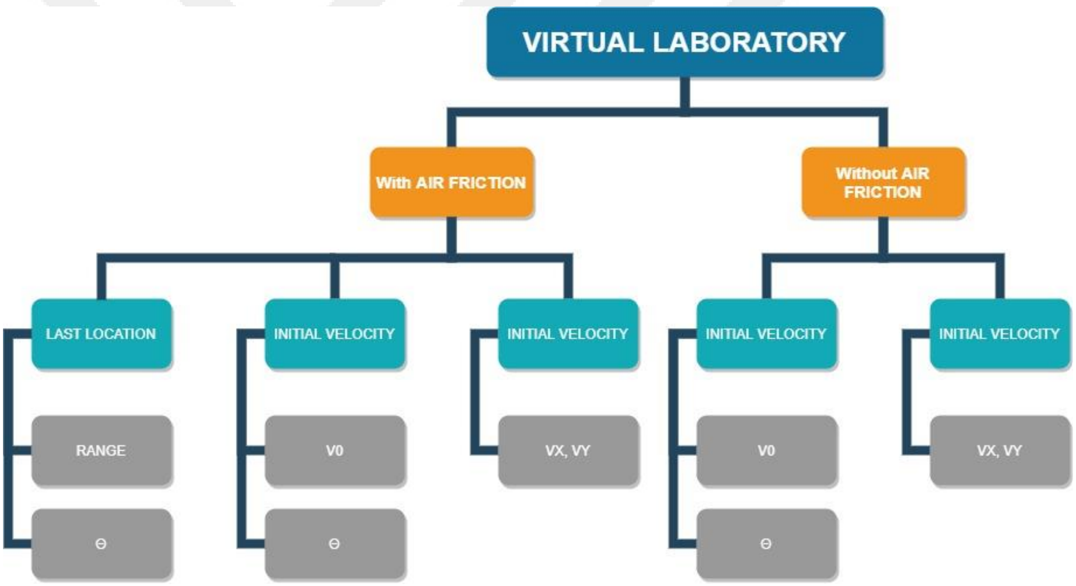



Figure 4.1 The basic scheme of the developed model

There are no other forces to cease or decrease the initial force except air friction in our environment. This problem is called "projectile movement with air resistance". In order to easily calculate, gravitational acceleration (g) is chosen as 9.8 m/s$^2$. If the user selects to enter the $V_x$ initial velocity on the X-axis and the $V_y$ initial velocity on the Y-axis are given as in Equation (4.1). The initial angle can be calculated using arctangent value as in Equation (4.2).

$$V_0 = \frac{V_x}{\cos \Theta} \quad V_0 = \frac{V_y}{\sin \Theta} \tag{4.1}$$

$$\arctan\left(\frac{V_y}{V_x}\right) = \Theta \tag{4.2}$$

In cases of there is air friction, the developed model needs the air friction force ($F_d$) value. As mentioned Method section, the model needs other parameters. As it is known, the force equals the multiplication of the acceleration and the mass according to Newton's second law ($F =$ ma). In light of this law, the values of acceleration (a) on the X and Y axis can be calculated as $a_x = F_{dx}/m$ and $a_y = F_{dy}/m$ respectively. The last parameter is the time interval ($\Delta$t). Now we can find the range (x) by placing these values in Equation (3.12) for each time. It can be impossible to find initial values if we have only the endpoint of the motion. The main reason for this is the calculation of the next point of movement in each time interval. Therefore, since we only have an endpoint, we do not know the processes in between.

## 4.2 Implementation

To implement the proposed model, three different technologies are used. Although our study is not a computer game, Unity is a suitable environment for our work. The most suitable programming language for our study is C# due to its strong object-oriented capability and Unity compatibility. Equations of mechanics are modeled and simulated using the C# programming language in .NET framework. To create a VR laboratory Unity Game Engine is used. Also, the developed laboratory should be observed via an HMD. Because of that, we used the Oculus Rift S VR device.

.NET or Microsoft .NET is an open-source and cross-platform development platform, which has a collection of languages and libraries. In short, .NET is a software development framework. With .NET, multiple languages, editors, and libraries can be used to build web, mobile, desktop, gaming, and IoT.

.NET has three programming languages that are C#, F#, and Visual Basic. C# is a simple, modern, object-oriented, and type-safe programming language. F# is a cross-platform, open-source, functional programming language for .NET. It also includes object-oriented and imperative programming. Visual Basic is an approachable language with a simple syntax for building type-safe, object-oriented applications (Microsoft, 2020a).

C# or C# .NET is an elegant and type-safe object-oriented language that enables developers to build a variety of secure and robust applications that run on the.NET Framework. To create Windows client applications, XML Web services, distributed components, client-server applications, video games, database applications, etc., the C# programming language can be used (Microsoft, 2020a).

Unity is a cross-platform game engine for creating games in both 2D and 3D. Unity supports building games for many platforms such as iOS, Android, Windows, PlayStation, etc. Since its release in 2005, Unity is one of the most popular game engines. Unity gives the ability to the users to create games and experiences in both 2D and 3D. For the main scripting in Unity, C# is used. Unity allows the specification of texture compression and resolution settings for each platform that the game engine supports. Unity editor is supported on Windows and macOS. An editor is available for Linux as well but it is in an experimental stage (GeeksforGeeks, 2020).

Oculus Rift S is a VR headset released by Oculus VR. It has an LCD visor. Its resolution is 1280x1440 per eye. The speed of the screen refreshment is 80 Hz (Oculus, 2020a).

As aforementioned, our study is not a video game however there are similar mechanics in our VR laboratory. The developed virtual laboratory allows the user to keep track of all the motion. In this way, we provide to show the user all rates of changes.

### *4.2.1 Implementation of Mechanics Equations*

The most important part of our study is the correct simulation. For this, mechanics equations must be modeled. As previously mentioned, there are two components of projectile motion. In our study, air friction affects the movement on the X-axis. The motion on the Y-axis is only affected by gravitational acceleration.

In our study, the main motion is chosen as projectile motion. However, as is known, it is the combined form of more than one motion. These are horizontal and vertical motions. The initial position of projectile motion is seen in Figure 3.1. The state of the motion before reaching the maximum height is as in Figure 4.2.

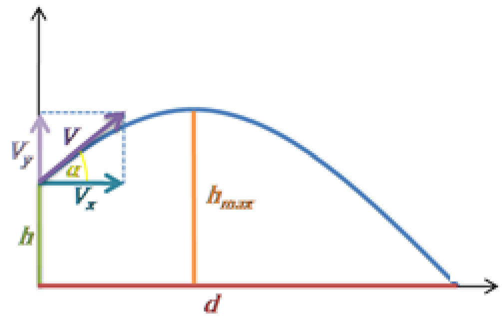



Figure 4.2 An example of projectile motion before reaching the maximum height (PhysicsCatalyst, 2019)

When the motion reaches the maximum height, it becomes the state of Figure 4.3. At this point, it is called as the horizontally launched projectile motion. In Figure 4.3, the Y-axis component's value of the $V_{max\_h}$ velocity is 0. If there is no air friction in the system, the X-axis component is the initial value. If there is air friction, the X-axis value of the $V_{max\_h}$ value will be less than the initial speed.

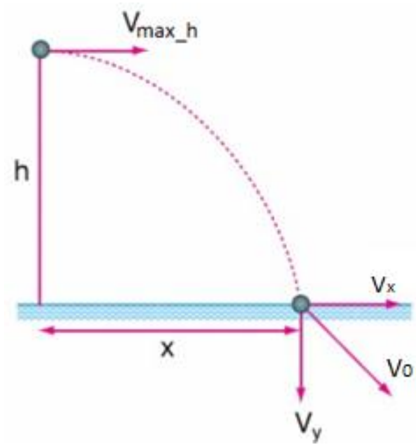



Figure 4.3 Horizontally launched projectile motion

Although projectile motion passes through physical positions as in Figure 4.2 and Figure 4.3, it is basically a combination of vertical motion and horizontal movement as in Figure 4.4.

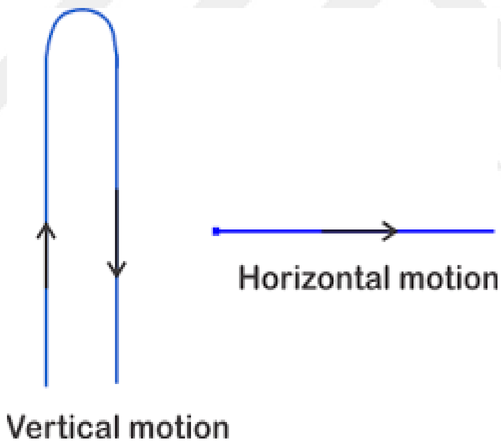



Figure 4.4 Vertical motion and horizontal motion (PhysicsCatalyst, 2019)

As a requirement of our study, the user should experience all of the aforementioned states. All of these states occur when the motion begins. Therefore, according to the moment when the user pauses the motion, the remaining parts of the motion should be recalculated and the object should continue its route.

The entire trajectory of the object can be found with basic motion equations. If there is no air friction in the system, the time of flight can be found using $t_{flight} = 2V_{0y}/g$. With the help of the time of flight, $R_{max} = V_{0x}t_{flight}$ or $R_{max} = 2V_{0x}V_{0y}/g$

equations can be used for the maximum distance. Also, due to the fact that the maximum height of the motion depends on Y-axis velocity, the time of flight, and gravitational acceleration, we can find maximum height using $h_{max} = gt_{flight}^2/2$.

Until this point, we talked about the system without air friction. Air friction affects the object every smallest possible time interval during the motion. Practically, it can not be possible to calculate each step. Thus, a predefined time interval should be determined. If the user did not choose any time interval, we accept it as 1 ms, in our study.

### *4.2.2 Implementation of VR Laboratory*

In our work, whenever the user wants, s/he can pause the motion and examines outputs of the paused situation. At this point, we used other motion equations previously mentioned. Unity's coding environment starts with two default functions: *start* and *update*. The function *start* is used to initialize the program. The function *update* is to calculate changes during program execution. Based on values given by the user the maximum height, the maximum range, and the time of flight can be calculated into the function *start*. All changes in each step of the time interval are done into the function *update*.

In order for the thrown object to move with a smooth trajectory, it is necessary to have values in as little time intervals as possible. Choosing the time interval correctly depends a bit on the hardware features. Although we numerically calculate very small time intervals, Oculus Rift S can draw them completely. As mentioned in previous sections, Oculus Rift S has an 80 Hz refreshment rate. This means it is capable to draw 80 frames per second. In other words, it draws 1 frame in 12.5 milliseconds. Consequently, we have 12.5 milliseconds for calculating the results of each step according to our time interval, sending these results to Oculus Rift S, and processing and drawing there.

According to experiments on the function *update*, Unity executes this function 130 times per second approximately. This means each execution longs nearly 8 milliseconds. Because of that, we choose the time interval as 8 milliseconds for the motion without air friction. In this way, it remains up to 4.5 milliseconds for Oculus Rift S to display the results.

In Algorithm (4.3), projectile motion without air friction is shown. The variable *t_interval* keeps the time interval. We know the maximum height, maximum range, and time of flight, as aforementioned. Then, we can decide how many steps the movement will be calculated using the ratio of the time of flight and time interval as line 2. To draw a smooth animation of projectile motion, we need ranges, height, and Y-axis velocity values for each step. So, we keep them into corresponding arrays. After the calculation process, all arrays and initial X-axis velocity are sent to the drawing process.

(4.3)

```
   Draw_Motion(V0_x, V0_y)
1  t_interval = 0.008
2  step = t_flight / t_interval
3  R[] = {0}
4  h[] = {0}
5  V_y[] = {0}
6  V_x[] = {0}
7  FOR i = 0 to step
8    R[i] = V0_x * (i * t_interval)
9    h[i] = g * (i * t_interval) * (i * t_interval) / 2
10   V_y[i] = V0_y - (g * (i * t_interval))
11   V_x[i] = V0_x
12 END FOR
13 FOR i = 0 to step
14   Draw_Projectile(R, h, V_y, V0_x)
15 END FOR
```

If there is air friction in the system, the acceleration changes of the object for each step should be calculated. If there are any acceleration changes in the system, this means the velocity of the object changes. As mentioned in the previous chapters, we can find each acceleration using Newton's second law ($F = ma$). The X-axis component of the acceleration is found with $a_x = -F_d \cos \Theta / m$ and the Y-axis component is found with $a_y = -g - F_d \sin \Theta / m$. So we should update our algorithm. In Algorithm (1), lines 10 and 11 are respectively changed to:

- `V_y[i] = V_y[i - 1] + (t_interval * (a_y[i - 1]))`
- `V_x[i] = V_x[i - 1] + (t_interval * (a_x[i - 1]))`

After calculating the projectile's all possible states, we can set the VR laboratory up. Parameters of *Draw_Motion* function in Algorithm (1) are axis components of the initial velocity $V_0$. In the program, we collect necessary parameters from the user via the interface.

As in Figure 4.5, at the start of the experiment, the program asks the user whether air friction in the system.


Figure 4.5 Opening menu of the developed virtual laboratory

According to user choice, there are two types of sub-menu in the program. As mentioned earlier, if there is air friction in the system, the program presents to the user two other options. The user can enter the initial velocity and the initial angle or the X-axis and Y-axis components of the initial velocity as inputs. The sub-menu of this part can be seen in Figure 4.6.

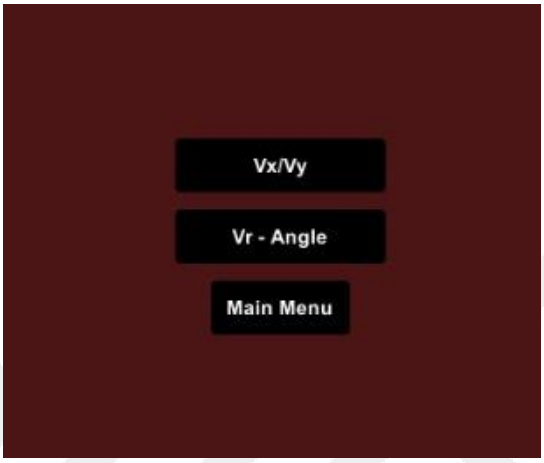



Figure 4.6 Sub-menu of the program for air friction

If there is no air friction, the program can do reverse engineering for the input of the maximum range. Also, this sub-menu has features with the previous sub-menu such as Figure 4.7.


Figure 4.7 Sub-menu of the program, if there is no air friction

The experiment setups for both sub-menu are nearly the same. The first step of the program is to decide the trajectory of the object. After the user enters the parameters, the trajectory is calculated and shown as in Figure 4.8.

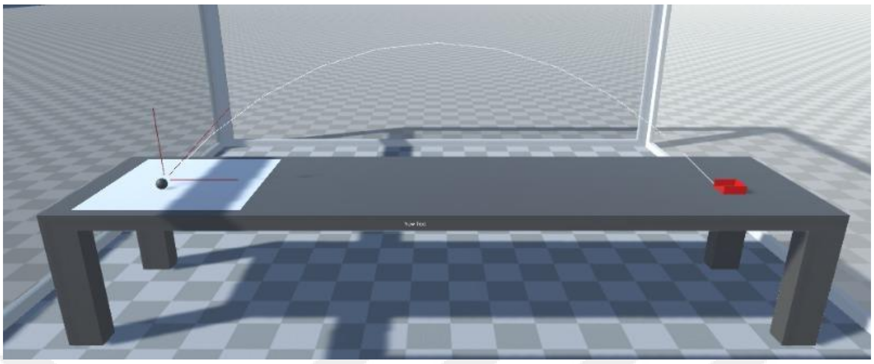


Figure 4.8 The trajectory of a projectile motion according to initial parameters

When the user pauses the motion, the latest position of the projectile can be seen on the trajectory as in Figure 4.9.

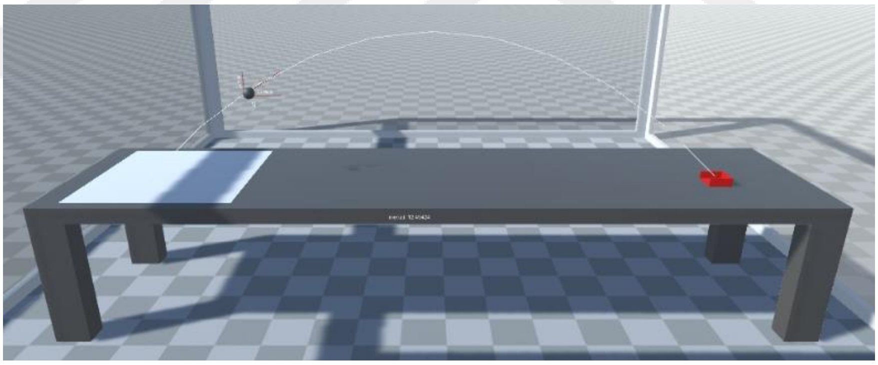


Figure 4.9 The position information of the projectile after the motion starts

Some times the user does not want to see the trajectory because of the crowd of the screen. Then, there is a little feature for hiding the trajectory. This case is seen in Figure 4.10.

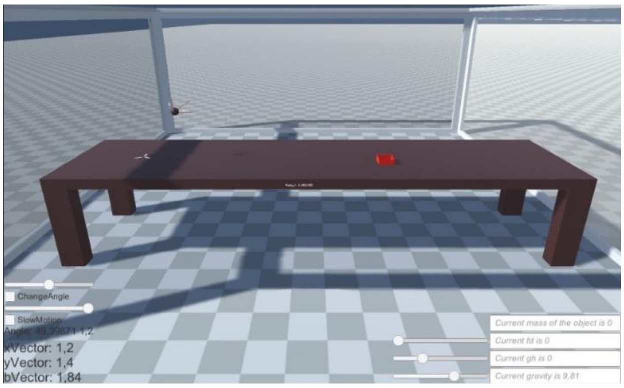



Figure 4.10 An example of the setup of an experiment

We can see the main setup of the experiment environment in Figure 4.10. On the left bottom of the screen, the user can adjust the initial angle. The red box on the table is the goal of the motion. Its location is determined according to initial parameters. The user can see the range of the motion center of the table as in Figure 4.11.

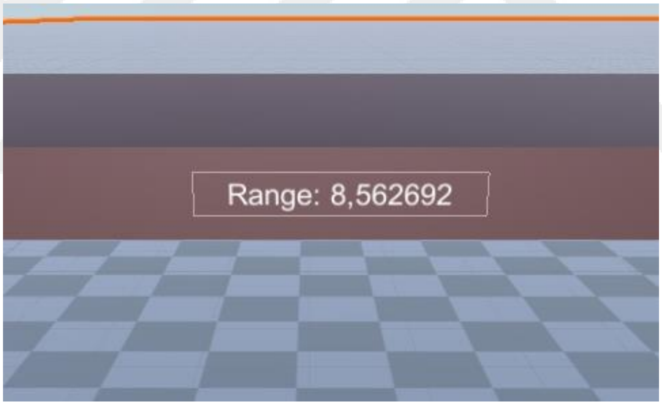



Figure 4.11 An example of the range of a projectile motion

The user can pause the motion whenever s/he wants and sees the recent velocity and vector of the projectile as in Figure 4.12.

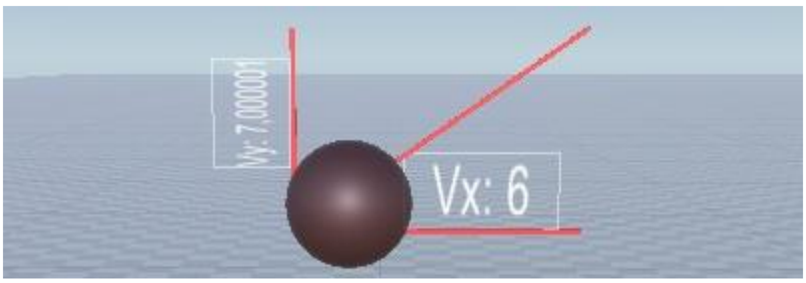



Figure 4.12 An example of the current values of the projectile

### 4.3 Results

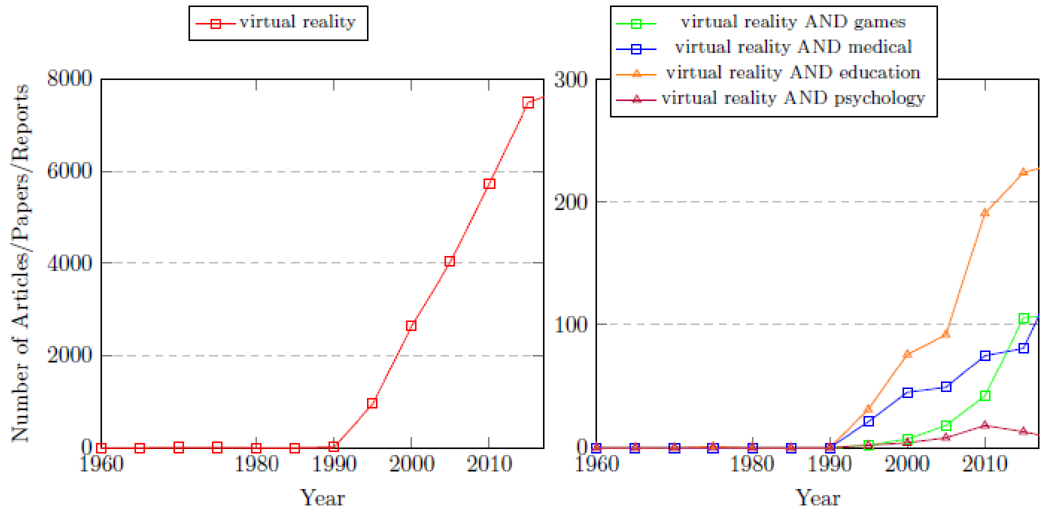
After several tests to prove our simulation correct, successful results have been obtained in both air friction and air frictionless environments. The robustness of the system is measured by how accurately it gives the results. Especially when there is air friction in the system, the comparison between the results of each execution of the motion shows us if the time interval between each calculation step is narrowed, more precise results are obtained. In other words, this narrowing brings us closer to the true nature of the motion. As in Table 4.1, air friction changes the range of the motion. On the other hand, as we mentioned before, the initial velocity of the motion, when there is air friction, cannot be found if we have only the range information.

In Table 4.1, for each set, each input value represents the same initial values. For example, considering the first set, if we choose the initial velocity as 80 and initial angle as 60, the X-axis and Y-axis values of this initial speed will be 40, 69.3 respectively. Therefore, it can be seen that air friction is one of the major factors, which deviates the projectile from its trajectory. For the 1st input set, the maximum range of the experiment with air friction is nearly three times as much as the air frictionless.

Table 4.1 Result sets of the developed simulation

| | | | With air friction (Drag coefficient = 0.005) | Without air friction |
|---|---|---|---|---|
| 1st set | 1st option | $V_{0x} = 40$<br>$V_{0y} = 69.3$ | Range = 174.4m | Range = 565m |
| | 2nd option | $V_0 = 80$<br>$\Theta = 60$ | Range = 174.4m | Range = 565m |
| | 3rd option | Range = 565m<br>$\Theta = 60$ | - | $V_0 = 80$ |
| 2nd set | 1st option | $V_{0x} = 21.2$<br>$V_{0y} = 21.2$ | Range = 71m | Range = 91.7m |
| | 2nd option | $V_0 = 30$<br>$\Theta = 45$ | Range = 71m | Range = 91.7m |
| | 3rd option | Range = 91.7m<br>$\Theta = 45$ | - | $V_0 = 30$ |

We know that works on VR increasing especially since the 90s as in Figure 4.13.a. The use of VR in education has been increasing since 2000, compared to other areas such as in Figure 4.13.b.




a) Number of paper about VR b) Working areas of VR since 1960

Figure 4.13 Reported works about VR (Kenwright, 2019)

Many studies on VR report that a high percentage of students learn the topic when they use VR. It is known that, especially, applied sciences' courses need a practice environment such as a laboratory. On the other hand, with the help of VR technologies, we began to carry physical laboratories into a virtual laboratory. The studies about the performance comparison between traditional and virtual laboratories prove that students' preferences tend to VR technologies as in Figure 4.14.

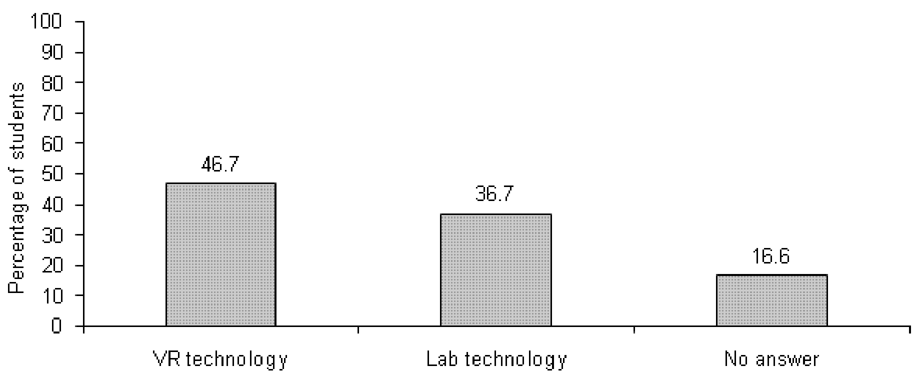



Figure 4.14 Preference for different technologies among study group (Nadan & Watson, 2011)

## CHAPTER 5
## CONCLUSION

### 5.1 Conclusion

We begin this thesis with an assertion that with the help of a virtual laboratory, we can facilitate the learning process of mechanics. We can accept that we have reached our goal by completing the virtual laboratory design. In addition, we predict that students who experience our system will increase their learning performance.

The first step we take on this path is to simulate mechanics equations. Even if we had designed a virtual laboratory only for the projectile motion, it was necessary to investigate all physics mechanics. Due to the air friction phenomenon, the system has the concept of force. Thus, our system has not only been a simple motion inspection environment but has studied almost all Newtonian mechanics which are statics, kinematics, and dynamics. By the way, Newtonian mechanics are the topic that our target population encounters the most.

Our study is work on kinematics basically if we ignore air friction. However, our system has a feature to calculate air friction thus the field of dynamics is in our working field. On the other hand, the user can pause the motion whenever he/she wants. In this situation, the user can see all the statics parameters of the projectile. As we have demonstrated in the previous chapter, our simulation method works successfully. This proves that Euler’s numerical method can be a good choice for the solution of mechanics and, maybe, other physics fields.

The second step is to visualize simulations we created in VR. At this point, we used Unity to digitalize the simulation and Oculus Rift S to experience the environment. However, there are several types of design and visualization technologies.

As a result of the investigation of our study and similar works, there is a future for VR technologies. With the advancement of hardware, the costs will drop and these technologies will be more reachable.

### 5.2 Future Works

In this thesis, the benefits of VR in education, especially in mechanics teaching, are examined in detail. The thesis put forward has been tried to be proved. We can say that we achieved our goals. However, this study is a stepping stone for future systems. Many larger studies can be done with modules to be added to this study or inspired by this study. Let's discuss what can be done.

We can examine the future of our study’s contributions from three different points of view. The most important one of our contributions is the contribution to the field of education. The designed VR laboratory can be upgraded in two different ways. The first way allows us to lead other subjects such as chemistry, history, etc. to be moved to VR with a similar approach. Although our study was made only within the framework of mechanics, similar studies can be done in any field with correct simulation methods. The point to be considered here is the correct mathematical models and VR visuals design accordingly.

The second point of view is about the advancement of our study. As known, in nature, motion does not only affect air friction. There are other factors such as the spin of the object and the surface friction. But, if the object spins at the same time in projectile motion, there will be a direction towards the depth axis (Z-axis). In this case, the simulation calculations change. Along with the parameters used, drawings and visuals in VR should also be updated. The surface friction affects the motion after the object hits the ground. If the proposed VR laboratory is enlarged, the surface friction can be important. Thus, a more advanced virtual mechanics laboratory can be obtained. The main reason that we do not include the spin motion in this study is that the subject of air friction, which is not in the curriculum of the target population, is difficult to adequately understand. Initially, it was thought that the addition of these parts would make the learning process more difficult. Besides, our work can be enlarged by adding other areas of physics such as thermodynamics, electromagnetism, etc.

Another issue that our study can help future studies is hardware developments. As we mentioned earlier, standard VR devices have the equipment following the designers' claims. However, as the training simulations and virtual laboratories increase, devices compatible with VR will be needed. For example, a test tube-shaped input device for chemistry or biology teachings can be designed. Improvements can be made in the content of the course in HMDs.

With the use of VR in education, VR designer needs will increase and change. Framework software specific to the field of education will be needed. Sometimes simulations are designed correctly, but it is wrong to display it in VR. Therefore, we cannot achieve the expected effect. The main reason for this situation is that today, common software environments are used to design a laboratory. Our work and the presence of other studies like this can create a new area for the programming language or software environment designers, thereby it can reduce the required workforce for repetitive work, such as virtual lab design. As is known, developers in many places in the world are doing similar works. VR teaching designs are made from the beginning of each study. The "repetitive jobs" we just mentioned increase the development time. With the help of our work, developers may be interested. Thus, framework software for educational purposes can be developed.

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