Multimodal and Networked Social VR Learning

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Thesis submitted in partial fulfilment of the requirements for the *Masters' of Science degree in Computer Science and Engineering*

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Multimodal and networked social VR learning

ABSTRACT

Since the early stages of formal educational activities, the learning process was standardized as a procedure that required social interaction between instructors and learners in order to be facilitated. Until now, the standard way of ‘learning’ is through attending a class at a school or university. There are many research attempts that target to accommodate VR technology in the learning process in order to create a much realistic as possible an environment for the learner and simulate real-life social interaction scenarios in which the learner can test his newly acquired skills and use them to solve a problem or perform a task. There are some basic educational theories on which one can be based in order to create such learning environment, suitable for instructional usage and through that, enhancing the learning process and facilitating learning in a way that might be extremely difficult otherwise. Today’s MOOC platforms like Coursera or Udemy can provide a fairly accurate simulation of the learning process inside a classroom, but limited in social interaction due to the lack of ‘presence’ (‘feeling of being and doing there’ in a virtual environment).

On that end, we propose an innovative online social VR platform which can simulate a number of social interaction cues presented in a real classroom. We implemented a University-like virtual auditorium environment with which the user can attend a course seminar via a mobile VR device or his/her smartphone. Our Social Virtual Learning platform is capable of simulating the entire process of a lecture utilizing a Server-Host-Client architecture which can simulate the auditorium , the professor and the students. To the best of our knowledge, there is no such platform that provides a highly accurate virtual collaborative learning experience that could ‘realistically simulate’ the social interaction cues of a real physical attendance.

Πολυτροπική και δικτυωμένη κοινωνική μάθηση σε Εικονική Πραγματικότητα

ΠΕΡΙΛΗΨΗ

Από τα πρώτα στάδια των εκπαιδευτικών δραστηριοτήτων, η διαδικασία εκμάθησης λειτουργούσε μέσω της φυσικής επαφής μεταξύ των ανθρώπων για να γίνει σωστή η διεξαγωγή της. Μέχρι σήμερα, ο τρόπος με τον οποίο διεξάγεται η μάθηση είναι παρακολουθώντας το ‘μάθημα’ από κοντά σε ένα σχολείο ή πανεπιστήμιο. Υπάρχουν πολλές έρευνες οι οποίες σκοπεύουν να συνδυάσουν την εικονική πραγματικότητα με τη διαδικασία της μάθησης προσπαθώντας να δημιουργήσουν ένα ρεαλιστικό περιβάλλον για τον μαθητευόμενο και να εξομοιώσουν πραγματικά σενάρια στα οποία ο μαθητευόμενος μπορεί να δοκιμάσει τις γνώσεις του και να προσπαθήσει να λύσει κάποιο πρόβλημα. Υπάρχουν κάποιες βασικές θεωρίες στις οποίες μπορεί κάποιος να βασιστεί για να φτιάξει ένα περιβάλλον μάθησης, το οποίο να μπορεί να χρησιμοποιηθεί για εκπαιδευτικό σκοπό και μέσα από αυτό, να βελτιώσει τη διαδικασία μάθησης και να κάνει την διεξαγωγή της με έναν τρόπο που θα ήταν πολύ δύσκολο αλλιώς. Τα σημερινά συστήματα όπως το Corsera ή το Udemy μπορούν να παρέχουν μια αρκετά καλή εξομοίωση της διαδικασίας μάθησης, αλλά υστερούν στην αίσθηση της ‘παρουσίας’. (‘Την αίσθηση πως του βρίσκομαι και κάνω’ μέσα σε εικονικό περιβάλλον).

Σε αυτό το σημείο, προτείνουμε ένα καινοτόμο σύστημα το οποίο μπορεί να παρέχει σχεδόν την ίδια εμπειρία στο χρήστη με αυτή που θα έχει σε ένα αληθινό πανεπιστήμιο. Δημιουργήσαμε ένα σύστημα με το οποίο ο χρήστης μπορεί να παρακολουθήσει μαθήματα σε ένα πανεπιστήμιο μέσα από μία φορητή συσκευή εικονικής πραγματικότητας ή ένα απλό τηλέφωνο. Ο εικονικός μας χώρος μάθησης μπορεί να εξομοιώσει ολόκληρη τη διαδικασία μιας διάλεξης ενός πανεπιστημίου χρησιμοποιώντας μία αρχιτεκτονική τύπου Πελάτης- Διακομιστής η οποία μπορεί να εξομοιώσει το πανεπιστήμιο ως ένα αντικείμενο, το καθηγητή και τους φοιτητές. Από όσο γνωρίζουμε, δεν υπάρχει άλλο παρόμοιο σύστημα το οποίο να παρέχει μια εύστοχη και συνεργατική εμπειρία μάθησης και βασισμένοι σε αυτό, στοχεύσαμε να κατασκευάσουμε ένα εικονικό περιβάλλον μάθησης που θα μπορούσε να αντικαταστήσει την ανάγκη της από κοντά παρακολούθησης.

Attestation

I understand the nature of plagiarism, and I am aware of the University's policy on this.

I certify that this dissertation reports original work by me during my University project except for the following (*adjust according to the circumstances*):

- The technology for streaming through a Unity3D Camera Object was implemented by RockVR and was downloaded from the Unity Asset Store.
- The library which receives and renders a stream on the mobile phone was created by VideoLAN.
- The MAGES SDK created by ORamaVR

Signature **Date**

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1 Introduction

1.1 Background and Context

Learning is the process of acquiring new, or modifying existing, knowledge, behaviours, skills, values, or preferences [1]. The ability to learn is possessed by humans, animals, and some machines; there is also evidence for some kind of learning in certain plants. Some learning is immediate, induced by a single event (e.g. being burned by a hot stove), but much skill and knowledge accumulates from repeated experiences. The changes induced by learning often last a lifetime, and it is hard to distinguish learned material that seems to be "lost" from that which cannot be retrieved.

Humans learn before birth and continue until death as a consequence of ongoing interactions between people and their environment. The nature and processes involved in learning are studied in many fields, including educational psychology, neuropsychology, experimental psychology, and pedagogy. Research in such fields has led to the identification of various sorts of learning. For example, learning may occur as a result of habituation, or classical conditioning, operant conditioning or as a result of more complex activities such as play, seen only in relatively intelligent animals [2]. Learning may occur consciously or without conscious awareness.

Learning can also be defined as a process that occurs within nebulous environments of shifting core elements – not entirely under the control of the individual [3]. Learning (defined as actionable knowledge) can reside outside of ourselves (within an organization or a database), is focused on connecting specialized information sets, and the connections that enable us to learn more are more important than our current state of knowing.

Learning environment refers to the diverse physical locations, contexts, and cultures in which students learn [4]. Since students may learn in a wide variety of settings, such as outside-of-school locations and outdoor environments, the term is often used as a more accurate or preferred alternative to *classroom*, which has more limited and traditional connotations—a room with rows of desks and a chalkboard, for example.

The term also encompasses the culture of a school or class—its presiding ethos and characteristics, including how individuals interact with and treat one another—as well as the ways in which teachers may organize an educational setting to facilitate learning—e.g., by conducting classes in relevant natural ecosystems, grouping desks in specific ways, decorating the walls with learning materials, or utilizing audio, visual, and digital technologies. And because the qualities and characteristics of a learning environment are determined by a wide variety of factors, school policies, governance structures, and other features may also be considered elements of a “learning environment.” [4]

A virtual learning environment (VLE) is a set of teaching and learning tools designed to enhance a student's learning experience by including computers and the Internet in the learning process. [5] The principal components of a VLE package include curriculum mapping (breaking curriculum into sections that can be assigned and assessed), student tracking, online support for both teacher and student, electronic communication (e-mail, threaded discussions, chat, Web publishing), and Internet links to outside curriculum resources. In general, VLE users are assigned either a teacher ID or a student ID. The teacher sees what a students sees, but the teacher has additional user rights to create or modify curriculum content and track student performance. There are a number of commercial VLE software packages available, including Blackboard, WebCT, Lotus LearningSpace, and COSE [5].

1.2 Scope and Objectives

The main goal of this thesis is to create and evaluate the possibility of having a fully social VR based Learning Environment in which students will be able to attend any school or university without the need of relocation and attendance or lifestyle costs. It is supposed to give people from all around the world the ability to participate any lecture from any university from their home using a simple VR or Non-VR based mobile device such as the Oculus Quest VR Headset or a simple smartphone or tablet. The application is designed to be easy to use in order to satisfy the majority of learners without the need of having any strong technological knowledge.

1.3 Achievements

With this project we managed to create a VR and Non-VR capable multimodal cross-platform application that can simulate the experience gained from actually attending a lecture at a university. With this program everyone has the ability to attend his or her university of choice without worrying about attendance costs or relocations. Everyone can sit at his home and through his mobile device, VR or Non-VR, can join and attend lectures from any university that has integrated this Virtual Learning Program.

1.4 Overview of Dissertation

In the following sections we will analyse how we were able to create this Virtual Learning Environment, the techniques used and how we managed to use simple devices as end points with the capabilities of simulating social user interactions while attending a real course, by being able to truly attend a lecture from the comfort of his home. We will see how the base application was created, the one that represents the classroom itself and how the students were able to join this lecture and attend normally. We will also differentiate student profiles using mobile VR devices from the ones that do not have a mobile VR device and how they can use their own smartphones or tablets to join the class.

2 State-of-The-Art

This section describes previous work on virtual learning environments as well as other similar projects and publications on VLE's.

2.1 The early stages of virtual learning environments

The idea of having virtual environments for learning came up several years ago even before virtual reality was achieved. It started as a base concept of having the learners play a game in which they would accelerate the process of learning. One of the first ever projects that tried to implement a 3D virtual learning environment was created in Australia back in 2002 and was based on the three principles of constructivism [6]. These principles explain how one can facilitate learning through a virtual environment and that one can actually increase his knowledge base by interacting with the virtual world.

Figure 1: The University Campus as shown in the application

That project was about a virtual laboratory, representing a chemistry lab at Charles Strut University of Australia (CSU) in which students were practicing some chemical experiments. Everything inside the virtual laboratory was identical to the real one and was created that way for students to know exactly where each tool they would need would be. The application used was a regular one, meaning that it was played with a monitor and required no hard to find equipment.

Figure 2: The chemistry laboratory

By the end of the experiment, the students were tested inside the real lab doing the same experiments as they did in the virtual one and was noticed that some of them were able to fulfil their task. By doing the experiment in the virtual environment they learned how replicate and remember the steps needed in order to redo the experiment. As said, we here have some students (learners) that actually learned or increased their knowledge representation.[6]

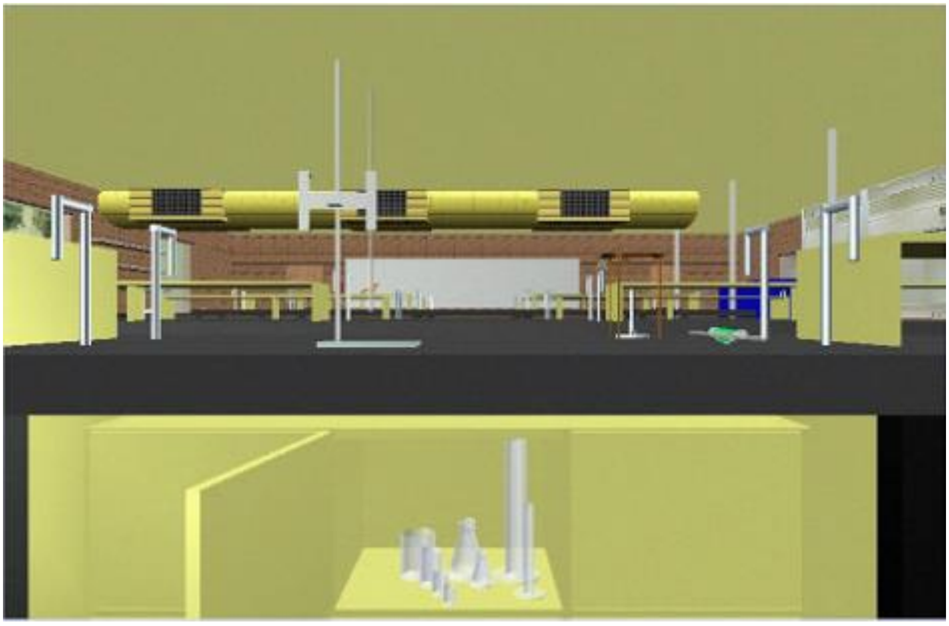


Figure 3: Tools inside the chemistry lab:

As of today’s standards, there are far more advanced virtual laboratories that can provide a more realistic experience, which is almost equal the experience gained from a real laboratory [7].

Figure 4: The LABSTER virtual chemistry laboratory

2.2 The Impact of Serious Games in the Learning Process.

Based on applications similar to the one explained above, a new kind of learning environment was invented, merging the aspects of learning and entertainment. [8] These applications were named Serious Games. The term *Serious Games* comes from the identity of the application itself, which is a game supposed to entertain the user and the fact that the player gets to learn something from playing the game. [8][9] It is a game with a serious nature around it, trying to maintain the player's attention through satisfaction and enjoyment, and at the same time educate him.

This games were firstly presented as simulations to improve education, both in and out of the classroom. [10] These games were called ‘pen-and-paper’ based games as the video game industry was not yet established.

The use of games in educational circles has been practiced since at least the twentieth century. Use of paper-based educational games became popular in the 1960s and 1970s, but waned under the Back to Basics teaching movement.[11] (The Back to Basics teaching movement is a change in teaching style that started in the 1970s when students were scoring poorly on standardized tests and exploring too many electives. This movement wanted to focus students on reading, writing and arithmetic and intensify the curriculum [12])

The early 2000s saw a surge in different types of educational games, especially those designed for the younger learner. Many of these games were not computer-based but took on the model of other traditional gaming systems both in the console and hand-held formats. In 1999, LeapFrog Enterprises introduced the LeapPad, which combined an interactive book with a cartridge and allowed kids to play games and interact with a paper-based book. Based on the popularity of traditional hand-held gaming systems like Nintendo's Game Boy, they also introduced their hand-held gaming system called the Leapster in 2003. This system was cartridge-based and integrated arcade–style games with educational content. [13] Also in the 2000s, educational games saw an expanse into sustainable development with titles such as Learning Sustainable Development in 2000 and Climate Challenge in 2006.[14]

By 2010, serious games had evolved to incorporate actual economies like *Second Life*, in which users can create actual businesses that provide virtual commodities and services for Linden dollars, which are exchangeable for US currency. In 2015, Project Discovery was launched as a serious game. Project Discovery was launched as a vehicle by which geneticists and astronomers with the University of Geneva could access the cataloging efforts of the gaming public via a mini-game contained within the *Eve Online* massively multiplayer online role-playing game (MMORPG). Players acting as citizen scientists categorize and assess actual genetic samples or astronomical data. This data was then utilized and warehoused by researchers. Any data flagged as atypical was further investigated by scientists.

2.3 Moving from a Virtual Learning Environment(VLE) to a Massive Open Online Course (MOOC).

As technology was improving rapidly in the past years, the design pattern of a VLE needed to change. It is extremely difficult to have all students in the same place either for attending a real class or a virtual. There are many factors taking place that restrict the students and prevent them from attending their desired school or university. The idea was to implement a learning environment that would be accessible from anywhere and would grant the privilege to the learner to communicate directly with the teacher.

A **massive open online course** (**MOOC**) is an online course aimed at unlimited participation and open access via the web. [15] In addition to traditional course materials, such as filmed lectures, readings, and problem sets, many MOOCs provide interactive courses with user forums to support community interactions among students, professors, and teaching assistants (TAs), as well as immediate feedback to quick quizzes and assignments. MOOCs are a recent and widely researched development in distance education, [16] first introduced in 2006 and emerged as a popular mode of learning in 2012. Early MOOCs often emphasized open-access features, such as open licensing of content, structure and learning goals, to promote the reuse and remixing of resources. Some later MOOCs use closed licenses for their course materials while maintaining free access for students.

The first MOOCs emerged from the open educational resources (OER) movement, which was sparked by MIT OpenCourseWare project. The OER movement was motivated from work by researchers who pointed out that class size and learning outcomes had no established connection, with Daniel Barwick's work being the most often-cited example. Within the OER movement the Wikiversity was found in 2006 and the first open course on the platform was organized in 2007. Ten–week course with more than 70 students was used to test the idea of making Wikiversity an open and free platform for education in the tradition of Scandinavian free adult education, Folk High School and the free school movement.[17] The term *MOOC* was coined in 2008 by Dave Cormier of the University of Prince Edward Island in response to a course called *Connectivism and Connective Knowledge* (also known as *CCK08*). CCK08, which was led by George Siemens of Athabasca University and Stephen Downes of the National Research Council, consisted of 25 tuition-paying students in Extended Education at the University of Manitoba, as well as over 2200 online students from the general public who paid nothing. All course content was available through RSS feeds, and online students could participate through collaborative tools, including blog posts, threaded discussions in Moodle, and Second Life meetings.

Alongside the development of these open courses, other E-learning platforms emerged — such as Khan Academy, Peer-to-Peer University (P2PU), Udemy, and ALISON — which are viewed as similar to MOOCs and work outside the university system or emphasize individual self-paced lessons.

2.3.1 Student experience and pedagogy

2.3.1.1 Students served

By June 2012 more than 1.5 million people had registered for classes through Coursera, Udacity or edX. As of 2013, the range of students registered appears to be broad, diverse and non-traditional, but concentrated among English-speakers in rich countries. By March 2013, Coursera alone had registered about 2.8 million learners.[18] By October 2013, Coursera enrollment continued to surge, surpassing 5 million, while edX had independently reached 1.3 million.

A course billed as "Asia's first MOOC" given by the Hong Kong University of Science and Technology through Coursera starting in April 2013 registered 17,000 students. About 60% were from "rich countries" with many of the rest from middle-income countries in Asia, South Africa, Brazil or Mexico. Fewer students enrolled from areas with more limited access to the internet, and students from the People's Republic of China may have been discouraged by Chinese government policies. [19]

Koller stated in May 2013 that a majority of the people taking Coursera courses had already earned college degrees.

According to a Stanford University study of a more general group of students "active learners" – anybody who participated beyond just registering – found that 64% of high school active learners were male and 88% were male for undergraduate- and graduate-level courses.

A study from Stanford University's Learning Analytics group identified four types of students: auditors, who watched video throughout the course, but took few quizzes or exams; completers, who viewed most lectures and took part in most assessments; disengaged learners, who quickly dropped the course; and sampling learners, who might only occasionally watch lectures. They identified the following percentages in each group: [20]

Course	Auditing	Completing	Disengaging	Sampling
High school	6%	27%	29%	39%
Undergraduate	6%	8%	12%	74%
Graduate	9%	5%	6%	80%

Table 1: Percentage of students of each course:

Jonathan Haber focused on questions of what students are learning and student demographics. About half the students taking US courses are from other countries and do not speak English as their first language. He found some courses to be meaningful, especially about reading comprehension. Video lectures followed by multiple choice questions can be challenging since they are often the "right questions." Smaller discussion boards paradoxically offer the best conversations. Larger discussions can be "really, really thoughtful and really, really misguided", with long discussions becoming rehashes or "the same old stale left/right debate."

MIT and Stanford University offered initial MOOCs in Computer Science and Electrical Engineering. Since engineering courses need prerequisites so at the outset upper-level engineering courses were nearly absent from the MOOC list. Now several universities are presenting undergraduate and advanced-level engineering courses.

2.3.1.2 Educator experience

In 2013, the Chronicle of Higher Education surveyed 103 professors who had taught MOOCs. "Typically a professor spent over 100 hours on his MOOC before it even started, by recording online lecture videos and doing other preparation", though some instructors' pre-class preparation was "a few dozen hours". The professors then spent 8–10 hours per week on the course, including participation in discussion forums.

The medians were: 33,000 students enrolees; 2,600 passing; and 1 teaching assistant helping with the class. 74% of the classes used automated grading, and 34% used peer grading. 97% of the instructors used original videos, 75% used open educational resources and 27% used other resources. 9% of the classes required a physical textbook and 5% required an e-book.

Unlike traditional courses, MOOCs require additional skills, provided by videographers, instructional designers, IT specialists and platform specialists. Georgia Tech professor Karen Head reports that 19 people work on their MOOCs and that more are needed. The platforms have availability requirements similar to media/content sharing websites, due to the large number of enrolees. MOOCs typically use cloud computing and are often created with authoring systems. Authoring tools for the creation of MOOCs are specialized packages of educational software like Elicitus, IMC Content Studio and Lectora that are easy-to-use and support e-learning standards like SCORM and AICC.

2.3.2 The Benefits of MOOCs

2.3.2.1 Improving access to higher education

MOOCs are regarded by many as an important tool to widen access to higher education (HE) for millions of people, including those in the developing world, and ultimately enhance their quality of life.[16] MOOCs may be regarded as contributing to the democratisation of HE, not only locally or regionally but globally as well. MOOCs can help democratise content and make knowledge reachable for everyone. Students are able to access complete courses offered by universities all over the world, something previously unattainable. With the availability of affordable technologies, MOOCs increase access to an extraordinary number of courses offered by world-renowned institutions and teachers.

2.3.2.2 Providing an affordable alternative to formal education

The costs of tertiary education continue to increase because institutions tend to bundle too many services. With MOOCs, some of these services can be transferred to other suitable players in the public or private sector. MOOCs are for large numbers of participants, can be accessed by anyone anywhere as long as they have an Internet connection, are open to everyone without entry qualifications and offer a full/complete course experience online for free.

2.3.2.3 Sustainable Development Goals

MOOCs can be seen as a form of open education offered for free through online platforms. The (initial) philosophy of MOOCs is to open up quality Higher Education to a wider audience. As such, MOOCs are an important tool to achieve Goal 4 of the 2030 Agenda for Sustainable Development.

2.3.2.4 Offers a flexible learning schedule

Certain lectures, videos, and tests through MOOCs can be accessed at any time compared to scheduled class times. By allowing learners to complete their coursework in their own time, this provides flexibility to learners based on their own personal schedules.

2.3.2.5 Online collaboration

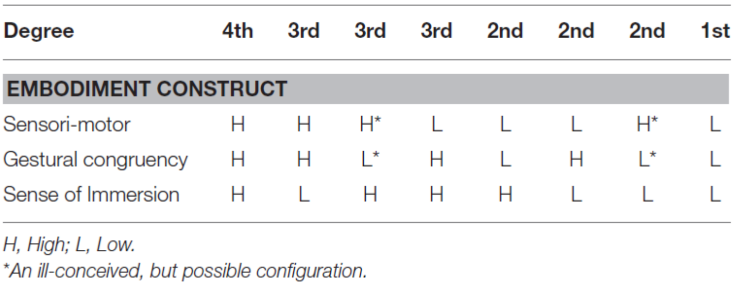
The learning environments of MOOCs make it easier for learners across the globe to work together on common goals. Instead of having to physically meet one another, online collaboration creates partnerships among learners. While time zones may have an effect on the hours that learners communicate, projects, assignments, and more can be completed to incorporate the skills and resources that different learners offer no matter where they are located.

2.4 Other Research on VR Learning

2.4.1 Embodied Education

In the recent years, there has been many research on how to facilitate the learning process through a VR headset or 3D environments on applications. Examples of research conducted on this field is learning through hand gestures using VR.

There are theories that try to achieve “Learning” through hand controls and gestures, embodying the learner’s cognition into the learning process. As an example if this theory, there was an experiment using the Microsoft Kinect Sensor. The learners had to move their hand in order to complete a gear system test (Mina C. Johnson-Glenberg, 2018). In that study, the earners that understood mechanical advantage (on a traditional test) also showed greater competency during gameplay, because they consistently chose the correct diameter gear during a virtual bike race. This is an example of how gesture can be part of both the learning situation and assessment.



Degree	4th	3rd	3rd	3rd	2nd	2nd	2nd	1st
EMBODIMENT CONSTRUCT								
Sensori-motor	H	H	H*	L	L	L	H*	L
Gestural congruency	H	H	L*	H	L	H	L*	L
Sense of Immersion	H	L	H	H	H	L	L	L

H, High; L, Low.
**An ill-conceived, but possible configuration.*

Figure 5: Construct magnitude within degrees in the Embodied Education

The above figure (Figure 1) shows the original embodied taxonomy which consisted of four delineated degrees along the continua of the three constructs.

It is said that, when learners experience high levels of presence, they suspend disbelief enough to engage meaningfully with the virtual. It is known that learning is facilitated by engagement and motivation (Csikszentmihalyi, 1997).

> **“If feeling presence connotes that the learner’s body is in the virtual world, then higher presence might also correlate with higher levels of embodiment. (Mina C. Johnson-Glenberg, 2018)”**

2.4.2 Healthcare

Virtual Reality can also be used in training for healthcare professionals. With VR they can retain crucial information and even expand their knowledge and skills (Alice Bonasio, 2019).

In healthcare, professionals are tasked with learning and retaining huge amounts of knowledge and skills. They undergo an enormous amount of training to ensure excellence when treating patients.

A critical problem that is met in healthcare is the standard for today ‘Learning Process’ with which they learn and acquire skills. Reading from textbooks and can be easily ‘forgotten’ and can cause an extremely difficult situation in the medical field.

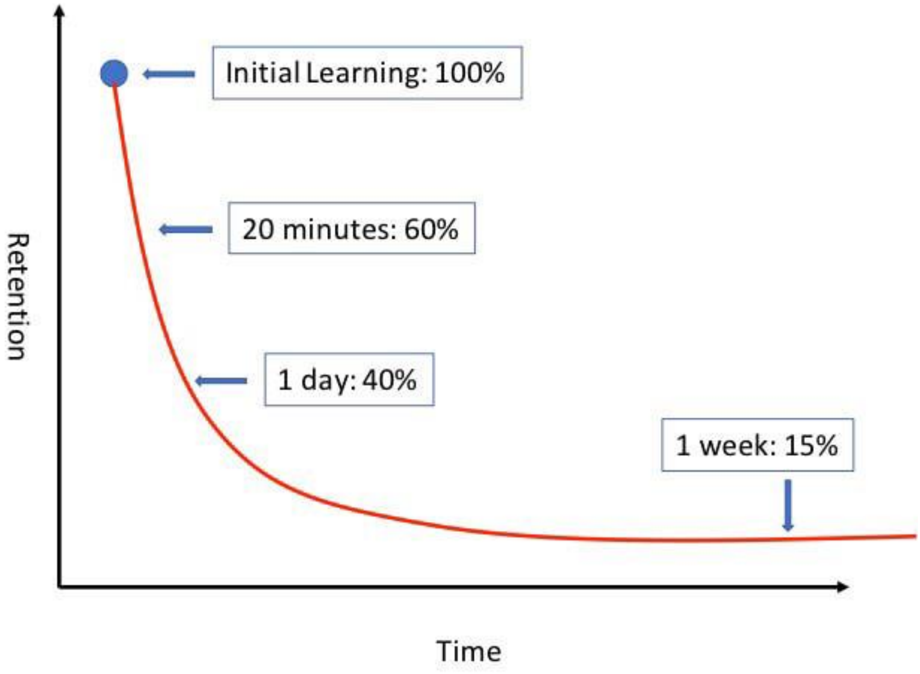


Figure 6: The forgetting curve (Alice Bonasio, 2019)

With today’s VR technology, it is possible to create applications which can help healthcare professionals to retain their knowledge by ‘transforming’ the “text-book” training model used and delivering a VR-based model in which they can see what the textbook says and try various combinations to see different outcomes.

By applying healthcare in a VR environment, the professional can be sure about ‘what to do’ when a patient comes with a specific problem.

> **“The learner can move and rotate the virtual body and when certain body parts are “touched” a description of the part and its function is provided. Layers of virtual tissue can be removed so that the inner workings of the body can be explored.(Alice Bonasio, 2019)”**

2.4.3 Other Studies

Learning can be facilitated through various VR models. Another approach is the 'Gamification' of instructional applications (*Michael D. Kickmeier-Rust, 2014*). This field, however, is tremendously challenging at the same time. There are some hey questions that are rising from this kind of education: How intensive, fast, or deep can be learned with and in a game? Which games are suitable for which purpose? Is there an added value at all? These are some example of questions raised from this kind of educational material.

To address this issue, the concept of 'Gamification' was introduced, in order to utilize game characteristics for non-game applications to make them more engaging and at the same time maintain their educational value.

> **"It is frequent repetition that produces a natural tendency (*Aristotle*)"**

Other examples show that VR training can enhance the learning process through repeating the same task until the learner 'learns' how to do it (Michael Casale, 2018). VR can support almost any kind of educational material and because there are no consequences in case of error or mistake and the learner can just redo the task until he gets the 'gasp of it'. By using VR training it is also easier to remember steps and movements. The human brain has the tendency of retaining information at a much great scale if the information is delivered physically. VR training targets to simulate the real process and thus, it is possible for the brain to retain greater amounts of information at much fewer time (*Eric Krokos, 2018*).

> **"Throughout history, humans have relied on technology to help us remember information. From cave paintings, clay tablets, and papyrus to modern paper, audio, and video, we have used technology to encode and recall information**
>
> **(Eric Krokos, 2018)"**

3 Social Virtual Reality interaction as Part of the Learning Process

Thousands of formal investigations have been conducted into the science of learning over the last century in an attempt to understand learning behaviours. Dating back to the studies of ancient Greek philosophers, most of the behavioural learning 'best practices' that have been uncovered remain largely untapped in their application to real-world training environments. This is often due to the rigid resource constraints of real-world training – time and money. However, recent rapid advances in immersive technologies such as virtual reality (VR) have allowed trainers to replicate real-world training environments. [*Michael Casale, 2018*]

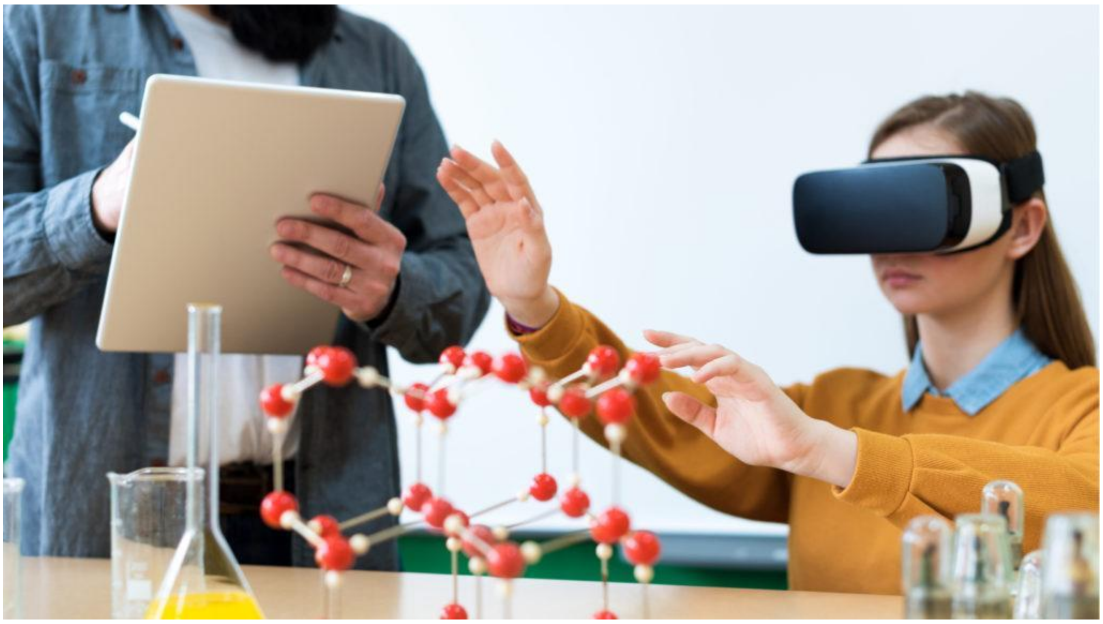


Figure 7:Student undertaking VR lesson

"VR is the tool that can now deliver on the wealth of knowledge that the scientific community curated about best practices over the past 100+ years."

3.1 Why VR is beneficial to the Learning Process.

There are many reasons that VR can raise the bar of the standard way of learning. For starters, a virtual reality headset is affordable. On the other hand, relocation expenses are too much for the average family salary. Another reason is that one can experience learning from the comfort of his home. There is no need to leave friends and family behind and leave for at least 4+ years. But there are reasons that prove that one can facilitate learning through VR and the learner can gain almost the same experience as physically being inside the learning environment [21].

VR learning provides some key components (benefits) that are required for the learning process: [*Michael Casale, 2018*]

1. Perceptual Fidelity

Put in its simplest form, the brain learns by strengthening (and weakening) relevant connections between functionally distinct areas in the brain. Strengthening happens when relevant features of the to be learned concept or object are activated coincident with a set of features related to the 'output' – a decision, emotion reaction, motor response, other concepts or objects, etc.. Ultimately, this strengthening and learning process helps us improves our ability to cope with the world around us – knowing what food is safe to eat, remembering the location of the nearest water source, and who is friend and who is foe.

> **"Using current virtual reality technology, it's possible to create a training experience that provides sufficient perceptual fidelity based on what we know drives real-world behavior change."**

2. Affective Fidelity

Affective fidelity essentially refers to the fact that the affective reactions experienced in the real world – stress, anxiety, surprise -must be sufficiently replicated in the training experience in order. It's well understood that affective features produced by the environment (e.g., quarterback blitz, sales meeting) can interfere with critical cognitive behaviours (e.g., recognition, decision-making).

3. Experiential Learning

The ability to make decisions as they happen in the real world environment.

The above are three of the benefits that VR learning provides, but there are certainly others. The ability to train with an optimal repetition training schedule, the incorporation of other critical sensory information are also of factors that facilitate learning

Figure 8: Using VR in the learning process

3.2 The Valley of Learning Capacity

After experimenting with various learning solutions we discovered an interesting pattern regarding the correlation of user-experience and the increasing of the knowledge base of the learner. Without a doubt, the level of learning a user can gain from a learning session relies significantly on the implemented interactive capabilities that form the general user experience. As a result, to make a beneficial learning environment for the learner in means of learning capacity, we need a more realistic environment and user-avatar behaviour. However, there is the exception of serious games that provide high levels of user experience at the cost of learning capacity. These applications are targeting to increase the user's knowledge base by providing a "Gamified" environment but in many of them the "Gamification" level is too high to be considered as learning material. At that point, the application is just a game.

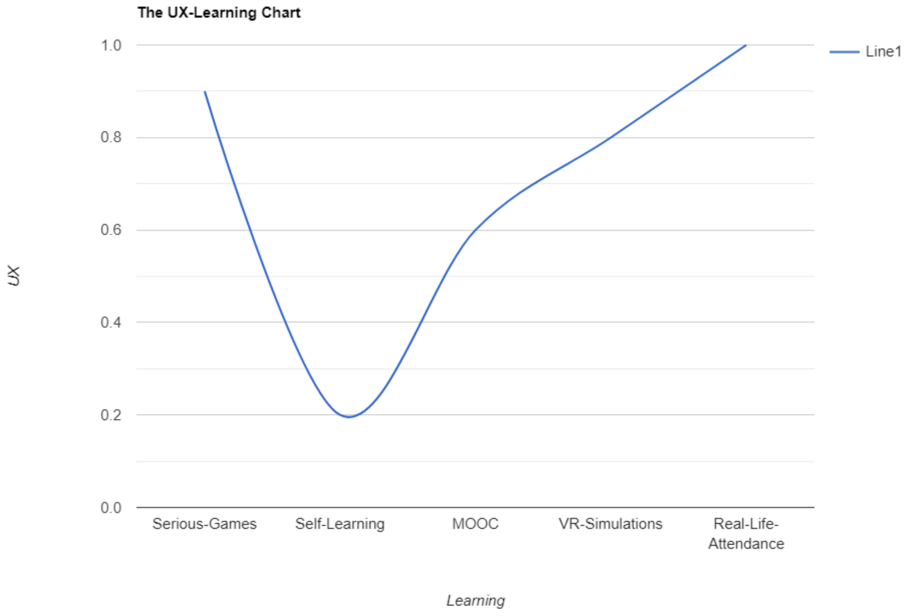


Figure 9: The UX-Leaning Chart

In the above graph we see that the best case scenario in terms of UX and Learning Capacity is the physical attendance of the learner inside the learning environment. VR-Simulation try to simulate the real-life scenario by adding multiple users inside the same learning environment in order to interact and communicate with each other.

4 Our Social Virtual University Classroom methodology

Up to this point, we presented the basic principles of facilitating learning through VR applications. This model is capable of creating an environment that facilitates learning based on the experience the learner gains by “existing” in the virtual environment. Utilizing the VR technology, developers can create applications that users can use to “learn”. However, what is the next step? What can be done to enhance the learning process? Until now we have some Cognitive VR applications that can provide the learner with instructions of “how to do something”. Yes, it is possible to learn from those applications but the knowledge level one can gain from those is limited. We needed something that will have the ability to simulate what happens inside a real learning environment, for example a real classroom.

In order to achieve a real classroom like simulation, **we introduce a VR-based Virtual Learning Environment which takes the form of a real University Amphitheatre** utilizing the above stated benefits of facilitating learning through VR applications. This virtual classroom encapsulates all principles that are required in order to have a learning environment which is as close as possible to a real university lecture room.

Figure 10: The Interior of the virtual classroom

The classroom has the capacity to fill in 60 students and one professor, more than enough that is required to be considered as an actual class. The professor stands on the bottom front area in front of the board and the students take seats in the student area. The professor also has the ability to use a projector to view presentation slides on the board.

4.1 Assigning Roles

Like the one we can see in the implementation of the most knows MOOC's such as Corsera and Udemy, the user that creates the online session takes the role of the professor. In our application, the host can only be created from the desktop application which is only accessible from the instructor. The instructor creates the online session (host) and "dives" in the virtual amphitheatre waiting for students to join his class.

The students from the other hand, can join the class from their mobile VR device such as the Oculus Quest VR headset. Once joined, the student is given a seat inside the virtual room and can attend the lecture the professor (host) is about to start.

Figure 11: Students attending a lecture at the virtual university

Up to this point, we have constructed the main structural components of the Virtual University Classroom and each user's role. The advantages of this solution are mainly focused on the realism level and interactivity between student and teacher. Being able to see the professor's avatar face to face inside a classroom can trick the brain to believe that the user is really inside an amphitheatre.

4.2 Facilitating Learning through the Virtual University Classroom

One of the major goals of this project was to implement a learning environment which replaces the need to physically attend a lecture. In this way, the learner can experience learning from his kitchen table, couch or bed, by using a VR headset and joining an online course. The student is required to have a VR headset that provides a 6 DoF head and hand tracking. This tracking behavior is essential unlike other online learning platforms due to the ability of the student to freely move his body inside the virtual room. There is no need for the student to press buttons or other UI elements in order to interact with the professor or with his fellow students. For example, if the student has trouble understanding a part of the lecture's material, he can just raise his hand in order to catch the professor's attention and ask for him permission to speak.

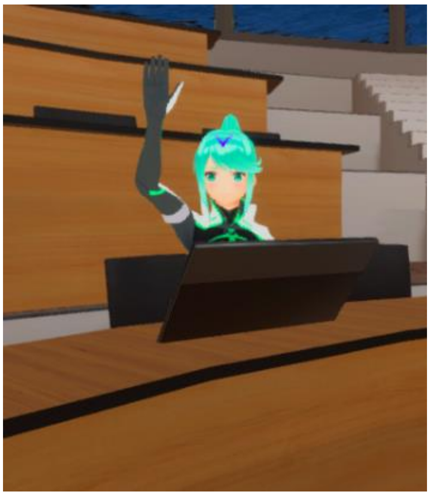


Figure 12: VR student raising her hand to 'catch' the professor's attention

The figure above illustrates the student raising her hand requesting a more explicit explanation due to misunderstanding of the lecture's material. The ability to request a more detailed explanation is an essential part of the learning process. If such a feature was not present, the learner could have "holes" in his knowledge representation of the lectures material. Those "holes" can cause a chain reaction to the student's *flow of understanding*, from the moment the student's understanding "breaks" it is highly possible that the student will not understand many parts of the lecture's material from that point onward, as the rest of the lecture will probably be depended on already explained (and considered as known) material.

"The domain knowledge should be represented in a more realistic way in order to allow the adaptive and/or personalized tutoring system to deliver the learning material to each individual learner dynamically taking into account her/his learning needs and her/his different learning pace."
[Konstantina Chrysafiadi, 2013]

4.3 Socializing the Learning Process

Based on the principles of constructivism (Barney Dalgarno, 2002), it is essential to have a group of learners undertaking the same authentic activities with the support from teachers. Groups of learners working together and developing their understanding of concepts through a social learning process is important. Communication within a simulated environment relevant to the ideas being discussed can provide a greater ‘sense of place’ than other text-based alternatives. Also, the distributed virtual environment can allow learners to undertake tasks together, rather than just communicate and teachers can provide support to the learners as they undertake tasks.

Figure 13: VR student explaining some of the lecture's material to the non-VR student

The figure above shows how one student can explain some of the lecture’s material to another student who has gaps in his knowledge representation. According to the principle of ***dialectical constructivism*** it is necessary to give the learners the ability of verbal communication and communication through the use of gestures. That way, if one student has gaps in the representation of his knowledge domain, another student can provide support and fill those gaps, correcting the first student’s knowledge base on that topic.

> **“Dialectical constructivism (rooted in a contextualistic metaphor) emphasizes the construction of new structures out of organism/environment interaction.”**
> **[David Moshman, 1982]**

4.4 The Professor as the Facilitator of Learning

Up until now, we saw how the virtual classroom can be used as a learning environment from the student's point of view based on the ***Endogenous and Dialectical Constructivism Theories*** and expanding what is provided by the today's standard online learning methods. Is this it? Can this implementation of a 3D Learning Environment provide an accurate simulation of a real-life training model? The answer to that is no. Based on the ***Constructivist Theories of Learning*** there is one more theory that is required in order to successfully facilitate learning through a 3D learning environment. That is the Endogenous Constructivism model that suggests that the role of the teacher should be to act as a facilitator in providing experiences that are likely to result in challenges to learners existing models.

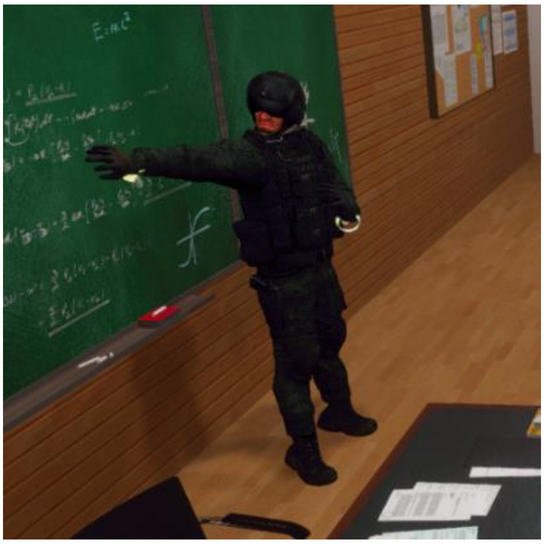


Figure 14: The professor doing a lecture at the university

In the above figure we see the teacher explaining a lecture's material to the students. Like in a real classroom, the professor can make questions about the explained material in order to force them to 'think' and provide an answer. That question can act as a challenge to the students' representation of their knowledge domain according to the lecture's material he previously explained. For example, the professor can ask for a solution to a problem based on the explained material and the student will have to provide the solution to that problem. The professor should not provide a step-by-step methodology for the solution, but can provide hints that will direct the students on the correct path of finding the solution or try to redirect a student if that student's knowledge domain on the specific topic is incorrect.

5 Our Social VR-Based Learning Environment's User Experience method

Extending user support with Non-VR mobile devices

In the previous sections we explained how we can facilitate learning through the use of VR technology. This technology is, without a doubt, beneficial to the learning process as stated in section 3, but it is not accessible to the majority of users around the world for two reasons:

1. Not affordable in terms of cost
2. Can easily cause motion sickness to the user

At the start of the implementation phase of this project, it was obligatory for the student to have a VR headset with 6 DoF tracking support. As we were reaching the final phase of the implementation, we noticed that it is not reasonable and practical to force the learner to succeed in attaining a VR headset with 6 DoF tracking capabilities. Especially if the learner suffers from motion sickness by wearing the device. So, we needed to find a solution that would grant the ability to the user to participate and attend the classroom with a Non-VR device.

The idea we came up with was the usage of a simple low budget smartphone or tablet. Smartphones and tablets these days tend to act as simple pocket computers and are able to support almost any application due to the high supportability provided by the Android operating system.

5.1 Adding Smartphone Support

When the idea of adding support for smartphones was conceived, the first thing we had in mind was a smartphone VR application. Today with Google's Cardboard and Samsung's Gear-VR, it is possible to create application for mobile smartphone that support VR. Gear-VR also comes with a controller in order to have movement and in general user input in the VR application.

As we were implementing the necessary features in this integration, we unfortunately reached a dead end. The idea was to create an application that could run on an Android smartphone in order to solve the issues discussed in section 5. Especially the second one. We noticed that we were making the same exact application with the same issues. Both Gear-VR and Google Cardboard are sold separately and Gear-VR comes with a 100€ price-tag. Even if the user can afford these cases, it will still be a VR application, making the user vulnerable to motion sickness. At that point we understood that we needed an application without VR support and stopped the integration for smartphone-based VR.

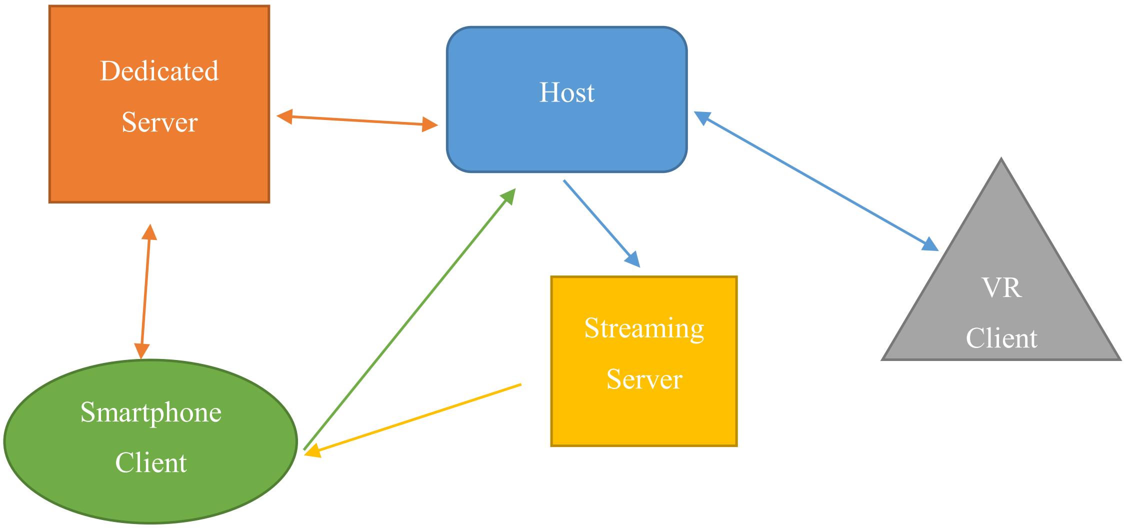
To address the issues stated in section 5, we needed an application that could run normally and without issues on low budget smartphones and tablets. So, we came up with a practical, yet not simple to implement solution and we introduce the method of ***attending the classroom via remotely-controlled live streaming***.

5.1.1 Enable Social VR learning for the Smartphone User

Porting a Unity3D application to a smartphone is not always the best solution. Smartphones do not have the same levels of computational power as the VR headsets do. In order to make the application compatible with the majority of mobile devices we decided to create a simple Android application which receives the camera feedback via live streaming. As a simple mobile application, it cannot connect to the Unity Network Layer. So, we had to create a custom network layer that supports connections between android applications and Unity3D.

The idea was to create the custom layer from scratch, using a C# Server which would be compatible with Unity3D applications. The Network Layer used in the application with smartphone support consists of a dedicated server which "knows" which hosts are online and sends that information to the smartphone client. The client then chooses a lecture (host) and is redirected from the Server to the Host where he joins the host's class.

From the host's side, when creating a room, his IP address and lecture information are sent to the Server, updating the information the clients can see when they open their client.



The Host – VR Client is a simple connection between two end points interacting with each other. Both of them send and receive information through Unity’s Network Layer for Multiplayer.

Our implementation comes with the rest of the architecture between the Host and the Smartphone Client. As shown in the graph above we have one dedicated c# server managing the communication between host and client. The server has a constant connection with the host and “sees” if the host is online for a lecture. The client, connects to the server and receives information about which lectures are available to join.
Once the user selects a lecture, his connection with the server is cut off and establishes a peer-to-peer connection with the selected host. The host is receiving data from the client about his actions (FoV level, head orientation etc.) and sends the captured frames from the client’s avatar to the streaming server. The client receives the stream from the streaming server.

5.1.2 The Definition of Live Streaming

Live streaming refers to online streaming media simultaneously recorded and broadcast in real time. It is often referred to simply as streaming, however this abbreviated term is ambiguous due to the fact that "streaming" may refer to any media delivered and played back simultaneously without requiring a completely downloaded file. Non-live media such as video-on-demand, vlogs, and YouTube videos are technically streamed, but not live streamed.

Live stream services encompass a wide variety of topics, from social media to video games to professional sports. Platforms such as Facebook Live, Periscope, Kuaishou, and 17 include the streaming of scheduled promotions and celebrity events as well as streaming between users, as in videotelephony. Sites such as Twitch.tv have become popular outlets for watching people play video games, such as in eSports, Let's Play-style gaming, or speedrunning. Live coverage of sporting events is a common application.

User interaction via chat rooms forms a major component of live streaming. Platforms often include the ability to talk to the broadcaster or participate in conversations in chat. An extreme example of viewer interfacing is the social experiment Twitch Plays Pokémon, where viewers collaborate to complete Pokémon games by typing in commands that correspond to controller inputs.

5.1.3 Enhancing the UX of live streaming with remote-controlled actions

Live streaming, as shown in the previous section is a service that allows a streamer to "stream" the content of his screen or application to a wide group of users through Twich.tv or YouTube. The users viewing the content can see whatever the streamer wants them to see and cannot make any adjustments to the streamed viewport.

In the case of a VR application, the viewers see what the streamer sees from within his VR goggles. Viewers cannot move the streaming camera or make any interactions with the game (application) the streamer is playing.

As we were in the brainstorming stage of the smartphone implementation, we were having huge problems with the identity of the application. The most reasonable way of live streaming in our application was to stream the content from the professor's (host) camera. But what would be the point in that? If we had implemented it like that, we would have a simple cognitive learning experience. Our application was supposed to simulate a realistic scenario. We somehow needed to create a non-VR mobile application, with VR capabilities. Is that even possible? How can one create a mobile application with no VR-like support and use it for a realistic learning experience where user interaction is essential?

That is when we came up with the idea of assigning a dedicated camera to each mobile user and allowing him to remotely control his assigned camera. This solution consists on an avatar that is spawned and assigned to the user at the time he joins the class. When the avatar is spawned, a dedicated streaming camera is attached on that avatar's head and starts live streaming the captured frames to the user's mobile device. That way, we can have multiple mobile users inside the classroom, each one of them receiving live streamed content from his avatar's camera.

Figure 15: The streaming camera attached on the avatar's head

After testing this integration, we found out that we were facing a problem that could not be ignored. We were basing the whole classroom on the ***Constructivist Theories of Learning***, were interaction between users is an essential part of the learning process. This user can only look and listen from the streamed content of his avatar's camera. There is no interaction between his fellow students or the professor. If he does not understand something of the lecture's material and does not have a correct representation on the required knowledge domain, there is no way he can ask for some kind of guidance, either from the professor or the other students. That could be a great problem in the learning process and its facilitation because the process itself will not have the ability to increase his knowledge base.

It is without question, impossible to provide this student the same level of experience that is gained from the student using a VR headset due to the lack of interactive capabilities. It is possible though, to raise the experience level and try to put it as close as possible to the level of the VR student. In order to have a fundamentally correct Virtual Learning Environment we needed to have this type of student based on constructivist theories. What this student lacks is the ability to request for the professor guidance and the ability to interact with his fellow students.

In order to give him the opportunity of requesting guidance, we implemented a feature to grant him the freedom of raising his avatar's hand. If the learner is unable to understand part or parts of the lecture's material, he can issue a command from his mobile application and have his avatar raise its hand just like a VR student. That way, the professor can see that that student would like to have permission to speak.

Figure 16: non-VR student raising his hand

The last needed feature we lacked in order to provide a full experience to the smartphone user was the ability of verbal communication. As it is, the user can only look around and listen to sounds but the ability to talk to others is necessary. After researching various ways of communication, we noticed that the best case scenario in this situation is a voice service that transmits voice data packs over IP layer. The service name is Voice over IP and is openly used by countless remote communication services like Skype or Discord.

With the VoIP we can capture voice frames (data packets) from the mobile devices microphone and send it over a simple socket to the host once the connection with the host is established.

From the host's side, the received voice frames can be played back from an Audio Source on the client's avatar. That way the client can be heard from the whole class.

VoIP offers excellent call quality. The person you're calling can't tell whether you're using VoIP or POTS—there's little difference in quality. While it's true that there might be occasional hiccups in transmission, the technology has evolved to the point where service interruptions or interference are no more frequent than a POTS connection, and call quality is considerably better than typical cell phone reception.

6 Conclusion

6.1 Summary

With the system described above, it is proven possible to create an online virtual learning environment for most learning areas. There can be multiple users, VR or non-VR, attending the same lesson and preserving the feeling and experience of physically participating. In this example, it grants all freedoms a student can have in a classroom, from raising his/her hand and ask for further explanation, to gossiping with the student right next to him/her. With this, we can have the first online virtual university in a couple of years, minimizing the distance between home and university, attendance cost, relocation expenses and the feeling of being alone in a foreign country in case of relocation.

6.2 Evaluation

In this Thesis we presented a work that aims to simulate the learning experience gained from a real learning environment. The ultimate goal was to minimize distance without altering the traditional way of learning. But the goal by itself was not enough to assure as that this work can be used in a wider range of universities or schools around the world. We needed some kind of assurance that this project will lower the attendance learning experience.

As shown by the results of our evaluation tests, the majority of the instructors called to do a lecture using our system managed to easily complete a lecture without altering the way they teach inside the classroom. Based on this quantitive (*Richard M. Grinnell Jr., 2005*) result, we understood that the idea of this project was a success, and that the professors can do the lectures with ease as they do every day in a university campus.

For the students we used the same evaluation approach. From this side got the most positive feedback. All our students managed to attend a lecture without fail or interruptions. We could say that this was expected due to the way a student attends a lecture. The students "job" is to sit on a chair and keep his attention at the professor. This is easily replicable.

From what we got with this quantitative approach that we used to evaluate our system, we got feedback that can highly recommend the systems usage in a wide range.

Testers	Complete Lecture
Instructors	80%
Students	100%

Table 2: Percentage of testers who successfully completed a lecture

According to the table above, almost every person who tried the system managed to use it properly. But in order to have a more faultless result we had to also evaluate the quality of the system (*Richard M. Grinnell Jr., 2005*).

For this we had the testers fill up a questionnaire in which they would rate the system from 1 to 10 in a couple of questions. We distinguished each rating as 'Negative', 'Neutral' and 'Positive' ranging from 1-3, 4-6 and 7-10 respectively.

Testers	Positive	Neutral	Negative
Instructors	70%	20%	10%
Students	50%	30%	20%

Table 3: Percentage of the feedback gained from the testers about the system. The students' positive mark corresponds to the VR students. The Neutral and Negative marks are the Mobile Phone users.

From this qualitative approach we noticed that the main reason for not giving a positive feedback is coming from the non-VR students using the mobile phone. The lack of verbal communication between the student and the professor creates holes in the students(learners) flow of understanding and removes the feeling of presence and breaks the students attention. From the VR students' side, the evaluation showed great results having all VR students giving positive reviews of our system.

6.3 Future Work

The evaluation stage of this project showed good results in general but, a system of such scale still has some limitations. The most noticeable flaws that put the development of a system of such scale on hold are both maintenance/computational costs and the ranges of Internet bandwidth.

Being able to support multiple non-VR devices in the same classroom via livestreaming comes with a great financial cost. Unfortunately, the computing power needed for streaming directly to each non-VR device is extremely high at the moment so, in order to use a classroom that consists of multiple non-VR devices such as smartphones or tablets would require an entire room full of state of the art CPU's serving as the livestreaming server. This means that it does not only require absurd amounts of computational power, but also a large amount of electricity. Combined, for today's standards at least, they bring the cost of development of this service to an inconceivable amount of money.

On the other hand, technological advancements are becoming more and more frequent the past years. It will not take too long until some kind of device or CPU is produced that provides huge amounts of computing power at a logical price. That said, development of such system is not unthinkable provided that 2019 has everything needed for the development stage of this kind of project except the cost which is supposed not to be an issue in a couple of years.

The other matter that requires extreme caution is the Internet. The bandwidth that is vital in order to livestream a simple full high definition (FHD) video is approximately 4Mb. Imagine having to use 4Mb upload speed to 150 students.

$$4 \text{ x } 150 = 600\text{Mb}$$

600Mb is the minimum bandwidth for 150 participating students. Of course, that excludes data transfers needed for movement and user synchronization. If we add everything, things will exceed the 1Gb Ethernet cable Cap that exists nowadays and is the standard for everyone.

Fortunately, there are ways to go above that Cap so, this can be partly easily addressed by installing a high-capacity data transfer hardware. With this hardware, speeds can go up to 100Gb, which poses no problem even if the number of non-VR consecutively participating students are 200. Of course, if that number goes to more than 2000 for example, it could still be a huge issue but, to be realistic, no one can have 2000 or 4000 students in his classroom, usually that number of participants is less than 200. For instance, Universities can have a maximum number of 300 student in one classroom.

In this demo, minimal livestreaming latency and delay was not a priority. There is a delay of approximatelly 7 seconds which prevents the streaming service from being usable. Fortunately, this delay can be easily minimized if we proceed with an integration of a service that provides livestreaming with a minimal delay and latency. This delay is less 30ms and is used for remote gaming. That technology combined with this project, can provide the non-VR user the ability to participate in real-time. Although the non-VR user cannot move freely like the VR user does, the experience gained from the participation is almost equal.

Our Publications Related To This Work

1. George Papagiannakis, Nick Lydatakis, Steve Kateros, Stelios Georgiou, and Paul Zikas. Transforming medical education and training with VR using M.A.G.E.S. In SIGGRAPH Asia 2018 Posters, SA '18, pages 83:1{83:2, New York, NY, USA, 2018. ACM.

2. P Zikas, V. Bachlitzanakis, M. Papaefthymiou, S. Kateros, S. Georgiou, N. Lydatakis, and G. Papagiannakis. Mixed reality serious games for smart education. In European Conference on Games Based Learning 2016. ECGBL'16, 2016.

3. Geronikolakis, E., Zikas, P., Kateros, S., Lydatakis, N., Georgiou, S., Kentros, M., Papagiannakis, G., “A True AR Authoring Tool for Interactive Virtual Museums”, In: Visual Computing in Cultural Heritage, Liarokapis, F., Voulodimos, A., Doulamis, N., Doulamis, A. (Eds.), (to appear), Springer-Nature, Series on Cultural Computing, 2020

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Appendix 1

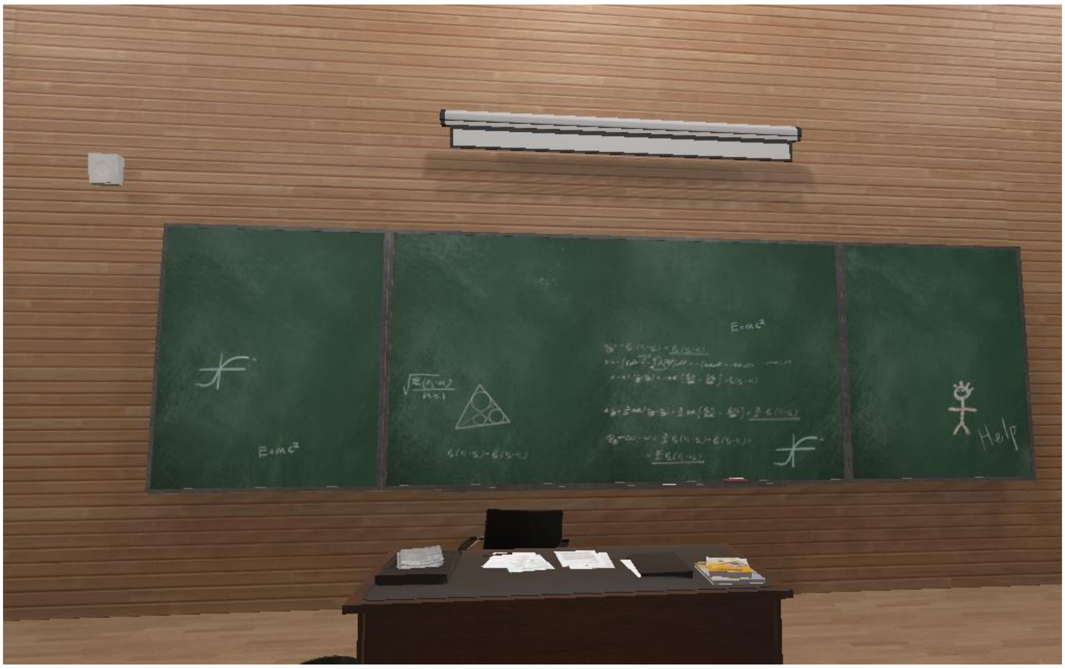
Implementing the 3D Virtual Learning Environment

A. Constructing the University Classroom

The initial task was to create a three dimensional virtual classroom, the place where the lectures were to happen. This cannot be considered as an easy task because of the workload and time needed to have a virtual representation of a classroom that is close to a real one.
As this project tries to simulate the experience a student has in a real university, the representation of the environment (*the classroom*) should be as close as possible to reality.

The classroom has the capacity to fill in a hundred students and one professor, more than enough that is required to be considered as an actual class. The professor stands on the bottom front area in front of the board and the students take seats in the student area. The professor also has the ability to use a projector to view presentation slides on the board.

Now, as for the environment surrounding the classroom, it 'feels' like a park. The idea was to create an environment that is supposed to look friendly and comfortable, no one would like to attend a lecture in a classroom inside something that looks like a prison. This setting gives the feeling of attending a high prestige school built inside a park. But what would all of these matter if the users were not able to look outside the classroom? That is why, the classroom itself has windows. All users inside the class are able to look outside and have a look at what is around them. It is not meant to be distracting thou, which is the reason that all windows are placed in the back side of the room. If there was a window right on top of the blackboard, some students would gladly stare at the birds flying happily outside. That could cause a problem and it would not be the professor’s fault nor the students, it would be an error in the classrooms design. The classroom itself would give a reason to some students to get distracted and not have their attention at the professor.

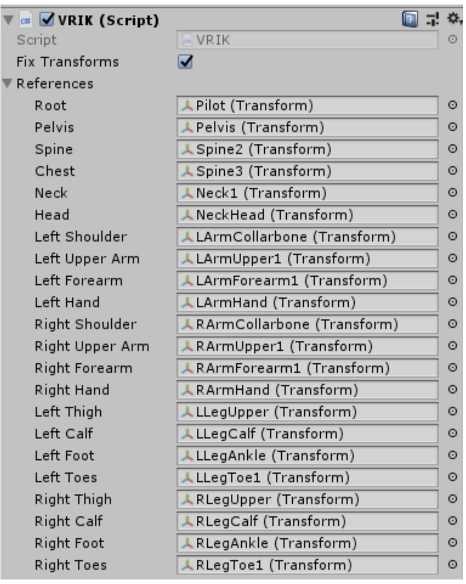


a. Creating the Professor and Implementing His Role

The professor has a major role inside a classroom. He is the one doing the lecture, the one keeping order in class, the one presenting a lessons material and the one writing notes on the blackboard. He is also responsible for starting and ending a class. The professor is required to be a Desktop VR user (Oculus Rift, HTC-Vive etc) because those devices provide 6 degrees of freedom to the user and these degrees are required for the Human Rig IK (inverse kinematics) on the professor's avatar.

b. Granting the Professor Free Movement inside the Scene

In order to give the best experience to both the professor and the students attending the class, a simple yet difficult to implement procedure was needed. The professor should be able to move around the scene and have the freedom of doing the lecture as he/she would do it in real life. That way, the teacher would have the feeling of actually lecturing a class and the students would be intrigued to pay attention to the professor as if that was a real one in front of them.



☑ **VRIK (Script)**

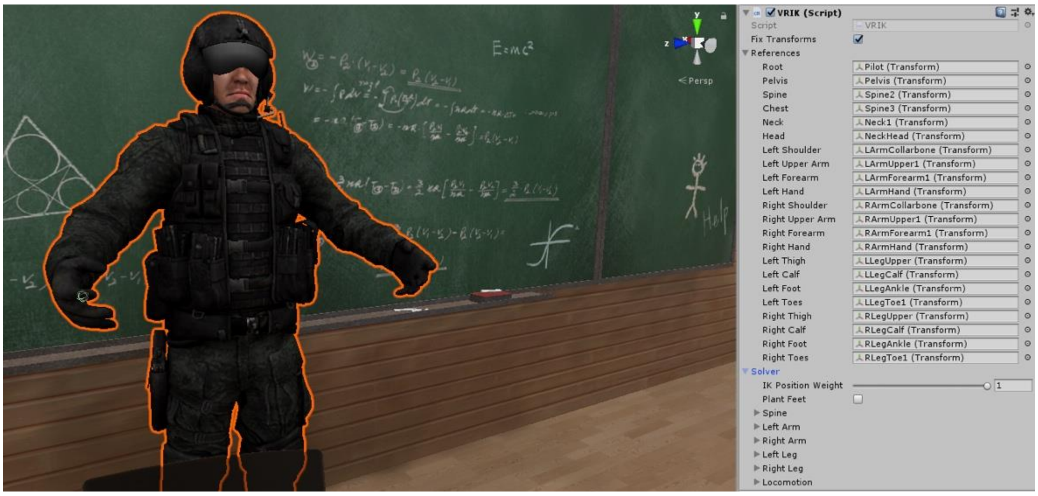
Script	VRIK
Fix Transforms	☑
References	
Root	Pilot (Transform)
Pelvis	Pelvis (Transform)
Spine	Spine2 (Transform)
Chest	Spine3 (Transform)
Neck	Neck1 (Transform)
Head	NeckHead (Transform)
Left Shoulder	LArmCollarbone (Transform)
Left Upper Arm	LArmUpper1 (Transform)
Left Forearm	LArmForearm1 (Transform)
Left Hand	LArmHand (Transform)
Right Shoulder	RArmCollarbone (Transform)
Right Upper Arm	RArmUpper1 (Transform)
Right Forearm	RArmForearm1 (Transform)
Right Hand	RArmHand (Transform)
Left Thigh	LLegUpper (Transform)
Left Calf	LLegCalf (Transform)
Left Foot	LLegAnkle (Transform)
Left Toes	LLegToe1 (Transform)
Right Thigh	RLegUpper (Transform)
Right Calf	RLegCalf (Transform)
Right Foot	RLegAnkle (Transform)
Right Toes	RLegToe1 (Transform)

Having an avatar moving like a real human is a difficult task. Fortunately, with the Human Full-Body IK, this issue can be addressed, binding the avatar to the user's body.

This kind of technology gives us the possibility to move each joint of the avatar according to the movement of our body. By understanding and connecting the joints of the avatar similarly to our body structure, we are able to transform our movement into animation at run-time, without the need of pre-recorded animations. That way, for the sole reason that the avatar follows exactly the user's movement, it provides a vast amount of possible ways the professor can use to maintain order in class and make the lecture interesting like a real one.

Also, from the student's side, they will be looking at an avatar close to a real human teacher, not something made out of a game like Pac-Man. Imagine a student trying to pay attention to what the professor is saying and the professor is something like a statue made of marble. For the student it would be extremely boring and difficult to keep paying attention to him. Some students might find it hilarious having a statue with wheels moving around the class.

With the right joint restraints on the avatar, it can move without having issues that distract students from class and the students can attend class and get the same level of understanding from the lecture as if they were attending one in a real university.



VRIK (Script)

Script	VRIK
Fix Transforms	☑
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Root	Pilot (Transform)
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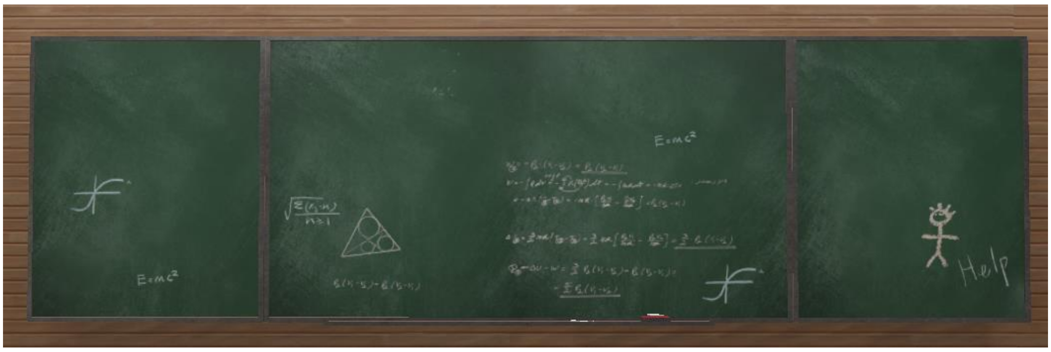
Right Hand	RArmHand (Transform)
Left Thigh	LLegUpper (Transform)
Left Calf	LLegCalf (Transform)
Left Foot	LLegAnkle (Transform)
Left Toes	LLegToe1 (Transform)
Right Thigh	RLegUpper (Transform)
Right Calf	RLegCalf (Transform)
Right Foot	RLegAnkle (Transform)
Right Toes	RLegToe1 (Transform)
Solver	
IK Position Weight	1
Plant Feet	☐

c. Giving the ability to write on the blackboard

Another major issue that needed to be resolved was to give the professor the capability to write notes on the blackboard. One simple solution to this problem would be to create each page of notes on an external program like Photoshop and show them like a slideshow in class at run-time.



This solution would have worked out pretty well, the professor would be able to show the notes on board and the students would be able to see them. But that would not be enough. Until now we were creating a classroom that 'feels' like it's inside a real high prestige university. If we were just presenting notes on the blackboard like a power point slideshow, it would totally break any kind of presence for both the professor and the students. To counter this break of presence, a solution was required that would give the professor the ability, to write down notes on the blackboard manually at run-time. In order find that solution, we needed to look deeply inside the structure of our problem. We want to be able to write on the blackboard. What is it made of? If we look inside the model presenting the board we see that it has a material which gives it colour and normal properties, but we just want to alter the colour so, we just need the albedo texture. To address this issue an algorithm was created that could give us the ability to change a set of pixels on the texture at run-time. Because it is not supposed to modify, or rather, paint the entire texture but only a small set of pixels, this algorithm was called ***Texture Re-Paint***.

Texture Re-Paint is a technique which finds the intersection point of two objects and return's as a result the UV's of that point. The professor can take the *chalk* and write notes on the blackboard. Once the *chalk* starts intersecting with the blackboard we get the UV's of the blackboard's interaction point and paint them with the colour of the *chalk*. This technique creates a circle around the intersection and re-paint's all UV's inside that circle. This circle is modifiable in order to make it easily reusable for all kinds of *chalks*.

d. Talking To the Students

Human language can be defined as a system of symbols (sometimes known as lexemes) and the grammars (rules) by which the symbols are manipulated. The word "language" also refers to common properties of languages. Language learning normally occurs most intensively during human childhood. Most of the large number of human languages use patterns of sound or gesture for symbols which enable communication with others around them.

In a classroom, verbal communication is an essential part that is needed to enable smooth course delivery. Teachers are able to explain the lecture material through the use of spoken language or gestures to the students and students are able to ask questions about something they do not understand.

At this point there are 2 ways a student can attend the lecture. The first is via mobile VR (Oculus Quest) and the second is via mobile streaming. For that reason two types of verbal communication were implemented. One for each type of student respectively, VR or Non-VR. Students that join a class can talk through their device's microphone (or any kind of microphone if connected to their device) and listen through the speakers or headphones.

e. VR Students

Mobile VR (Oculus Quest) comes with an embedded microphone. Voice functionality works as implemented by the Unity Networking System. The host (professor) creates a room (class) and the student joins it. After that, voice functionality is processed by the Networking Plugin and is transferred between host-client in a bidirectional way so both users can talk to each other and have a normal kind of conversation.

Each VR student avatar has an Audio Listener and a Audio Source component on it.
An Audio source component is a representation of 3D audio from a specific object inside a scene. It is attached to a GameObject for playing back sounds in a 3D environment. Its primary use is to play back pre-recorded audio clips but, it also gives the ability to stream sound from an Audio Listener from another device running the same application through the use of a simple Voice Chat plugin.

An Audio Listener is Representation of a listener in 3D space. Implements a microphone-like device and plays that through the primary audio output which can be either speakers or headphones. Each avatar (player character) receives an Audio Listener at the time its created (spawned) and for each scene there is only the player's Audio Listener in order to comply with Unity's limit of having one Audio Listener per scene.

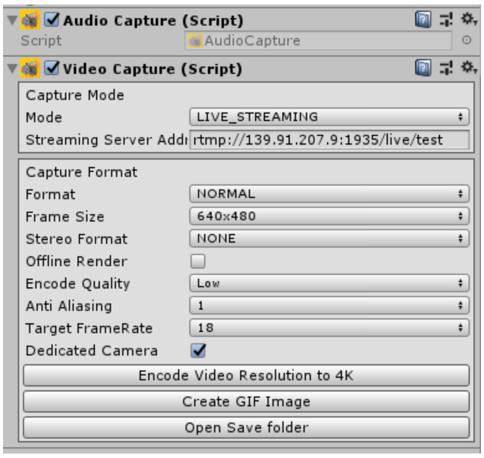
The student's Audio Listener receives sound coming from the Teacher's or other student's Audio Source. In case of an online multiplayer session, the sound data is transferred via the Voice Chat plugin and delivered through the Audio Source of the receiver. The receiver (student/teacher) can have multiple Audio Sources around him (one for each avatar in the scene) which simulates the hearing of 3D sounds of a real environment.

f. Live-Streaming from a Unity3D application to mobile

We explained above that speech interaction with the Non-VR students is achieved by using a streaming service. There are many livestreaming services that could allow the students to see what the professor sees or look from a specific point in the scene from a dedicated camera. Those services could be either Twitch or YouTube or other similar platforms that provide streaming services.

These platforms could provide us a simple solution to our problem of interaction between students with mobile devices but, the goal is to simulate an entire classroom. Each student had to be able to participate from his/her own seat inside the room and have free movement capabilities. By using services like Twitch, the student would have been bound to watch from a certain fixed camera, which would probably be placed in front of the professor's desk and would not have the freedom to look around at will and interact like a normal person. This would entirely break the feeling of presence for all mobile users.

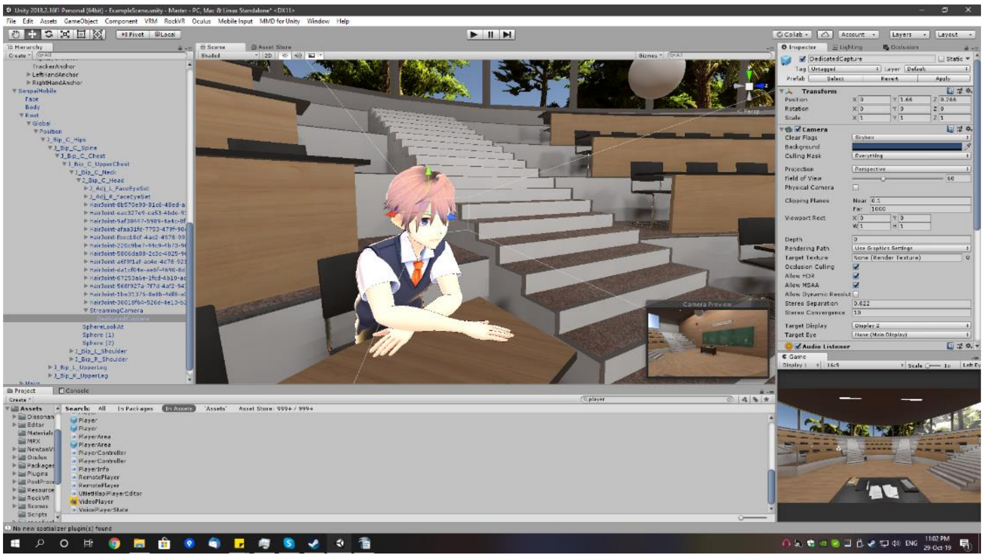
The solution to this problem was to have each mobile student have its own dedicated camera, which is on his avatar's head, and streaming the content of that camera to that student. Each student is placed on a different location in the room when he joins the class and when the avatar is created a camera is assigned to that avatar to work like the student's eyes. That camera receives the frames normally as if it was the main camera in the scene but, instead of displaying those frames on the monitor, it streams them to the user represented by that avatar.



☑ Audio Capture (Script)
Script: AudioCapture

☑ Video Capture (Script)
Capture Mode
Mode: LIVE_STREAMING
Streaming Server Addr: rtmp://139.91.207.9:1935/live/test

Capture Format
Format: NORMAL
Frame Size: 640x480
Stereo Format: NONE
Offline Render: ☐
Encode Quality: Low
Anti Aliasing: 1
Target FrameRate: 18
Dedicated Camera: ☑



☑ DedicatedCapture ☐ Static
Tag: Untagged Layer: Default
Prefab: Select Revert Apply

Transform
Position X 0 Y 1.66 Z 0.266
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1

☑ **Camera**
Clear Flags: Skybox
Background
Culling Mask: Everything
Projection: Perspective
Field of View: 60
Physical Camera: ☐
Clipping Planes: Near 0.1 Far 1000
Viewport Rect: X 0 Y 0 W 1 H 1
Depth: 0
Rendering Path: Use Graphics Settings
Target Texture: None (Render Texture)
Occlusion Culling: ☑
Allow HDR: ☑
Allow MSAA: ☑
Allow Dynamic Resolut: ☐
Stereo Separation: 0.022
Stereo Convergence: 10
Target Display: Display 2
Target Eye: None (Main Display)

☑ **Audio Listener**

Display 1 16:9 Scale 1x Left Ey

Appendix 2 – User guide

In order to run the application the user has to:

1. Start the RTMP Server for livestreaming. For this project we used nginx on the default streaming port 1935
2. Start the dedicated c# Server.
3. Open Unity editor and host a lecture (start application).
4. Run the mobile or the VR application and join (or both)

For the mobile application:

1. Open the android application on the smartphone
2. Wait until it finds a lecture (host)
3. Select to join

Appendix 3 – Installation guide

Building VideoLAN VLC library to receive the Streamed Content

As explained in section 3.2.4. the desktop application streams the camera feedback from the avatar to the user and the mobile application renders those frames on the background of the mobile application. There was no need to implement this from scratch as there are many media players who do the same thing. Our choice was VLC Media Player from VideoLAN.

The VLC Media Player is an open-source project created from VideoLAN and can be downloaded free of charge at https://www.videolan.org/index.html.

VLC media player

VLC is a powerful media player playing most of the media codecs and video formats out there.

In this project we did not need the media player as a whole, instead we only used the library that implements its features. The application should be able to work on an Android platform and it is recommended to download the source code and build it for Android (https://www.videolan.org/vlc/download-sources.html).

In order to build the library, a Linux based OS is advised with a cross-platform compiler. To build the library we used Linux Ubuntu 18.04 LTS and as a compiler the Mingw32.

The first step was to get the VLC library and build it with Mingw32. We download the stable branch from VideoLAN's git that was recommended by VideoLAN's wiki. (https://wiki.videolan.org/AndroidCompile/)

```
git clone https://code.videolan.org/videolan/vlc-android.git
```

Once the repository is cloned, we need to download and install all requirements and dependencies that the library needs to build.

```
sudo apt-get install automake ant autopoint cmake build-essential libtool-bin \
     patch pkg-config protobuf-compiler ragel subversion unzip git \
    openjdk-8-jre openjdk-8-jdk flex python wget
```

The last thing needed here is the Android NDK and SDK.
The SDK can be downloaded from: https://developer.android.com/studio#downloads.
It is safe to download the latest Android SDK found in the above website.

The NDK provides support for native code in Android platforms and can be downloaded from here: https://developer.android.com/ndk/downloads/index.html .

The recommended NDK version is ***NDK r18b.***

When the dependencies stated above are installed, we need to open the terminal and start building libVLC:

For starters, we have to set the environment variables that point to the Android SDK and NDK.

This can be done with the following commands:

*Set **$ANDROID_SDK** to point to your Android SDK directory*

```
export ANDROID_SDK=/path/to/android-sdk
```

*Set **$ANDROID_NDK** to point to your Android NDK directory*

```
export ANDROID_NDK=/path/to/android-ndk
```

Add some useful binaries to your **$PATH**

```
export PATH=$PATH:$ANDROID_SDK/platform-tools:$ANDROID_SDK/tools
```

If the above are done correctly, we have set the environment for libVLC to build. We only need the library, not the Media Player, so we use the following command to build it:

```
sh compile.sh -l -a <ABI> -r
```

<ABI> is the target platform in which we want the library to run. In our case, we are testing on an ARMv7a type device so the command we used was as follows:

```
sh compile.sh -l -a armeabi-v7a -r
```

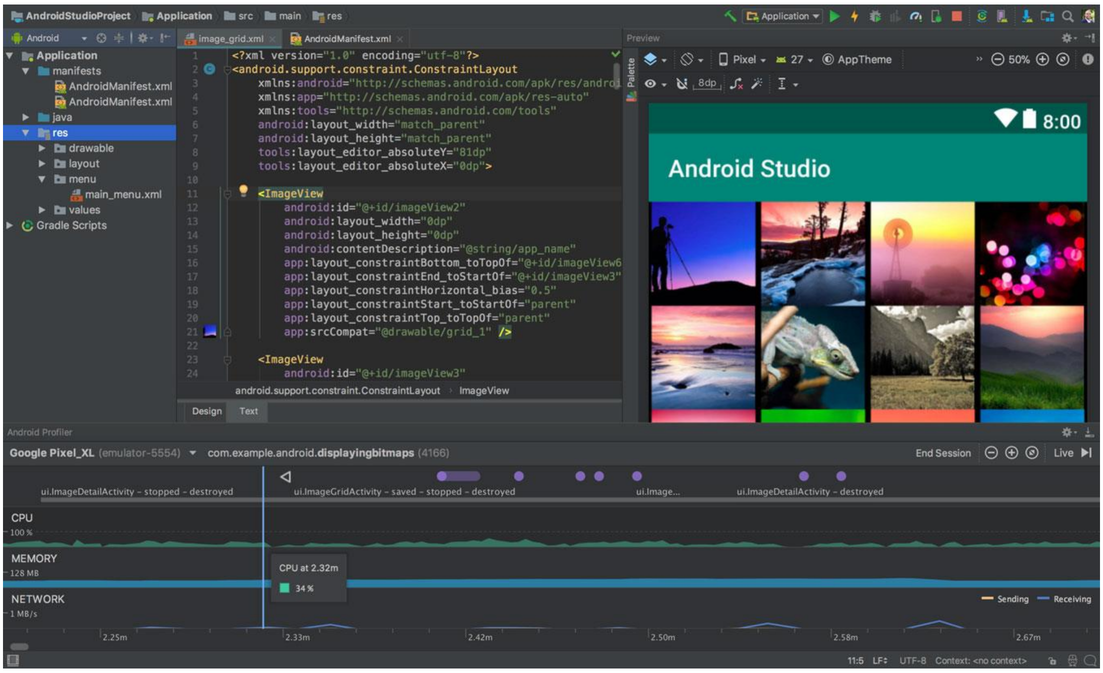
The above command generates an Android Archive file (.aar) located in libvlc/build/outputs/aar/

We this, we have finished building the VLC library and can move on to creating the mobile application.

Creating the Mobile Application

At this point, we should have the Android VLC library built and ready to use.

From here on we are going to use an Integrated Development Environment (IDE) in order to create the application. The recommended IDE for Android development is Android Studio and can be downloaded from here: https://developer.android.com/studio



```xml
<?xml version="1.0" encoding="utf-8"?>
<android.support.constraint.ConstraintLayout
    xmlns:android="http://schemas.android.com/apk/res/androi
    xmlns:app="http://schemas.android.com/apk/res-auto"
    xmlns:tools="http://schemas.android.com/tools"
    android:layout_width="match_parent"
    android:layout_height="match_parent"
    tools:layout_editor_absoluteY="81dp"
    tools:layout_editor_absoluteX="0dp">

    <ImageView
        android:id="@+id/imageView2"
        android:layout_width="0dp"
        android:layout_height="0dp"
        android:contentDescription="@string/app_name"
        app:layout_constraintBottom_toTopOf="@+id/imageView6
        app:layout_constraintEnd_toStartOf="@+id/imageView3"
        app:layout_constraintHorizontal_bias="0.5"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toTopOf="parent"
        app:srcCompat="@drawable/grid_1" />

    <ImageView
        android:id="@+id/imageView3"
```

Android Studio is the official integrated development environment (IDE) for Google's Android operating system, built on JetBrains' IntelliJ IDEA software and designed specifically for Android development. It is available for download on Windows, macOS and Linux based operating systems. It is a replacement for the Eclipse Android Development Tools (ADT) as the primary IDE for native Android application development