



Norwegian University of
Science and Technology

Supporting Facilitators of Collaborative Learning using Mixed Reality

Helping Experts in Teamwork Facilitators
observe groups collaborating in Virtual
Reality

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Preface

This is a Master's Thesis in Computer Science at NTNU, it was carried out during the autumn and spring semester of 2017/2018. We are writing this for people who have an interest in furthering the fields of VR/AR/MR, either in technical terms as a computer scientist or for pedagogues who share the same vision as us in using this technology as a tool for learning and collaboration.

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Abstract

Experts in Team is a compulsory subject for all master students at NTNU. Here students collaborate in inter-professional groups with the goal of improving their own knowledge and skill of teamwork and cooperation through exploring innovative solutions on problems relative to the village's theme. One of these themes is 'VR/AR for learning and training'. Learning Assistants, known as facilitators, are employed to support the students during the course. At this village some groups may elect to collaborate remotely with another group located on another NTNU campus. This has caused problems for the facilitators, as there are no tools or specific guidelines for facilitating collaborative groups in VR/AR. The purpose of this master was to explore the concept of facilitating groups in VR/AR and try to provide a prototype solution for group facilitation in VR/AR. Our solution was to develop a mixed reality application in Unity, based on an already existing application developed in Unreal. Our version was to include support for Microsoft's HoloLens, merging VR and AR into one platform. This platform is known as Mixed Reality. Our findings, together with theory show that there is a need to provide the facilitator these tools, and by testing the prototype we also propose some requirements for such tools.

Keywords: Virtual Reality, Augmented Reality, Mixed Reality, Experts in Teamwork, Collaborative Learning, Experiential Learning, HoloLens, Immersive Headsets, HTC Vive.

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1 Introduction

1.1 Motivation

With the new rise of Virtual- and Augmented Reality technologies, devices like HTC Vive[5], Facebook's Oculus[6], as well as Microsoft's HoloLens[3] and Immersive Headsets[4] have revolutionized the way we see and interact with digital information. These technologies have great potential, not only for entertainment and leisure, but for educational and collaboration purposes as well.

Virtual- and augmented reality have had a long history dating all the way back to the 1960s, but it has only in the past several years become available to the masses. [7] This led to a resurgence where entertainment was the main driver. This is reflected in that Oculus stated that the Rift's first focus is gaming[8], and that HTC's partner, Valve, is one of the biggest names in the games industry[9]. Even Augmented Reality technology was made popular by applications like Snapchat[10] filters and the hugely popular game Pokémon Go[11].

Entertainment might be a reason for their initial success, but there has also been applications of Virtual- and Augmented Reality outside of entertainment, like helping Norwegian children to learn math[12] or helping apprentices learn building systems[13]. These applications show that this kind of technology might have an even greater purpose outside of entertainment. In addition, the educational system will soon gain even greater focus on educating experts in the field. A project initiated by AR-FOR-EU called Code Reality aims to develop courses for teaching augmented reality in higher level education. [14] They estimate to have trials ready as soon as 2019.

As a head start, NTNU has established an Experts in Teamwork(EiT) village called "Virtual and Augmented Reality for Learning and Training". Both authors attended this village during the spring semester of 2017. During this semester we got to experience first hand some of the cutting edge technologies related to virtual and augmented reality. E.g. being able to try the HoloLens, a very new and expensive device. This was also where we got introduced to the Four Campuses One Reality project.

Four Campuses One Reality is a cross-campus project that aims to put NTNU at the forefront of collaborative innovation. The project got started because *"the merger of NTNU Trondheim, HIST, Gjøvik University College and Ålesund University College, led to new challenges in supporting collaboration between students and em-*

ployees across campuses, both within and between cities." [15] It aims to create "innovative physical and virtual learning arenas and connecting distributed teaching and research groups across NTNU with modern technology." [15] In practice the project is looking to create VR-labs across the campuses of NTNU and among other things develop an application, named IVR-Connection, which allows students and staff to collaborate through virtual reality. This project is currently blooming [16] and as a result, on the 29th of May 2018, two VR labs was officially opened at two of NTNU Trondheim's campuses: Dragvoll and Øya.[17]

During the EiT Course, one of the authors, Stian, worked on a project that consisted of expanding on IVR-Connection. This application was also at the same time expanded upon by two other groups linked to the EiT village. One of which was located in Gjøvik. The three groups collaborated on testing and expanding IVR-Connection by having weekly meetings in the virtual environment provided by the application. Each week, selected participants from each group would enter the virtual world and provide status reports, share ideas, and test each others solutions. This had great potential for being a productive way of collaborating across large geographical distances. Experiencing and developing for these technologies during the EiT course is the main reason we chose this theme for our thesis.

1.2 Problem Description

Collaborating in virtual reality has been more work than value in the context of EiT. Partially because there was some technological difficulties with the application and the devices, but mostly because we just were not used to collaborating in a virtual environment. In EiT, when a group is not performing optimally, a facilitator can step in and help them achieve greater efficiency by asking questions to foster further discussion. However, in virtual reality, this proved to be a little bit more challenging. The facilitator had a hard time getting an adequate overview over the collaborative situation in the virtual world, and because he was not co-present in the virtual space, it was also hard for him to relay feedback effectively. Facilitation had a great effect on our groups efficiency outside of virtual reality, thus in this thesis we wanted to further expand the concept of IVR-Connection to better support the cross campus collaborative learning occurring through the EiT village "VR/AR for learning and training".

To achieve a more effective way to facilitate the groups working collaboratively in Virtual Reality, we propose a way to observe and interact with the students inside the Virtual Environment through an Augmented Reality platform. This means having the IVR-Connection application, which only supports VR devices, support a cross platform solution with an AR version of IVR-Connection. In the AR version, the facilitators could spectate and interact with the Virtual World the students

found themselves in.

1.3 Research Question

These research questions aim to guide our efforts in exploring solutions for combining augmented- and virtual reality to support and facilitate collaborative learning in the context of EiT.

RQ How to use mixed- and virtual reality to support and facilitate collaborative learning in the context of EiT?

RQ1 How to use virtual reality to support and facilitate collaborative learning in the context of EiT?

RQ2 How to use mixed reality to support and facilitate collaborative learning in the context of EiT?

RQ3 What are the advantages and disadvantages of both approaches?

2 Background

2.1 EiT

Experts in Teamwork(EiT) is a compulsory subject for Master students at NTNU. There are about 80 villages, each with its unique village theme. The general theme for the villages are problem areas from society and working life. In each village, students are divided into groups and are to define their own project related to the village theme.[18]

The point of EiT is for students to develop interdisciplinary teamwork skills. By composing each EiT village of students from a wide range of disciplines, each student will learn how to work together in interdisciplinary groups. There is also a focus on reflection of one's own contribution in a team, and reflection on the team as a whole.[18]

To help the students in their reflection endeavours, EiT has employed teaching assistants to observe the students as they work. These facilitators are to help the groups by asking questions, and stating some of their observations to foster discussions and further introspection in the group. The facilitator is never to command, or directly give instructions to the group.

2.1.1 VR/AR for learning and training

"Virtual and Augmented Reality for Learning and Training" is an EiT village led by Ekaterina Prasolova-Førland. On NTNU's page about the village it says (Translated to English): *"In this village we are going to explore innovative solutions for collaboration in VR/AR with our sister-village at NTNU-Gjøvik (led by Simon McCallum). Some of the groups will therefor have the opportunity to collaborate on their projects with the Gjøvik-students in a virtual arena with HTC Vive and Hololens. The group projects can also be done in collaboration with a selection of local businesses and international actors."*

This master thesis is written in collaboration with this village. It is through this village that we have gotten access to authentic users and resources, like hardware and lab space.

2.2 NTNU Dragvoll VR Lab

The VR lab at Dragvoll started out as a small repurposed office room at the department of "Education and Lifelong Learning". The space contained two computers, each connected with an HTC Vive. The Vives shared the same spatial area, only di-

vided by a digitally defined split of the room. In other words the lab was cramped and didn't support many concurrent users.

In the beginning of January 2018, the lab was moved to a repurposed computer lab completely renovated to serve the purpose of a modern VR lab. At the time of writing this thesis, it contains 4 semi-separated booths, 5 VR ready computers, 4 HTC Vive setups, 3 Windows Mixed Reality headsets, one Oculus Rift, and 3 HoloLenses. With all this new technology operating simultaneously in the same space, there were some unforeseen issues. These issues are addressed in section 6.2.6.

2.3 Concepts

In this section we will define the concepts central to this thesis.

2.3.1 Virtuality Continuum

The Virtuality Continuum (VC), as shown in Figure 1. *"Is a concept which relates the mixture of classes of objects presented in any particular display situation."*[1] This article, *"A Taxonomy of Mixed Reality Visual Displays"* by Paul Milgram and Fumio Kishino[1] introduces the concept of a "virtuality continuum" to describe the range of environments shown on any particular display. The articles focus on the taxonomy of Mixed Reality displays, and is also one of the earliest adapters of the concept of Mixed Reality.

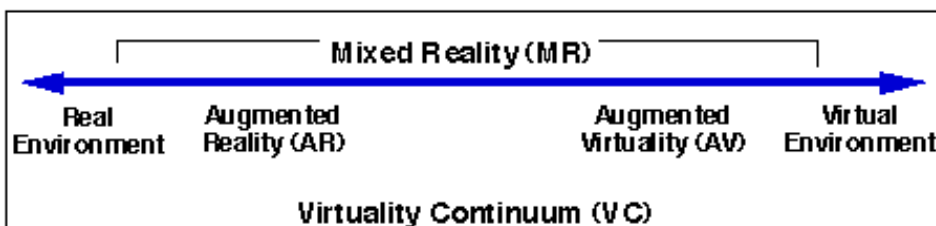


Figure 1: Simplified representation of a "virtuality continuum".[1]

Virtual Reality

Milgram's and Kishino's description of Virtual Reality (VR) from their paper[1]. VR is the concept of a virtual space where the user is fully immersed in a virtual world, usually through a Head Mounted Display (HMD). This means that the environment, and everything the user sees and interacts with is completely synthetic. The environment can emulate the real world and seem like reality, be it fiction or otherwise. This Virtual Environment (VE) can also be a world where our physical laws do not apply. On the virtuality continuum, as shown in Figure 1, this type of

environment resides on the furthest extreme, opposite the real environment.

Augmented Reality

Augmented Reality (AR) is the concept of a real environment with digital elements superimposed, enhancing the users perception of reality[1]. This is achieved by rendering these digital "holograms" on a transparent display which the user sees through (e.g. Microsoft's HoloLens[3] or Magic Leap[19]). The same effect can also be achieved by superimposing the digital elements onto video captured by a camera in real-time.

Mixed Reality

As shown in Figure 1, a Mixed Reality (MR) display can reside anywhere between the extremes of the virtuality continuum[1]. The technology has moved on since 1994, when the paper by Kishino and Milgram was published. *"Since then, the application of mixed reality goes beyond displays but also includes environmental input, spatial sound, and location."*[2]

Microsoft, especially, has expanded on the application of Mixed Reality. And in the article "What is mixed reality?"[2]. MR is described like this: *"Most mobile phones on the market today have little to no environmental understanding capabilities. Thus the experiences they offer cannot mix between physical and digital realities. The experiences that overlay graphics on video streams of the physical world are augmented reality, and the experiences that occlude your view to present a digital experience are virtual reality. As you can see, the experiences enabled between these two extremes is mixed reality"*[2]. This spectrum is found in Figure 2

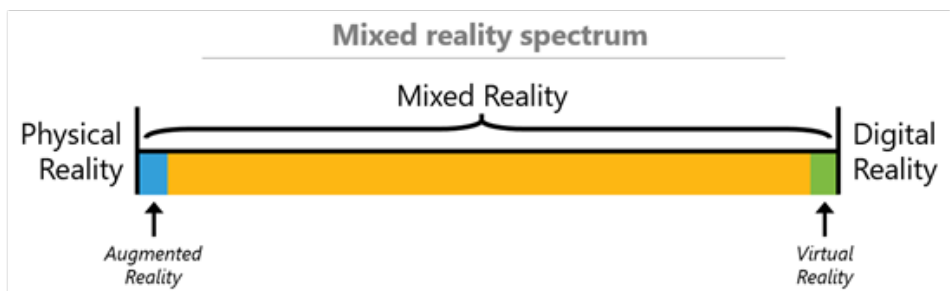


Figure 2: The Mixed Reality Spectrum[2]

In Figure 3 the two main device types that deliver Windows Mixed Reality is listed. These are: Holographic devices, which have the ability to place digital content in the real world[2]; and Immersive devices, which have the ability to hide the physical world and replace it with a digital experience.[2]

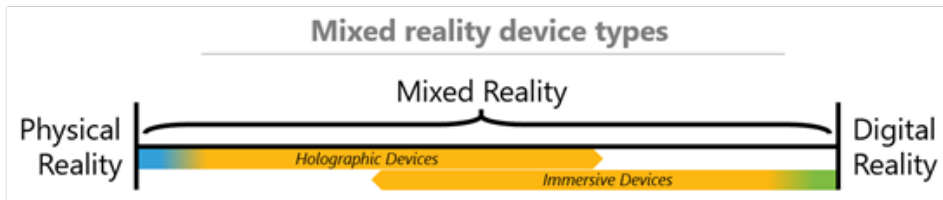


Figure 3: Mixed reality device types.[2]

2.3.2 Holograms

Holograms are "objects made of light and sound that appear in the world around you, just as if they were real objects." [20] Basically they are the digital objects the user of the Hololens sees and interacts with. The objects can be placed anywhere in the room, and responds to gaze, gestures and voice commands. In our application, the hologram the user will experience, is a live version of the virtual world where the users of the immersive headsets are collaborating. This world is scaled down to fit the table or floor.

2.3.3 Collaboration

Collaboration is, by Rochelle and Teasley, defined as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem." [21]. In their paper they further distinguish 'Collaborative' problem solving and 'Cooperative' problem solving. The latter divides work between the participants, whilst the former is a mutual engagement where the participants make a coordinated effort to solve a problem together. [21]

2.3.4 Immersion

Immersion in relation to computer games is "used to describe the degree of involvement with a game" [22]. In the paper by Brown in 2014 he defines three different levels of immersion: Engagement, engrossment and total immersion. Each level has its own barriers that needs to be removed for that level of immersion to be possible. Entering a higher level of immersion is correlated with having a higher level of concentration and focus [23]. For IVR-Connection this is one of the concepts that can give the user an advantage over collaborating in real life.

2.3.5 Presence

Jennet et al. presents two different perspectives on the definition of presence [23]. The first has basis in the rationalistic tradition, and defines presence as a psychological sense of being in a virtual environment [24]. With this perspective the level of presence has to be evaluated through user feedback. The other bases itself

on the Heideggerian/Gibsonian metaphysics, and relates presence to the ability of "successfully supported action in the environment" [25]. With this perspective presence can be evaluated through empirical means. Presence and immersion have a lot in common and are often used interchangeably. However, Jennet et al. argues that presence is a state of mind, while immersion is an experience in time [23]. With this distinction presence and immersion are allowed to overlap, but it is also possible to have one without the other. For example, a user can fit the definition of being immersed while playing Tetris, but it would be hard to imagine the user feeling present in the Tetris world of falling blocks. [23]

2.3.6 Facilitation

Facilitation can be viewed as a response to the requirements of meeting management. This is easily seen when the facilitator is not a member of the group, but rather a meeting specialist who aids the group in acting to meet its objectives. An essential function of a facilitator in any setting is to create and sustain an environment in which a group can accomplish its tasks and learn about itself in the process. It is worth noting that when 'facilitation' is used in the context of this thesis,

2.4 Technology

In this section we will cover the technology that made everything possible. This master is based on cutting edge technology from Microsoft and Unity.

2.4.1 Universal Windows Platform

Universal Windows Platform (UWP) provides a common app platform for every device that runs Windows 10. An UWP app is written in C++ /WinRT or C++ /CX and has access to the Win32 APIs that are part of the UWP. These Win32 APIs are implemented by all Windows 10 devices.[26] Examples of devices running Windows 10 are: Desktop computers, phones, XBOX and Hololens.

2.4.2 Mixed Reality Toolkit

"The Mixed Reality Toolkit is a collection of scripts and components intended to accelerate development of applications targeting Microsoft HoloLens and Windows Mixed Reality headsets. The project is aimed at reducing barriers to entry to create mixed reality applications and contribute back to the community as we all grow."[27]

2.4.3 Unity

Unity is a game engine for creating 2D, 3D, VR, AR and MR games and apps. It has its own graphics engine and a full-featured editor that enables you to create games, and deliver your content to virtually any media or device. Unity also features services like cloud building, multiplayer network, version control and analytics. Unity is also at the forefront of the growing VR market. An estimated 90% of Samsung

Gear VR games and 53% of Oculus Rift (games at launch) were[sic] Made With Unity. [28]

2.4.4 Unreal

One of the oldest and most used game engines. The Unreal Engine[29] has been used by multiple award winning AAA games. It is Written in C++ and is highly optimized for PC, VR and Mobile platforms. With the resurgence of VR, Epic Games have shown great commitment to the VR platform, offering one of the most extensive development suites for VR. Its blueprint framework sets the bar for developing an unreal application low, and they have also introduced a way of creating VR applications in VR.

2.4.5 Hololens

The Hololens[3] is Microsoft's holographic device. Using inside-out tracking, it is a fully mobile head mounted device running Windows 10. It has full six-degrees of freedom movement and uses a see-through display to render the "holograms".



Figure 4: The hololens headset[3].

2.4.6 Immersive Headsets

Under the Mixed Reality Moniker, the Immersive Headsets[4] are VR headsets which use built-in inside-out tracking. With no need for external sensors, and only one cable for connection with the PC; One can enjoy VR from anywhere. Headsets are provided by multiple different big name retailers, all providing their own designs and solutions for the platform.



Figure 5: The different Immersive Headsets. [4]

3 Related Work

Microsoft's MR technology is very new, and for this reason there is not a lot of research and exploration on different uses of the technology. There are some collaboration oriented applications made for VR and AR platforms, VR especially has had some progress in this area. First we will introduce some technology and research that has been instrumental in the development of the Unity version of IVR-Connection.

We will also shortly introduce some central concepts in Experiential and Collaborative learning that provide the basis for EiT and the inter-campus activities. They also shape the requirements for the system we are developing.

3.1 Experiential Learning

Experiential learning is a learning theory that places experience at the center of the learning process and is driven by the resolution of the dual dialectics of action/reflection and experience/abstraction. [30] The experiential learning(ELT) theory defines a cycle of experiential learning with four interacting steps, each corresponding to one part of the dual dialectics: Active experimentation (action), concrete experience (experience), reflective observation (reflection) and abstract conceptualization (abstraction). [30]

Since the theory's first mention by David Kolb in 1971 [31], researchers from all over the world have shown interest in the subject. ELT has through this proved to be a robust and interdisciplinary theory, addressing learning and educational issues in many different fields. [30]

In the student guidebook for EiT[32], the method of learning in EiT is explained as experiential-based. By exposing the student to situations that arise in collaborative work ". *Students develop skills in collaboration by reflecting on these situations throughout the project life cycle.*"[32] This is further supported by facilitation provided by the village supervisors and learning assistants(Facilitators).[32] In essence, EiT provides a framework for students to work in groups, in order to learn how to work in groups. This is achieved through Collaborative Learning.

3.2 Collaborative Learning

Collaborative learning is, according to Dillenbourg, "*a situation in which particular forms of interaction among people are expected to occur, which would trigger learning mechanisms*". [33] This definition, though it is very broad, helps expose the

critical element of learning collaboratively. Namely triggering the learning mechanisms. Dillenbourg proposes four categories of ways to increase the probability of triggering these mechanisms: Setting up the initial condition, over-specify the 'collaboration' contract with a scenario based on roles, scaffold productive interactions by encompassing interaction rules in the medium, and monitor and regulate the interactions. [33]

A similar division was proposed in a more recent paper by Lee. It divides collaborative learning into six procedural elements meant to distinguish collaborative learning from other types of small-group learning: Intentional group formation, continuity of group interaction, interdependence between group members, individual accountability, explicit attention to the development of social skills, and instructor as facilitator. [34]

In Lee's list the instructor is required to act as a facilitator. Which entails that the *"role of the instructor is one of an expert peer or coach, who offers advice, encouragement and clarification while promoting reflective dialogue and critical thinking through the issuing of timely and relevant questions."* [34] Dillenbourg's last category concerns monitoring and regulating the group interactions. This category suggests, like Lee, that the instructor does not take the role of a tutor, but instead takes the role of a facilitator. Dillenbourg sees this as important *"[...] because the point is not to provide the right answer or to say which group members is right, but to perform a minimal pedagogical intervention (e.g. provide some hint) in order to redirect the group work in a productive direction or to monitor which members are left out of the interaction."* [33] Thus both Lee and Dillenbourg lists facilitating as a critical component to learning collaboratively.

3.3 Computer Supported Collaborative Learning

Computer Supported Collaborative Learning(CSCL) refers to, as the name suggests, collaborative learning facilitated by the use of a computer. Either by using an application specifically designed for such a purpose, or by simply using computer mediated tools in the collaborative learning process.

Lee states that, using virtual environments for CSCL *"[...] allow geographically dispersed users to explore an environment concurrently, with each represented by a surrogate persona or "avatar" visible to other users, and with tools allowing text-based or audio communication. More importantly, these environments allow two or more users to jointly and synchronously undertake kinaesthetic or tactile activities within the game or world."* [34] He concludes that *"[...] well-designed learning interventions using virtual world environments can manifest the key ingredients or elements of collaborative learning."* [34] However, if not designed properly the affordances of immersing students in a virtual environment might become a disadvantage, as

it can distract the students attention away from the task at hand. [35]

In the EiT village "VR/AR for learning and training" there are one or two groups who work remotely with Gjøvik. When we participated in the course there were two groups, this year there was one. This was facilitated through the Unreal Version of IVR-Connection, where the students had meetings and check-ins/outs. Their assignment was to improve upon the application. In the context of EiT and Collaborative learning, this was effectively a form of Computer Supported Collaborative Learning(CSCL).

Dillenbourg states that "*In the context of CSCL, the external regulator needs specific tools for monitoring the interactions occurring in different places and/or at different times.*" [33] This is further supported by Lee in his conclusion stating that it is "*[...] imperative that the centrality of the instructor playing an active role is not overlooked or underestimated.*" [34] In the context of this thesis, the external regulator mentioned by Dillenbourg would be the facilitators/learning assistants employed in the EiT course, and the specific tools would be our solution for observing the interactions between students in the virtual environment.

3.4 The Unreal version of IVR-Connection

The Unreal version of IVR-Connection's main goal is to provide a Virtual Environment to facilitate collaboration. This application is a result of the master thesis *Virtual Reality Collaboration: Using current virtual reality technology for long distance collaboration and meetings* by Nicklas Løkkeberg Nilsen. [36] It has since been worked on by bachelor and EiT students. It implements features for drawing on a whiteboard, image sharing, 360 video viewing, a prototype for sharing 3D models, and a prototype for simulating laser physics. Since we had to remake IVR-Connection in Unity, we wished to provide a similar collaborative environment, even though our thesis is focused on the facilitator spectating we originally wanted to add.

3.5 Virtual Reality Spectating

In the master thesis *Virtual Reality Spectating*, by Jan Greger Hemb, a discussion on virtual reality spectating is conducted. Hemb builds on IVR-Connection and tries to add different forms of spectating to see which one the users prefer. His results found that virtual reality was the preferred way to spectate virtual reality, and that having freedom of movement was preferred to being limited. [37]

3.6 Augmented Reality Visualizations

In a recent study done by at Delft University of Technology about different ways of visualizing Augmented Reality, there was "*[...] significant indications that the use of*



Figure 6: The unreal version of IVR-Connection, usernames removed for user privacy

a ‘god-mode’ perspective for the remote expert provides the best situation awareness [...] [38]. In this context ‘god mode’ perspective refers to observing miniaturized versions of the virtual objects. In our solution this type of perspective is used to give the facilitator a good overview over the the virtual environment.

3.7 MR Sharing 250

MR Sharing 250 is a tutorial from Microsoft showcasing the possibility for combining the virtual reality of immersed headsets with the augmented reality of Hololens. [39] It contains the models and code for a small virtual environment, were the immersed headset users can solve puzzles in the environment and the Hololens users can observe them.

When developing the Unity version of IVR-Connection this tutorial was a part of the resources used. It was however not as useful as we thought it to be when we first discovered it. This tutorial and its resources had aged badly and did not support the newest updates from the Mixed Reality Toolkit and Unity. It was however possible to transfer the models and parts of the code, which with a little bit of modification gave us shortcuts to some common features. The player models were taken directly from the tutorial.

3.8 Other uses of VR/AR/MR for collaboration

Listed below are some of the examples of applications for collaboration that actively uses virtual, augmented, or mixed reality as its primary medium.

3.8.1 Facilitating Medical Training in Virtual Reality

In a master thesis by Henrik Trandem, he produced a room-scale virtual reality application that could "[...] help facilitate interprofessional healthcare training" [40]. The application made by Trandem was inspired by an application made using Second Life in "*Practicing Interprofessional Team Communication and Collaboration in a Smart Virtual University Hospital*" [41]

3.8.2 Masters of Pi

Master of Pi is a project that aims to redefine Product Lifecycle Management software by using VR technology. They want to do this by providing a collaborative, interactive digital space in which engineers can work across disciplines. This can reduce cost and complexity associated with constant refactoring of CAD data. [42]

3.8.3 CocoVerse

CocoVerse[43] is an application quite similar to the original IVR-Connection, both have the same idea of providing a virtual environment for collaboration. CocoVerse provides a way for users to "[...] sketch volumetric surfaces in 3D with a virtual paintbrush; create and manipulate objects; capture images with a camera, and place them as pictures; and write phrases using a speech-to-text system."

3.8.4 Holoportation

Microsoft is researching on new ways to communicate and collaborate using VR and AR platforms. One example of this research is "*holoportation*"[44]. Holoportation sends a live 3D-model of a real object or person to a user's head mounted display. This object or person will then appear as a hologram for the receiver. Here, the receiver can interact or communicate with an accurate 3D model of an object or person many miles away.

4 Methodology

In this chapter we will outline the process and methodology used in this master thesis.

4.1 Research Methodology

Our research method is based on gathering and formulating research questions. To answer these questions we employed both qualitative methods in the form of focus groups, and quantitative methods in the form of questionnaires.

4.1.1 Research Questions

Gathering and formulating the research questions was done based on conversations with our supervisors, existing theory and personal experiences with the topic. These questions started out broad, but through experiences and further exploration in the topics of collaboration, collaborative learning, EiT, and the concept of mixed reality, the questions became more refined and focused on what we really wanted to answer.

The final questions aim to combine augmented- and virtual reality to explore the possibilities of using HoloLens to support and facilitate collaborative learning in the context of EiT. With an added focus on how mixed reality compares to traditional VR, and if the results gathered can be applied outside of EiT.

RQ How to use mixed- and virtual reality to support and facilitate collaborative learning in the context of EiT?

RQ1 How to use virtual reality to support and facilitate collaborative learning in the context of EiT?

RQ2 How to use mixed reality to support and facilitate collaborative learning in the context of EiT?

RQ3 What are the advantages and disadvantages of both approaches?

4.1.2 Focus Groups

The results of this project were mainly evaluated through the qualitative method of focus groups. The focus groups were conducted in a semi-structured manner, and the guiding questions were rooted in the field of usability testing. The participants were facilitators and master students with experience in the field of VR/AR.

4.1.3 Questionnaire

Questionnaires were conducted through Google Forms. The data was mostly gathered from EiT students who were working with the Unreal version of IVR-Connection, and focused on comparing student satisfaction and experiences with the two different applications. The questionnaire was based on an earlier questionnaire given to the EiT students of 2017, regarding the evaluation of using IVR-Connection in the course. Some of the data gathered was also to be compared to the data gathered about the Unreal Version of IVR-Connection, as it had been heavily improved upon.

4.2 Software Development Process

4.2.1 Agile Software Development

The application was developed with an agile approach. It consisted of 3 main phases, each of which included several iterations. Each phase was conducted in the following order: Defining the backlog and then iterating repeatedly through feature design, implementation, and evaluation. Working with an iterative, agile approach let us adapt more easily to new discoveries. Which matched well with the exploratory nature of this project. Following are the main practices of agile development we subscribed to during this project:

Incremental Development

At the end of each phase we made sure to have a usable version of the application, and that each new phase gave rise to new user visible functionality.

User Testing

At the end of each phase a larger scale evaluation was carried out with real users. These user tests consisted of the users trying out the application with or without specific instruction. Specific instructions were only used when the application was mature enough to evaluate facilitation of a collaborative scenario. Testing with real users enabled us to get relevant feedback.

Unit Testing

Unit tests were used to quickly test the expected output of functionality within the program. This was important to speed up the progression due to the long build time associated with building applications for Hololens.

Version Control

Version control was handled through Unity Collaboration. With Unity Collaboration it was easy to follow which files the other person was working on at any given time. This was due to visual indicators next to the relevant files within the Unity editor itself. In addition, Unity Collaboration offers specific tools for merging Unity's binary files, something most other version control solutions can't do.

Pair Programming

Pair programming was used to ensure quality in critical areas of the code. It also helped speed up progression when we got stuck with our individual tasks.

Backlog

A backlog was used to keep track of the essential features of the application. We used the backlog as a reference for what the applications would be expected to contain at a finished stage. This allowed us to not lose sight of the finished product.

Task Board

A task board was established for each phase. It was populated with the essential features from the backlog estimated to be finished within the phase. The task board was sketched using Google Docs[45] and visualized using Trello[46], and was updated after each meeting. Having a task board helped us to gain a continuous overview of the progress within a phase.

5 Phase 1

5.1 Exploration

In the beginning of the first phase, time was spent looking for ways to integrate Hololens into the already existing IVR-Connection application. To accomplish this, we had to look at the code of IVR-Connection and browse online for already existing solutions for Hololens in Unreal.

5.1.1 IVR-Connection

IVR-Connection was developed in 2017, and used Unreal version 14.0. In relation to VR technology and especially Windows Mixed Reality, this could be considered as an old version of Unreal Engine. This meant that IVR-Connection needed an engine version update for it to be best able to support the newest VR technology, e.g. Hololens. We were tasked by our supervisors and stakeholders to update IVR-Connection to establish a stable baseline, a 1.0 release of IVR-Connection. This baseline was to act as the new official version that every other student working on the application would use. The aim was set at Unreal Engine release 4.18, as it provided a lot of new features and support for VR technology, making it a good version for a stable baseline for a VR application. Unfortunately it had no official support for Windows Mixed Reality and Hololens.

5.1.2 Hololens Support

The best way to support Hololens, was to support UWP. Unreal engine did not natively support UWP at the time, but Microsoft was working on a branch of Unreal that did. This branch also had a sub branch called `dev_MixedReality` which added support for Windows Mixed Reality. In addition there was a plugin called ProteusVR that added templates and blueprints for Hololens to this branch. ProteusVR had just reached version 1.0 and the lead developer promised to rapidly release updates as Windows' mixed reality branch evolved. The mixed reality sub branch did however not support Unreal engine 4.18 at the time. Since the priority for IVR-Connection was to support HTC Vive and be on the cutting edge of VR features, updating to Unreal engine 4.18 got prioritized over merging to the new Microsoft branch. In addition both the Microsoft branch and ProteusVR were both actively being developed. This meant that there was a chance for them both to catch up with 4.18 while we worked on the stable baseline for IVR-Connection. Thus Hololens support was set on hold until IVR-Connection 1.0 was finished.

5.2 Implementation

The strategy for updating IVR-Connection to Unreal engine version 4.18 was carried out in two steps. Since 4.18 didn't get released before 23rd of October 2017, the first step was to update to 4.17. This was to be able to address as many deprecation issues as possible before 4.18 released, making the transition a little bit smoother. After 4.18 was released, the IVR-Connection was updated again, bringing it up to date with the newest VR features Unreal could offer.

5.2.1 Plugins

There were two plugins attached to the original version of IVR-Connection: VR Expansion and VictoryBP. VR Expansion Released updates for 4.17 and eventually 4.18, so we did not need to modify anything using this plugin. That other one on the other hand seemed to be dead, and had not released any updates in a while. We therefore removed the plugin and rewrote the blueprints that had been using it. This was done with native functions within the Unreal engine.

5.2.2 Image Loading

The blueprints for loading and sharing images used features from the removed plugin which had no equal within the Unreal engine. Loading images had also previously proved to freeze the main thread while the image was being loaded. The solution to both these issues was finding a small piece of code that allowed for loading the images asynchronous to the main thread.

5.3 Evaluation

The evaluation of phase 1 consisted of 1 survey with 26 respondents and an internal evaluation regarding Hololens and Unreal.

5.3.1 Survey

The survey was a part of a stand at UKA technology conference, where people could come and test IVR-Connection for Vive before filling it out. The goal was to get an idea of what people think about using VR for collaboration and learning, as well as to get an overview of what features the respondents deemed most important in such a scenario.

Of the total 26 respondents, 46.2% had tried VR a few times before while only 11.5% had tried it many times, which leaves 42.3% that had never tried VR before that day. Because the definition of many and a few can vary from person to person, it only makes sense to make a distinction between those who had tried VR before, and those that had not.

The survey showed that interacting together in VR can be an exciting and engaging experience, since all respondents agreed to this. Which is reflected in their

excitement about the idea of using this for collaboration and lectures in the future. In other words, the survey confirmed that the concept of IVR-Connection was worth continuing on.

24 of the total 26 respondents said that they felt a strong or some sense of presence in the VR world, but only 11 agreed that it was easy to follow what the others were doing. When observing the respondents trying IVR-Connection, an emerging trend was that they lost track of the other users when they were teleporting. This might indicate that the application needs some features for tracking the other users location, e.g. adding spatial sounds and/or particle trails when people are teleporting like Nicklas mentions in his thesis [36].

As figure 7 shows, the most wanted feature was 3D drawing and working with 3D objects, with over 80% of participants wanting both. The next feature on the list is sharing a whiteboard, followed by voice communication, AI teaching assistant, movement capturing and 360 degree video streaming. At the bottom of the list, we find Avatar related features and file sharing. Since this question only asked people what they would like to see in the application, no rigid conclusion could be taken, but it helped us guide our decision of which features to focus on.

What functionalities would you like to see in a collaborative learning VR environment?

26 responses

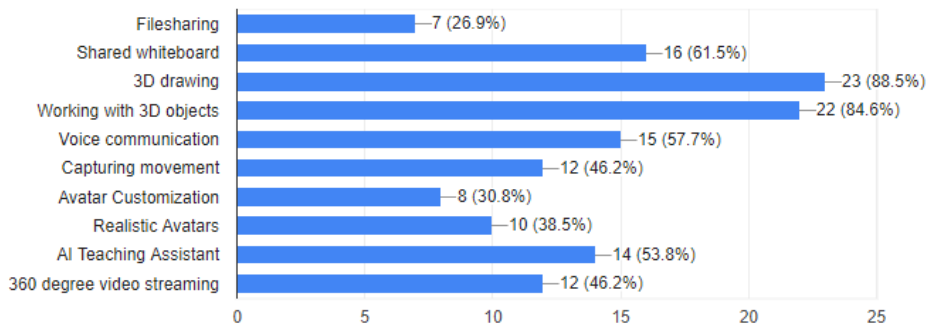


Figure 7: A chart showing what features people would like to see in IVR-Connection. The rest of the results from the survey can be found in attachments

5.3.2 Hololens

By the end of the first phase the mixed reality branch of Unreal developed by Microsoft was still stuck in 4.16, and ProteusVR had not seen any activity in 4 months.

This meant that we either had to switch back to Unreal 4.16 or find another way of using Hololens for a collaborative environment.

Switching back to 4.16 and using Microsoft's Unreal branch could make it unnecessarily complicated for the other students working on IVR-Connection, as well as limiting development when it comes to optimally supporting the newest standards and VR hardware. Thus we decided not to continue down the path to add Hololens support for IVR-Connection for Vive.

Instead we directed our attention towards Unity. Unity offered support for the newest in VR hardware and was Microsoft's own recommended engine for developing 3D applications for Hololens and Windows Mixed Reality. To further accelerate development Microsoft had also started working on a plugin, called Holotoolkit. This tool was developed as an open source project and had a high level of activity, which meant relatively frequent updates. In addition making our own software, meant more freedom to explore in the directions we wanted. Thus we opted to take the concept of IVR-Connection and implement it with Hololens support in Unity.

6 Phase 2

6.1 Requirements

The start of the second phase consisted of eliciting requirements for the new version of IVR-Connection in Unity. We had two goals for this version. The first was to implement similar features to those of the old Unreal version of IVR-Connection. Implementing similar features would enable us to make a more direct comparison between the two version, and would also enable us to carry over some of the work already done. The second goal was to add explicit tools for the facilitator. Since explicit tools for the facilitator is a critical component for supporting collaborative learning, especially in a EiT context.[33][34]This addition had the potential of enabling the facilitators of EiT to better support collaborative learning for the students.

From our previous experience with EiT and using the Unreal version of IVR-Connection for collaboration, we had learned that the most productive tools used were drawing, talking and image sharing. Even though they were the most productive tools, they still weren't the easiest of tools to use. Therefore we wanted to improve the implementations of these tools when applied to the Unity version.

The following requirements are elicited from the questionnaire from UKA, conversations with facilitators and students, theoretical background, and our own experiences from the Unreal version of IVR-Connection. The following subsections will list these requirements and give a short rational for each.

6.1.1 F1 - Collaboration Space

For the collaboration space our goal was to have a minimalistic design. This entailed the space only containing basic shapes with basic textures. Our expertise is not that of 3D modeling and design, and thus we could have risked falling into the trap of making the space become a distraction, leading attention away from the task at hand. We also did not want to lead the participants into focusing on giving feedback on this space, as this thesis is not directed towards research on the virtual environment itself.

The user should be able to enter a collaborative space. The collaborative space should have the following features:

1. The space must feel roomy and spacious at the same time.

2. The space must function as a collaborative space, e.g. not be too fancy or captivating.
3. The space must be easy to navigate, e.g. have objects placed about to give the user a sense of depth.

6.1.2 F2 - Avatar

For the avatar our goal was to give an adequate representation of the user by support the same basic features that the Unreal version of IVR-Connection did. Giving the user a point of reference for interacting with each other. A point was made of differentiating the avatar of the HoloLens from the avatar of the immersed headsets. This differentiation was meant to distinguish the differences between the role of the facilitator from the role of the student/collaborator.

The user should have an avatar that represents him/her in the virtual space. The avatar should have the following features:

1. The avatar should follow the movement of the player.
2. There should be 2 different avatars. One for immersed headsets and one for the HoloLens.

6.1.3 F3 - Movement

For movement our goal was to have as much freedom as possible. This was to facilitate removal of the barrier of engagement, that is limiting immersion. [22] Freedom of movement could also fall into the definition of *successfully supporting action in the environment* [25], which should help the users feel present.

The user should be able to move around in the virtual space. The movement should be governed by the following features:

1. The user must be able to walk around in the virtual environment by walking around in the real world.
2. The user must be able to teleport using a controller.

6.1.4 F4 - Multiplayer

For multiplayer our goal was to let the users create and join sessions using a comprehensive menu. As the requirements were made to describe a prototype, the menu itself would remain minimalistic for testing purposes.

The user should be able to connect to other users. The multiplayer system should contain the following features:

1. The user should be able to host a session from any supported device.

2. The user should be able to search for active sessions created by other users.
3. The user should be able to join an active session.
4. The user should be able to disconnect from the currently active session.

6.1.5 F5 - Drawing

For drawing, our goal was to make it easy and intuitive to use. The plan was to implement both 3D and 2D drawing, but with a priority on drawing in 2D as this was the functionality supported by the Unreal version of IVR-Connection. We also made the assumption that it is easier to write when drawing in 2D, which makes it fit the use case of writing down agendas and taking notes, both of which were instrumental to the meetings we had when taking the EiT course.

The user should be able to communicate and visualize through drawing. The drawing should be governed by the following features:

1. The user should be able to draw on a surface.
2. The user should be able to draw in the air in 3 dimensions.
3. The user should be able to choose a color to draw with.
4. The user should be able to erase what has been drawn.

6.1.6 F6 - Media Sharing

For media sharing our goal was to make it "plug and play" and easy to use. Media sharing was one of the least used, but still useful features from the Unreal version of IVR-Connection. The biggest reason it did not get used as much, was because it required a lot of setup and syncing outside of the program. So our criteria for implementing the same feature was that it should not be unnecessarily complex to use. If this criteria could not be upheld, the feature would probably become more of a distraction than add any value to the application. For testing purposes however we would consider adding the feature anyways, thus the criteria did not make it into the requirements.

The user should be able to share media like video and images to other users. The sharing of media should be governed by the following features:

1. The user should be able to open a sharing menu.
2. From the sharing menu the user should be able to share media with the other users.
3. When shared, a game object representing the media should be spawned in the virtual space.
4. The user should be able to move the spawned game object.

6.1.7 F7 - Voice Chat

For voice chat our goal was to let the users communicate using voice through the application itself. Something the Unreal version of IVR-Connection did not support. However, due to never having implemented a voice over IP service before, we were counting on external third-party software as a backup. Using third-party external software like Discord [47] would cover the same functionality as supporting it through the application itself. Thus the priority for implementing this was set to low.

The user should be able to communicate by using a voice chat. The voice chat should contain the following features:

1. The user should be able to speak to other users using a microphone.
2. When a user speaks there should be an indication of it in the virtual space.
3. The voice chat should be activated as soon as a user hosts a session.

6.1.8 F8 - Interactable Objects

For intractable objects, our goal was to give the user a medium for "breaking the ice", as well as to give a prototype to how shared 3D objects would be handled in the application. However, this feature got a low priority due to it being one of the main sources of elements that take attention away from the task at hand.

The user should be able to play around with physically intractable objects in the virtual space. These objects should have the following features:

1. The user should be able to pick up the object.
2. The user should be able to throw the object.
3. When thrown the object should maintain momentum according to the physical laws of the virtual space.

6.1.9 F9 - Hololens Spectating

For Hololens spectating our goal was to provide facilitators the tools necessary to better facilitate collaborative learning for the students. Based on the finding that 'god mode' is the best way to spectate through augmented reality[38], it was important to make the holograms small enough to get a good overview, but at the same time enable to facilitators to actually see what is going on. The most important aspect was to establish the concept, to let the facilitators to be able to give feedback.

The user should be able to spectate the virtual space by using a Hololens. Using the Hololens should be governed by the following features:

1. The user should be able to move the virtual collaborative space.
2. The collaborative space should be moved relative to the real world, e.g. can be place on a table or on the floor.
3. When using the Hololens the virtual space should appear small enough to fit on a table.

6.2 Implementation

The implementation of IVR-Connection turned out to be a bigger challenge than first anticipated. We had a lot of problems with getting the Microsoft's Mixed Reality 250 tutorial to work with the current version of the Mixed Reality Toolkit. This was because the tutorial had not been updated to the newest version at the time. We also ran into problems trying to implement one of the sharing examples that came with the toolkit. It turned out that we were working on a network that did not allow UDP broadcasting for discovery, which was required to run the network code shipped with the tutorial.

Due to these setbacks we had to change the priorities of our requirements in the middle of the phase. Our new goal was to only implement the minimal amount features required to get a relevant collaborative scenario for the facilitators to test facilitating with the Hololens. The features marked as the minimal requirements were the collaboration space, the avatar, movement, the match maker, drawing and Hololens spectating. The implementation of these minimal requirements are listed and described in the subsections below. With the exception of movement, because it was purely derived from the Mixed Reality Toolkit.

6.2.1 Collaboration Space

The collaboration space, aptly named "Immerzone", is the playing area where the immersed players can move around and interact with each other and the environment. It was designed to meet requirement F1. It has some boxes placed about to make it feel less empty, and a big whiteboard where the immersed players can draw. Attached to the gameobject is a LevelLogic script. It contains the logic for how the different headset types should spawn and scale the collaboration space.

6.2.2 Avatar

The avatar consists of a model with a PlayerController script attached, and was designed to meet requirement F2 and F3. The PlayerController script contains all the logic for how the player can interact with the virtual world. Due to lack of 3D modelling skills and time, the model for the avatar was taken from Microsoft's 250 Mixed Reality tutorial[39]. The model is under the MIT licence.

6.2.3 Match Maker

The match maker is based on Unity's match making system using UNET and Holo-Toolkit's example menu. The match maker contains logic for creating, searching for and joining matches and was extended to be able to transmit room data from Hololens to Hololens. The UI follows the player around and anchors around the bottom of the viewport. It only supported creating and joining matches. The join button was, for testing purposes, hard coded to search for matches, and then join the first match it found.

6.2.4 Drawing

From observation made of the EiT students of 2018 using the Unreal version of IVR-Connection, we found that they did not use the whiteboard as much. Drawing was implemented by giving the player a pen and a palette. The pen is used to draw on the whiteboard in the collaboration space. This is done by pointing the colored tip towards the whiteboard and drag it around, just like in the real world. The palette is used to change color. The player can change the color of the pen by touching the colors on the palette with the tip of the pen.

6.2.5 Hololens Spectating

Joining or creating a session while using a Hololens gives you a 'god mode' perspective of the collaboration space. Upon joining or creating a session, the collaboration space will spawn relative to you and your physical environment. The player can move the collaboration space by doing a tap gesture to pick it up, and another tap gesture to place it down again. The collaboration space will align with the spatial data gathered by the Hololens. Having a If someone with an immersed headset joins the session, they will appear in the collaboration space. The Hololens will thus be able to observe the interactions of those with the immersed headsets. Hololens spectating was implemented according to requirement F9.

6.2.6 VR Lab Space

Early January, the VR lab at NTNU Dragvoll finished construction. The lab consisted of four Vive headsets in different booths in the same room, each with its own set of base stations. The VR booths had an open design: With one of the side open and openings at the top of the walls. This caused the the base stations' infrared light to bleed into the adjacent booths. This introduced issues with the spatial tracking for some of the Vive headsets. Several solutions were applied to fix this issue:

1. Configure the base station in such a way that they could only one base station with a compatible setting.
2. Using sync cables to ensure that the correct pair of base stations synced to each other.

3. Stacking pieces of cardboard along the upper wall to block the light leaking over the wall.
4. Putting cardboard boxes with one side open over the base stations to limit the angle that they were sending light.
5. Using blinds to block any light entering through an opening in the side wall of one of the booths.

The first fix was supposed to stop the base stations from syncing with the wrong base stations, however, this solution was not perfectly consistent. The second fix was applied to address this issue, and this time the base stations consistently synced correctly to each other. The third fix stopped the light from leaking over the wall, effectively eliminating light leaks for some of the VR booths. Light bleeding from one booth to the other meant that the Vive headset would sometimes get confused about its spatial orientation. This had adverse effects for the person wearing the headset, as the world would move around erratically, often causing nausea or dizziness. To further assure that no light was escaping over the wall, fix 4 was applied. Fix 5 had to be applied to one of the booths due to a hole in one of the side walls. With all the base stations syncing correctly and the light leaks fixed, the Vive headsets were now operating predictably. The issues experienced with having multiple Vive setups in the same room will according to HTC Vive's website be addressed with the 2.0 version of SteamVR and the 2.0 version of the base stations. [48]

6.3 Evaluation

The evaluation of phase 2 consisted of a user test with 7 EiT students and 5 facilitators followed by a focus group session and a survey. Only the 2 facilitators from Trondheim were used for the focus group, but all 12 participants answered the survey. Due to some bugs in the network code, the multiplayer and cooperation aspect fell out of focus for the Unity Version of IVR-Connection, and only the individual features were properly tested. This means that only the concept of the application and the individual features were evaluated.

6.3.1 Survey

This survey was conducted as a part of the user test for phase 2. The goal was to gather data about the Unreal version and the Unity version of IVR-Connection to be able to compare the two. It also contained additional questions for general feedback that could be used to improve both of them. Due to the before mentioned issues with the Unity version of IVR-Connection, the facilitation part of the did not give any usable results.

As mentioned earlier the survey had 12 participants of which 75% had partic-

ipated in joint collaborative sessions using the Vive 2 times or more, with 50% having participated more than 8 times.

Lab Improvements

Figure 8 shows the suggestions for improving the VR lab. The suggestions mostly addressed issues that are related to having more than one HTC Vive setup in close proximity. This included the problem like light leaking into the wrong booth, causing problems for the headset in that booth. This is the same problem that we identified in the implementation part of this phase.

EiT Improvements

Figure 9 shows the suggestions for improving EiT in general for next years students. In practice these suggestions reveal external factors that might have had an impact on the results. Most of these factors involves unsatisfactory course planning in relation to synchronization of the two villages, and some involves better equipment for Gjøvik. However, the most interesting factor for this thesis, is the request for a specifically assigned facilitator for the collaborative sessions in IVR-Connection, which is what we are trying to implement tools for.

Student Responses to the Unreal Version of IVR-Connection

Most of the students thought that it was an engaging experience to collaborate with Gjøvik as a part of the EiT course, and there was a general consensus about wanting to use applications like this in the future, except for future student projects and social interactions where the opinions were divided. There was also a general consensus that the collaboration experience had been useful for their project.

Most of the students were either neutral or in agreement that collaborating in VR made them feel a strong sense of presence, and most student also felt socially connected to their collaborators. However, all students disagreed to it being easy to collaborate in VR, but agreed that it was easy to move around. For the main features they all disagreed to sharing images being easy, and opinions were split about drawing being intuitive.

Almost all of the students agreed that it was useful having a facilitator watch and give feedback during their session, indicating that there is a perceivable benefit to engaging a facilitator in addition to the theoretical benefit.

Student Responses to the Unity version of IVR-Connection

Only 4 of the students got to test the Unity version of IVR-Connection, and due to the issues with network code, did not get to test most of the features. The participants were told to answer neutral to the features that they did not test sufficiently. All students except one agreed that moving around and drawing was intuitive. Only one felt a strong sense of presence.

What should be improved in the physical lab space?

12 responses

Walls to the top
More workstations
More separated cubicles for the headsets (to avoid issues with the base stations) and also maybe have it as separated rooms to block off outside sounds. PCs that could be used outside of VR use (currently there is only one). Better ventilation.
noting
There should be more Vives such that fasilitators don't have to rely on that some members of the group is not present.
Positional audio, adding a way to gain attention without interrupting
Some form of set boundaries for use of headsets. As of now it is just one room and that proved to be challenging when using the microphones.
We had only two headsets, in the same room, with poor tracking. The main problem for us was to have a decent audio setup for four people in a single room with two joining in vr and two not. The Trondheim group were often frustrated by our audio performance.
increasing the number of headsets as well as creating detached space for each individual. The reason is that when all the group members are located at the same place it is impossible to use multiple microphones because of voice reflection.
Apart from some network issues, everything was ok.
Separate VR rooms for the Gjøvik campus
To keep it as it is, in a sense that the collaborative group wouldn't have to share with offline groups would be ideal.

Figure 8: Comments on how to improve the new VR lab at NTNU Dragvoll

6.3.2 Mixed Reality Application Concept

The same two facilitators didn't get to do a full test in the Mixed Reality version due to some technical difficulties. But both looked at the concept and a demo with the Hololens. The paragraphs below is a summary of what was said and discussed.

The avatar for the Hololens was too big and intrusive. It is important that the facilitators do not take up all the attention of the room, but rather act as a fly on the wall. At least when you are observing. When you are about to give feedback, having a feature that temporarily makes you able to acquire the students attention would be nice. Like for example descending down into their world with a gesture or another in-game indicator that would make them understand that you want their attention. It is important that this is comfortable for the students.

How could we improve Trondheim-Gjøvik collaboration in general for the next year EiT course?

12 responses

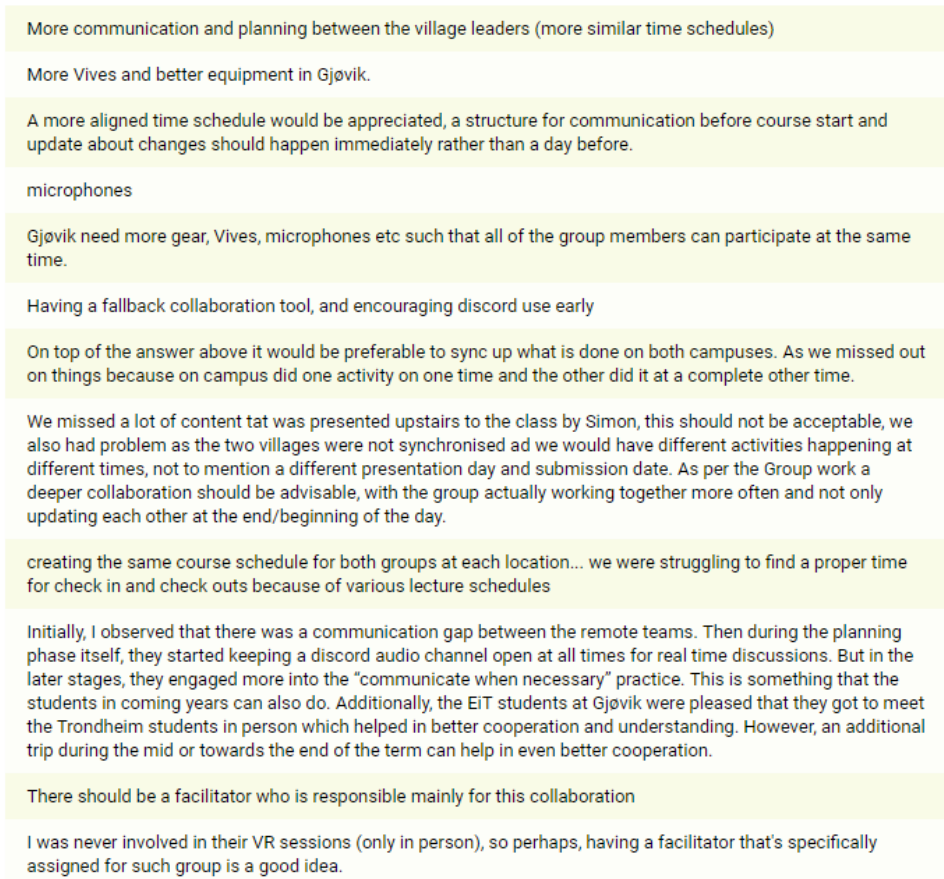


Figure 9: Comments on how to improve the Trondheim-Gjøvik Collaboration

The facilitators suggested that it would be nice to be able to write on the whiteboard while spectating as Hololens. By adding this feature the facilitator could explain both verbally and visually, and interact with what the students have written themselves. Especially useful for doing EiT exercises.

Even less body language to observe in this version. The application had only avatars with a moving body and a rotating head. No indicator for speech and no hands for gesticulating.

The facilitators also suggested adding the ability to import documents and write on them. This to be able to implement some EiT form exercises into the application. One way to do this is by implementing the ability to import images and draw on them. Making the user able to mark of on forms and saving the result for inspection by the facilitators.

6.3.3 Vive Application

Was tested by two facilitators. One with and one without the Vive headset which both had pros and cons. The following paragraphs is a summary of what was said and discussed in this interview.

The VR lab enabled one facilitator to watch the Trondheim side of the collaboration via the screens in the room. This required a lot of concentration and ended up being tiresome. It felt a little like watching TV and thus he felt more distant than usual when trying to facilitate. Watching through the participants eyes he only got to see what they were looking at, and trying to follow 4 screens looking for collaborative elements was hard. Especially since the level of body language he could read was limited, although he could see 3 of the participants in the room with him, their faces were obscured by the Vive headset. The hardware and equipment also posed limitations, especially on the Gjøvik side, since they only had one phone acting as a microphone. This generated a lot of noise, making it somewhat hard to follow conversations. The threshold for giving feedback and suggestions were higher, since his presence was only heard and not seen.

The students completed an EiT exercise named "take space, give space". "Take space, give space" is an exercise where each member of the group privately draws an illustration. The point of this illustration is to show how much space the individual group member perceives the other group members to inhabit socially within the group. The group will then collectively discuss each members illustration. To make this work in the VR environment it had to be modified, as the application did not support multiple whiteboards.

With some tweaking to the application, they managed to support two whiteboards. This led to a modification of the exercise. Each group, Gjøvik and Trondheim, would have each member draw an illustration about the other group's social space on their own team's whiteboard and make an additional drawing of their individual team's perceived space. And then present their illustrations. Each sides whiteboard can be seen in figure 10 and 11

Due to the reasons above and some software limitations this took a lot more time in VR than in the real world. Making it more effort than gain. One of the facilitators also noted that using Skype or another VOIP application with a video feed might have been more efficient for this type of exercise, at least for this version

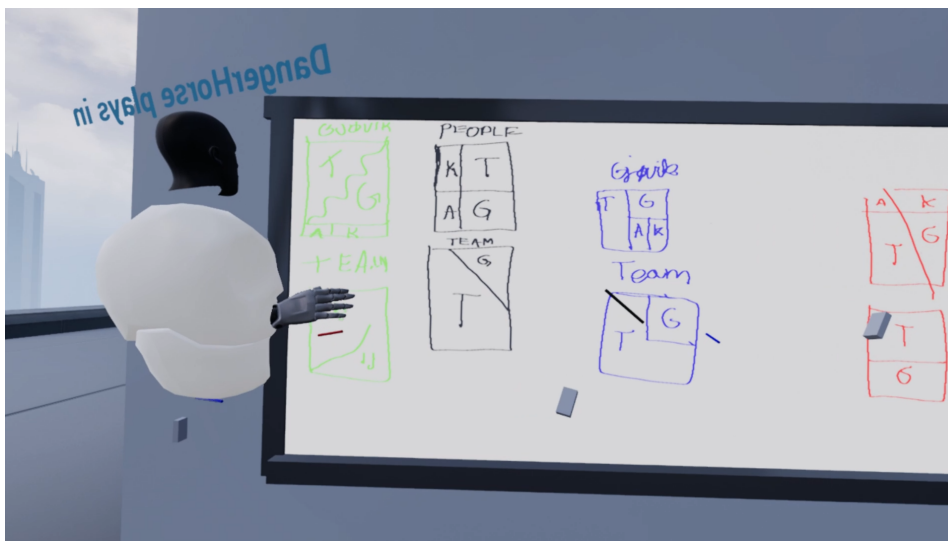


Figure 10: EiT students in Trondheim doing the 'take space, give space' exercise modified for the vive application

of IVR-Collaboration.

The other facilitator tried facilitating with the Vive headset and found that using VR can be uncomfortable and nauseating. For example when the headset picks up signals from the wrong base station, it will get confused and throw you around in the world. She also pointed out that it was hard to pick up on body language and was missing facial expressions, as these are signs she usually picks up on when facilitating in the real world. She also experienced that the VR world had a lot of unrelated stimuli. There is always something more interesting to look at, especially the first times you try it. And since the audio is only in their head, the visual stimuli might at times take more of your focus than intended. In other words, it might be harder to pay attention to what people are saying.

One of the facilitators stated that approximately 70% of communication comes from body language, and that the body language the EiT students used in VR was very different from what the facilitators had observed outside of VR. The facilitators speculated that this could be due to there being a different group dynamic when collaborating with Gjøvik in contrast to internally with each other. They also speculated that it could be due to the anonymity of the session. Especially when someone is talking and not referring to anything in the world, the students tended to look at their hands or pay attention to something else, at least visually. Another factor might be that this is an application that is part of a test project that the EiT

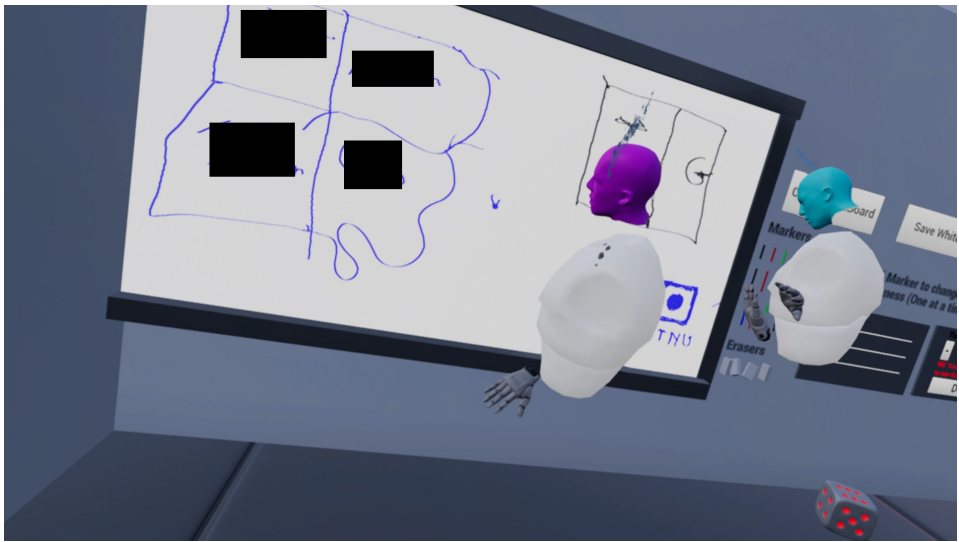


Figure 11: EiT students in Gjøvik doing the 'take space, give space' exercise modified for application, names removed for privacy

students didn't choose to use themselves. It has a lot of bugs and technical difficulties so the facilitators speculated that this could give them a "get it over with" mentality and make them not take it seriously.

Avatars and anonymity can be good for racial and gender bias, as neither of them are visually visible in the application. The facilitators agreed that keeping this feature could be good for inclusion and equality. But that it is still important to be able to distinguish between the different participants, and that name tags can be a good candidate for this. The facilitators also agreed that the avatars should match the purpose. For example do not use animals or crazy outfits for a normal meeting session.

Long sessions in VR can be tiresome and induce nausea for many different reasons. One thing the facilitators noted was that they found it strange that the students decided to stand during whole length of the meeting. This might be due to you not being able to see the chair beside you inside the VR world.

6.3.4 Requirements

Not all requirements were met for phase 2. Requirement F1, F2, F4 and F5 were partially met and F6 - F8 were not met at all. Requirement F9 was met, but lacked some specification that was added for phase 3, and requirement F3 was completely met. The rest of this section will briefly discuss the fulfillment of each requirement.

For requirement F1 it was hard to determine if it was met or not. Requirement F1.1 and F1.2 were too unspecific and hard to understand what was actually required. Requirement F1.3 seems to have been met, since none of the test participants had any trouble navigating the environment. To test this case thoroughly, it would also be required to test the application with people less experienced with VR.

The Avatar followed the player as describe in requirement F2.1, but did not have a separate avatar for Hololens as required by F2.2. This was due to F2.2 being of low priority when critical bugs were still present right before the test was conducted. Requirement F2 also lacked the specification for the two different avatars.

The requirement F3 was met. The player can move around by walking in the real world as described by F3.1 and teleport using a controller as described by F3.2. The player is thus able to move around in the virtual space.

Multiplayer was very unstable for phase 2, but the requirements were almost met anyways due to lacking specifications for stability and long levity. These specifications had to be added in phase 3 for a correct measure of working multiplayer functionality. Aside from that the requirements F4.1, F4.2, F4.3 were all completely met through the implemented match maker. Requirement F4.4 was however not met due to the lack of a disconnect feature, apart from forcibly closing the application by external means.

The Drawing functionality almost met the requirements specified in F5. Through a pen and a palette the player was able to draw on a surface (the whiteboard) as specified by F5.1 and choose a color by using the palette as required by F5.3. To be able to erase what had been drawn and thus fulfilling requirement F5.4, the player could select the color white, which was the same white as the whiteboard. Drawing in 3D as described by F5.2 was not fulfilled and was also set to a low priority for phase 3. The render method used for drawing also caused a lot of frame rate drops for Hololens, thus requirements regarding performance had to be added for phase 3.

Requirements F6 - F8 were, as mentioned earlier, not fulfilled at all. Mostly because these were given a lower priority than the rest of the requirements. Requirement F6 describes sharing media. This feature was implemented through image sharing with limited functionality, but was left out because it was difficult and complex to use, and due to the lack of a proper UI implementation. Requirement F7 described voice chat. The voice chat functionality was given a lower priority due to the expected problems with limited bandwidth through Unity's network service, and because using a third-party software was just as viable. Requirement F8 described intractable objects and was given a low priority due to the low impact it

would have on the completed product.

Requirement F9 was met for phase 2. The player was able to spectate the virtual space by using the Hololens, as well as move the collaboration space relative to the real world as specified by requirement F9.1 and F9.2. The collaboration space fit on a table as describe by requirement F9.3, but the interviews revealed that it was too small to follow what the immersed players were doing. Thus further specifications were needed for this requirement in phase 3.

7 Phase 3

7.1 Updated Requirements

For phase 3 it was necessary to update the requirements from phase 2. The updated requirements are mainly based on the interviews with the facilitators. The updated requirements are listed in this section.

7.1.1 F1 - VR Collaboration Space

No big changes were done to this requirement. F1.1 and F1.2 were rewritten to make more sense and be more precise, without changing the underlying meaning. The updated requirement is shown below.

The user should be able to enter a collaborative space. The collaborative space should have the following features:

1. The space must not be too big, and at the same time it must be spacious enough to not feel cramped.
2. The space must function as a collaborative space and not be too fancy or captivating, as this might draw attention away from the task at hand.
3. The space must be easy to navigate, e.g. have objects placed about to give you a sense of depth.

7.1.2 F2 - Avatar

For the avatar two additional requirements were added to make a distinction between the avatar for HoloLens and the avatar for immersed headsets. F2.3 describes the immersed avatar and F2.4 describes the HoloLens avatar. The updated requirement is shown below.

The user should have an avatar that represents him/her in the virtual space. The avatar should have the following features:

1. The avatar should follow the movement of the player.
2. There should be 2 different avatars. One for immersed headsets and one for the HoloLens.
3. The Immersed avatar should have a body, a head and two hands.
4. The HoloLens avatar only needs a head.

7.1.3 F3 - Movement

No changes were made to this requirement.

7.1.4 F4 - Multiplayer

For multiplayer two new requirements were added to specify the minimum requirements for the stability and capacity of a session. F4.5 describes stability and F4.6 describes capacity.

The user should be able to connect to other users. The multiplayer system should contain the following features:

1. The user should be able to host a session from any supported device.
2. The user should be able to search for active sessions created by other users.
3. The user should be able to join an active session.
4. The user should be able to disconnect from the currently active session.
5. A session should be stable and optimized for sessions lasting 30 minutes or more.
6. A session should support a minimum of 4 simultaneous users.

7.1.5 F5 - Drawing

For drawing, one new requirement was added to specify how much impact drawing can be allowed to have on the frame rate.

The user should be able to communicate and visualize through drawing. The drawing should be governed by the following features:

1. The user should be able to draw on a surface.
2. The user should be able to draw in the air in 3 dimensions.
3. The user should be able to choose a color to draw with.
4. The user should be able to erase what has been drawn.
5. Drawing should not lower the frame rate of the application with more than 10 frames.

7.1.6 F6 - Media Sharing

No changes were made to this requirement.

7.1.7 F7 - Voice Chat

No changes were made to this requirement.

7.1.8 F8 - Interactable Objects

No changes were made to this requirement.

7.1.9 F9 - Hololens Spectating

For Hololens spectating one requirement was updated and 3 were added. Requirement F9.3 was changed to reflect the new requirement F9.4. F9.4 describes the users ability to be able to scale the collaboration space. Requirements F9.5 and F9.6 describes a personal whiteboard for the Hololens spectator.

The user should be able to spectate the virtual space by using a Hololens. Using the Hololens should be governed by the following features:

1. The user should be able to move the virtual collaborative space.
2. The collaborative space should be moved relative to the real world, e.g. can be place on a table or on the floor.
3. The starting scale of the collaborative space should appear small enough to fit on a table.
4. The user should be able to scale the collaborative space.
5. The user should have its own personal whiteboard that can be scaled and moved in the same manner as the collaborative space.
6. The personal whiteboard should replicate what is drawn on the whiteboard in the collaborative space.

7.2 Implementation

During phase 3, improvements were made toward having a more stable and complete product based on the update requirements. This section lists the different features implemented and explains what was created and updated.

7.2.1 Collaboration Space

The collaboration was scaled to fit the height of the user better. To do this the overall height of the space was brought down and the width made a little smaller. On the scripting end, LevelLogic.cs now makes sure that both the scale and position of the space is synced relative to the avatars. This ensured that every player gets the same and correct state of the world.

7.2.2 Avatar

The Avatar was scaled to match the new scale of the collaboration space, and to fit better relating to the headset user and the ground. The goal of the new scale was to make it easier to feel immersed in the space. The avatar were also split into two different game objects. One for Hololens players and one for immersed headset players. This was to make it easier to develop individual features for the different hardware.

The Hololens avatar is now a cloud in the sky. This was to make the spectator

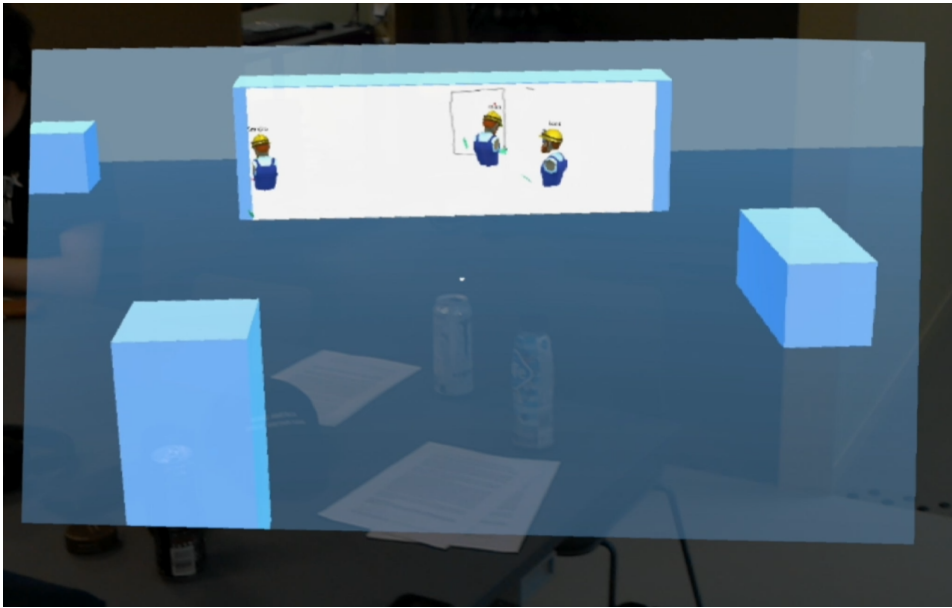


Figure 12: Three users and a facilitator multiplayer



Figure 13: Student looking at the facilitator

less intrusive to the ones collaborating in the space, while at the same time being

able to draw attention if needed. The cloud model was taken from Microsoft's 250 mixed reality tutorial.

The immersed avatar now has a pair of hands in addition to the body and the head. The hands will follow the movement of the motion controllers used with the immersed headset. If no controllers are connected, the hands will be hidden. A speech indicator was also added to let the other players see when someone with an immersed headset is talking. The speech indicator consists of a red ball over the players head. The red ball will be visible when the player speaks, and hide itself otherwise.

A name tag was added for both avatars. The name can be set in the menu before you join or create a session, and will hover above the players head. The name will help the players keep track of who's who.



Figure 14: The Immersed User Avatar



Figure 15: The Facilitator Avatar

7.2.3 Match Maker

The UI of the match maker was moved closer. This was to make it easier to read the labels on the buttons. A search button was added to let the player search for matches before joining. This was added to make the application ready to handle multiple sessions at the same time. When the player searches for a match, any session found will be displayed above the buttons in a list. The player can then select the session and click join to join the selected session.

The network code was optimized to send less data per second. This was needed due to the low bandwidth limit put in place by Unity's networking service. To accomplish this, all networked messages were forced to only happen a certain amount per second. Ranging from a couple to 30 times per second. This still wasn't really enough to keep within the limits. To properly fix this issue, we would need to either start paying for Unity Pro and Unity's network service, or implement another network system. None of these options were really valid. Unity Pro and its network services costs a lot of money, and implementing a new network system would have

taken more time than was available. In the end we chose to move on because the application now runs just long enough to do a short multiplayer test.

7.2.4 Drawing

Due to the network optimizations, the drawing feature had to be tweaked. The drawing data that had to be synced between clients was reduced to the smallest possible type. This resulted in that the color scheme for drawing now only supports 256 different colors, but for most practical purposes this should be enough to use the whiteboard effectively.

The drawing process also had to be optimized due to limited processor power on the HoloLens. To accomplish this, the logic of applying draw data to the whiteboard texture was separated from the draw logic itself. Because applying data to a texture is a CPU heavy task, this allowed us to reduce the CPU load by applying data less often. With the immersed headsets this was not an issue and thus they could continue to apply data as fast as they were drawing, but for the HoloLens the frequency was lowered to 10 times per second.

Lowering the frequency to 10 times per second synced the drawings on the whiteboard frequently enough to effectively follow what the other players were drawing. It also reduced the load on the CPU significantly, but the spikes generated still caused low frame rates when run on the HoloLens. The solution to this could be to use a shader for drawing on the whiteboard texture. A shader would move the work load from the CPU to GPU, which is much more optimized to handle such tasks. Even though this might have been a good solution, we lacked shader competence and time to learn and implement it properly. Resulting in any further optimization effort to be put on hold. In the mean time the application could be streamed from the computer to the HoloLens, effectively working around the issue.

7.2.5 HoloLens Spectating

The scale of the world as the HoloLens sees it was scaled up. This was to make it easier to follow what the immersed player was doing in the collaborations space. A bigger extra whiteboard that only the HoloLens can see was also added. This whiteboard can be moved around and placed relative to the real world, just like the collaboration space. This new whiteboard replicates what is drawn on the original whiteboard. This is to make it easier for the HoloLens user to see what is being drawn.

Because of the issues with drawing and network service, the HoloLens cannot effectively run the application on its own. A computer with Unity engine version 2017.2p1 and the source code from Git is needed. With Unity open you can stream the application to the HoloLens while letting the computer do all the heavy lifting. At the same time the HoloLens can still use gestures and gaze controls to interact



Figure 16: Drawing from student perspective.

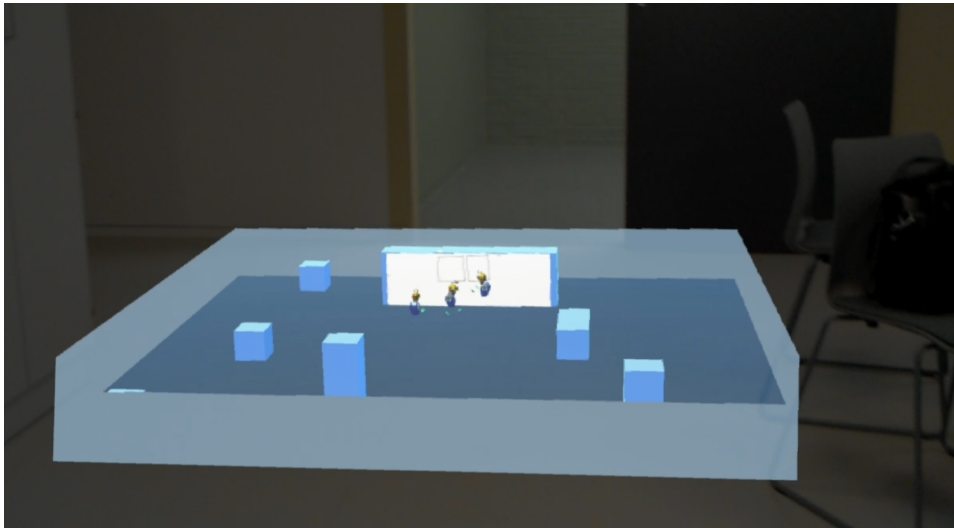


Figure 17: Facilitator observing drawing students.

with the application. Thus this work around let us test Hololens spectating without having to worry about limited hardware resources.

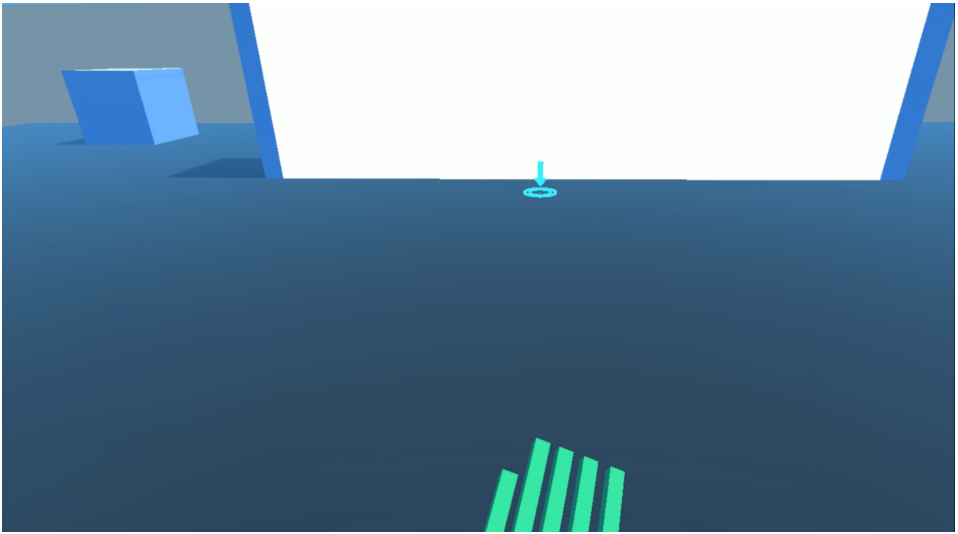


Figure 18: The Immerzone as seen by students looking at the whiteboard

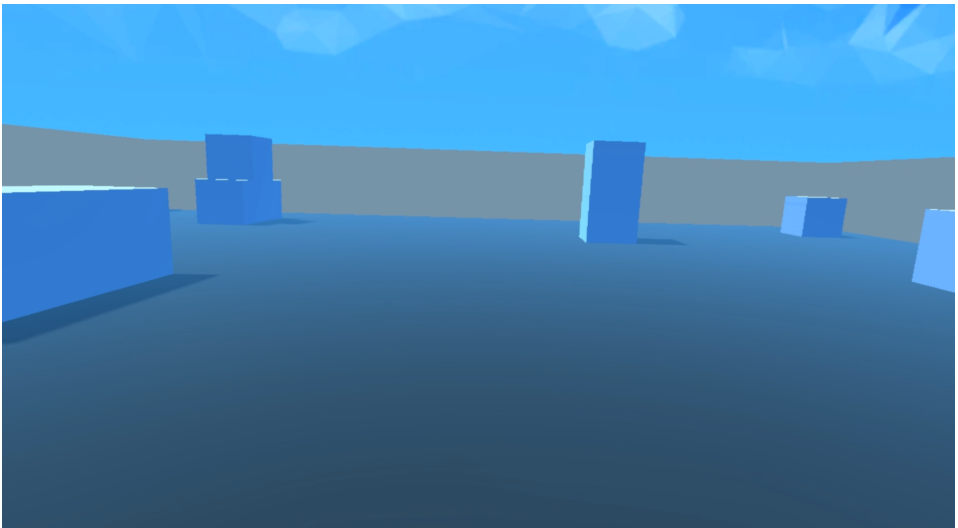


Figure 19: The Immerzone as seen by students looking back from the whiteboard

7.3 Evaluation

The evaluation for phase three consisted of one user test with two VR experts and a facilitator, followed up by a focus group session. In the test the VR experts were

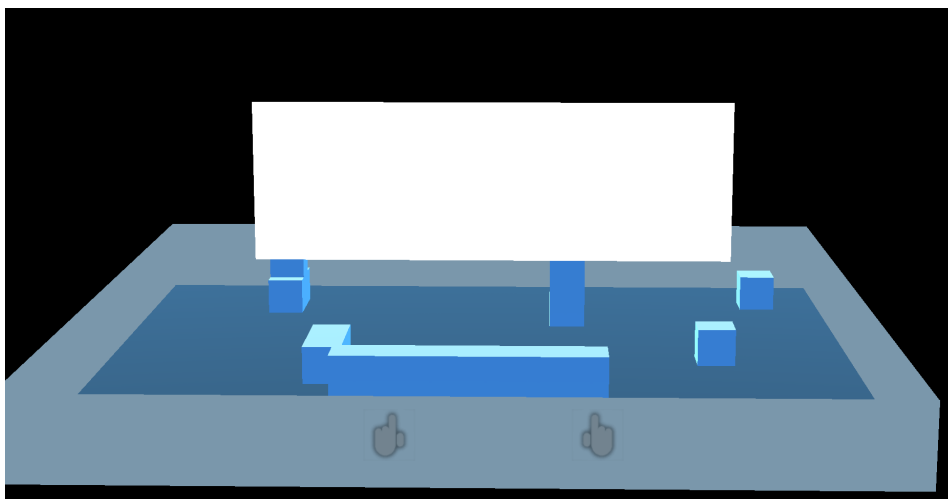


Figure 20: The Immerzone as seen by the facilitator, showing the facilitator whiteboard

told to cooperate to complete a drawing challenge while the facilitator observed and took notes of how they cooperated. The goal of the test was for the facilitator to evaluate if using Hololens for observing cooperation in VR gives any potential advantages when trying to facilitate.

7.3.1 Focus Group Feedback

The focus group consisted of 3 participants; One EiT facilitator and two VR experts. The two VR experts were both master students at NTNU, and had been working with VR for 1.5 years. Where one of them had spent a year working with the Hololens. The facilitator also participated in the focus group for phase 2, and have had half a year of experience with VR and facilitating.

The focus group was handled as a semi structured interview with open questions that everyone could answer and discuss. The goal was to evaluate if any improvements had been made since phase 2, and how the application stacks against IVR-Connection for Vive or collaboration in real life. Especially in relation to facilitating. The rest of this section contains a summary of what was discussed during this focus group session.

The whole focus group agreed that the strongest feature implemented so far, was the drawing. They said that it was easy and intuitive to use, and that it was an improvement to the drawing system implemented for IVR-Connection for Vive. The only thing that they thought was confusing, was which button they had to press to activate drawing. One of the VR experts suggested that adding a controller scheme

visualization could fix this issue. For the Hololens the facilitator said that it was now much easier to follow what was drawn on the whiteboard. This was mostly due to the addition of the personal larger whiteboard viewable for the Hololens user.

Both the VR experts and the facilitator said that they felt immersed in the world. They all forgot about the outside world and focused only what was happening in the application. One of the VR experts stated that the cloud in the sky was less intrusive than the old Hololens avatar, making it less distracting. The others agreed. When asked about the new hands, one of the VR experts said that it made him feel more present because he was able to wave and make other simple hand gestures. He also mentioned that this feature could be improved by implementing even better hands. For example by adding a skeleton mesh and allow the player to open and close the hand, or point with only one finger extended. The same was true for the head of the avatar.

The VR experts both agreed that it was easy to follow what the other was doing in the collaboration space. With the hands, speech indicator and a name tag, it was easy to grab attention when needed. They also added that they thought that the speech indicator and name tag would be especially helpful when collaborating with more people. The facilitator also agreed to all of this, but when using the Hololens the speech indicator and name tag was a little bit too small. The same issue was true for the hands. This meant that she had to move in close to clearly see who was talking and what gestures they were making. To fix this inconvenience, the scale of the name tag, the speech indicator and the hands could be increased when using the Hololens.

The facilitator stated that facilitating in MR is a lot different from facilitating in real life. She agreed that this was partially because you get less information about the subjects when you are facilitating MR, than you would if you were facilitating in real life. One of the biggest differences is the lack of advanced body language. She also added that although it is different and you get less information, it is still enough information to give feedback and facilitate cooperation. And added that it would probably be most efficient if you were observing the subjects cooperate in real life and in MR.

One thing that eased facilitating cooperation in VR, is the focus that comes with putting on a head mounted display and entering a virtual space with the sole purpose to collaborate. The facilitator meant that this makes it easier to facilitate, because almost everything that goes on in this space is related to collaboration. She also added that the Hololens comes with some advantages in relation to this phenomenon. First of all, the Hololens does not bring you, as a facilitator, completely away from the real world. This means that you can blend realities by observing the

virtual space while taking notes in your notebook in the real world. There is also a certain familiarity to placing objects on a table and watching it from different angles. This makes it easy to use and gives you a lot of overview of what is happening. Which is a huge advantage for a facilitator.

The facilitator also added that she felt that there was a lower threshold for giving feedback. The main reason for this was that she felt like a part of the virtual space when she was inhabiting the Hololens avatar. The VR experts agreed with there being a low threshold for starting a conversation, and added that the anonymity of the avatars might also be a factor to this. They all also agreed that another factor might be that they got to know each other before the test started. The facilitator added that getting to know each other might not factor in specifically on the threshold itself, but rather making everyone take each other more seriously.

Even though the threshold for giving feedback was lower, the facilitator added that the current version of the application did not give her a way to get the immersed players' attention. With this she meant that there was no incentive for the immersed player to look her way when she was talking. One suggestion to fix this was to add a feature that allowed the Hololens spectator to move down into virtual space to get on the immersed players level. Implementing something like this could help replicate the facilitation experience, because this is exactly what the facilitators do when they want to give feedback to EiT groups in real life.

The VR experts thought that when comparing this application to collaborating in real life, you would have to look at what the application brings to the table in terms of improved or added functionality to the real life setting. In other words, for the team using the application, it needs to be at least as good as collaborating without the application. One example was that they should be able to share documents and maybe use a web browser within the application. Which both are features of talking through VOIP or being a co-located team. Another thing they brought up was the use of a whiteboard. A drawable surface, like the whiteboard, is also a feature that exists in the real world, but the one of the VR experts argued that it is a lack luster to the potentials of a virtual world. He suggested that adding features to draw on anything and draw 3D directly in the air, and that this would elevate the application to go beyond what is possible in the real world. Effectively increasing the potential benefit of using such an application for collaboration.

The facilitator agreed that to use this application, some training would be required. She noted that using the Hololens requires some practice. Making the correct gesture with your fingers in such a way that the Hololens recognizes it, can be a challenge for new users. This barrier also affects the understanding of what the gesture does in the application, because it can be hard to tell if you did it right or not. The focus group agreed that this barrier could be mitigated by by playing

through Hololens' gesture training and having a tutorial within the applications itself. One of the VR experts added that the same was true about using the Windows Mixed Reality headsets, and that having a tutorial would probably help for that case as well.

Over all both the VR experts and the facilitator were positive to the concept and would want to see similar application in the future. They agreed that this type of application has its maximum potential when used by a team that is not co-located, but with some addition can also have value to a co-located team. Feedback from the facilitator combined with observation made during the tests has suggested that using a device like the Hololens, can have potential advantages over facilitating directly in VR or spectating with a computer screen. They thought that the application itself, if you look beyond the bugs and unstable network code, has potential to help students collaborate and facilitators facilitate using Windows Mixed Reality.

7.3.2 Requirements

For phase 3 most of the requirements were fulfilled or partially fulfilled, with some exceptions. The requirements F1, F2 and F3 were completely fulfilled. The requirements F4, F5 and F9, had had a lot of progress since phase 2, but were still only partially fulfilled. While the requirements F6, F7 and F8 had had no progress since phase 2, and were thus still not fulfilled at all.

The requirement F1 address the collaboration space and what properties this space should have to satisfy the user. This requirement was thus evaluated through user feedback. The users from the focus group all agreed that the collaboration space had a scale that made it neither too cramped nor too big, which fulfills requirement F1.1. Requirement F1.2 relates more to a finished product than the proof of concept versions, since it details the affordance that the atmosphere of the room emits. The requirement is however temporarily fulfilled because the space is definitely not too fancy or captivating. The requirement probably needs rephrasing or a new one should be added to encapsulate the intended purpose of the original requirement, making sure the space affords the task at hand. When asked about the ease of navigation relating to requirement F1.3, the VR experts said that they had no trouble navigating the collaboration space. This might not be true for users who are not as familiar with VR as they were, but the requirement was marked as temporally fulfilled, pending new data.

The requirement F2 describes the avatar and its components and behavior. This is a technical requirement since it only relies on the existence of certain objects or features. The final evaluation of this requirement was therefore evaluated internally. The application contains two different avatars. One for immersed headset users consisting of a body, a head and two hands, and one for Hololens users con-

sisting of only a head. This fulfills requirement F2.2, F2.3 and F2.4. Both avatars will follow the position of the user when using the application, thus F2.1 is also fulfilled. Through the focus group a new angle related to defining avatars emerged. The avatars should also serve a purpose and give the correct affordance. For example, a cloud might not be the optimal model for a facilitator, because being addressed by a cloud can be distracting. For further development, more requirements should be added defining the use case the avatars should fit.

No changes were made to the movement functionality and no changes were made to the movement requirements, thus all of F3 is still fulfilled as a result of phase 2. Features and requirements for F6, F7 and F8 also had no changes made since phase 2, thus these are still not fulfilled following phase 3.

The requirement F4 describes multiplayer and how it should behave and perform. This is a technically driven requirement since it relies on feature functioning a certain way. The final evaluation of this requirement was therefore evaluated internally. The requirements F4.1, F4.3 and F4.4 had no changes made to its related features. Therefore F4.1 and F4.3 were still fulfilled as a result of phase 2, while disconnecting could still only be done by external means, leaving F4.4 unfulfilled. The requirement F4.2 was fulfilled by the addition of a search button and a corresponding server list. As for the performance of the network session, it did not meet the set requirements. An average session did not last longer than 2 minutes with 3 or more players connected. With only 2 players connected the session could last a bit longer, but tended to disconnect at a random moment before the 30 minute mark. Therefore neither requirement F4.5 nor F4.6 were fulfilled. The reason for these instability issues is most likely due to the limit set on the free version of Unity's network service. To fulfill these bare minimum requirements with the current application, one would therefore either need to switch network service provider or buy a subscription to Unity Pro and pay the subscription fee for their network service.

The requirement F5 describes drawing and how it should behave and perform. This is another technically driven requirement since it relies on the existence of certain objects and the features related to those objects. The user can draw on a whiteboard with a color chosen from the palette. If the color white is chosen, it works as an eraser. This fulfills the requirements F5.1, F5.3 and F5.4. However the user cannot draw in the air in 3 dimensions. This feature was planned, but got a lower priority due to other pressing issues, and thus the requirement F5.3 was not fulfilled. The main changes to the drawing feature from phase 2 to phase 3 consisted of performance fixes. The goal was to fulfill requirement F5.5 and impact the performance with less than 10 frames per second. This was achieved for the immersed users, but not for the HoloLens. The HoloLens has a rather weak processor, and because our drawing method relied heavily on the processor, the HoloLens

dropped down to almost only 1 frame per second each time it tried to draw. To fulfill the requirement F5.5, one could try to implement a shader. A shader would move the workload from the processor to the graphics card, which is much better suited to deal with such tasks. For further development it would thus be reasonable to add a requirement defining the need for a shader to deal with drawing.

The requirement F9 describes the users ability to spectate using the Hololens. This contains a combination of technical and user experience based requirements, thus this requirement was evaluated both internally and with users. The requirements F9.1 and F9.2 had no breaking changes to the relevant features, and thus were still fulfilled as a result of phase 2. The starting scale of the collaboration space were changed for Hololens users to be a little bit bigger. The new size was according to users still small enough to fit on a table without it being impractical. Therefore the requirement F9.3 was fulfilled. There are no functionality implemented for scaling the collaboration space up and down, leaving the requirement F9.4 unfulfilled. The personal whiteboard was however implemented. This whiteboard replicates what is drawn on the whiteboard in the collaboration space and can be moved around, but not scaled. This means that the requirement F9.5 was only half fulfilled, while the requirement F9.6 was fulfilled. During the focus group it also became apparent that Hololens spectating could use more features. For example a feature that lets the spectator signal for attention when needed. Since Hololens spectating is the most important feature for this application, future work should focus on expanding the list of required functionalities to meet the demand of future facilitators at the EiT VR village.

8 Discussion and Conclusion

8.1 Limitations

Developing the application for this thesis has been challenging and time consuming. The tools for developing for Mixed Reality were very new, and under constant development. This caused bugs and errors which we could not effectively fix and we sometimes had to wait for an update to have the problem fixed. There was also updates that changed the core structure of the toolkit, which forced us to restructure the application to support the new version. The time spent developing cost us heavily in getting testers for the application, only being able to test during the last weeks of EiT. When we finally got to test, there was an unforeseen bug, we could therefore not collect any useful data from the questionnaire about the use of the Unity version of IVR-Connection in Phase 2. But through the conversations with the students and facilitators afterwards, we managed to salvage some data to present.

The Application itself also does not run properly on the Hololens. The hololens does not have a lot of power in terms of performance, sadly the act of drawing in the current version of the application is too costly, and will result in the application crashing on the hololens. We could circumvent this by running the application on the computer and streaming the visuals to the hololens, making the computer do all the heavy-lifting. This is not optimal, and we do have ideas for solutions for this problem, but no time to implement them.

We also faced problems with sharing between Hololenses. With very rudimentary knowledge about networking and developing multiplayer applications, we relied heavily on the framework provided by Unity. We used it to circumvent Eduroam's very strict NAT policy, enabling us to use the application wirelessly through Eduroam. It also quickly enabled the application to support multi-users. Although our reliance on using the Unity matchmaker also caused other problems which we had no control over.

Unity's multiplayer service limits concurrent users(CCU) to 20, and each client's bandwidth is 4kb/s. This is very little data, and is not enough to support the amounts that needs to be sent between client and host, even though we tried to reduce the bandwidth used as much as possible. When this cap is reached after a 2 minute buffer period, everyone is disconnected from the service and we have to restart. We discovered this too late to properly fix it, as a fix would entail setting

up our own servers and getting them approved through Eduroam. A quicker fix would be purchasing two Unity Professional subscriptions and then also pay for more bandwidth. However, we did not have the money required for that option.

Despite our limitations we feel like we have gathered enough results to provide a contribution to this very new field of research. There has been done research in collaboration in VR/AR[43][38], but as far as we know, no applications or research done about merging VR and AR to help support facilitators for groups in courses like EiT.

8.2 Discussion

Compared to the existing research in VR collaboration[43] and MR collaboration [38][44], our approach is quite unique. By combining virtual and augmented reality to aid facilitators in observing students collaborating in a virtual environment, we try to provide some of the tools required for CSCL as mentioned by Dillenbourg [33]. Both Dillenbourg [33] and Lee [34] puts emphasis on the facilitator as a critical component to collaborative learning. This is reflected in the survey from phase 2, where the students expressed a need for an assigned facilitator to observe and facilitate their collaborative sessions. Although the application needs more work to provide a stable platform for further in-depth testing, we believe the initial tests show that there are grounds for pursuing this line of research further. Our contribution in this context would be to provide an early prototype of how mixed reality may provide the tools required for the facilitators to do their assigned tasks.

We were unable to find existing research on VR solutions for supporting the facilitators. However one could infer from Hemb's thesis on Virtual Reality Spectating[37], and our discussions with the facilitators themselves in section 6.3.2 and 7.3.1, that in the context of VR collaboration in EiT, spectating VR from within VR is better than the 'mirror mode' of spectating. Although for facilitation this is not optimal, as the facilitators still expressed problems with this solution. We feel that in this context, while "immersed facilitation" is far better than being on the outside-looking-in, there needs to be further work done on improving VR solutions for facilitators. Our contributions here are providing initial problem areas and suggestions for solutions in these areas.

Aschenbrenner found that the best way to get a good overview using augmented reality, is by using the 'god mode' perspective [38]. Our findings indicate that one of the biggest drawbacks associated with "immersed facilitation" was the difficulty to get an adequate overview, and that getting a good overview was critical for the facilitator. We further learned that facilitating using augmented reality does not produce the same issue, and thus we can conclude that Aschenbrenner's conclusions regarding the 'god mode' perspective also applies to facilitation for CSCL in

the context of EiT.

When facilitating for EiT in a real world setting, the facilitator ensures that the group process is not being disturbed while observing. At least not before having gathered an adequate amount of data for feedback. We found that extra care should be taken when designing tools for facilitation of CSCL environments to make sure that the tool does not become a liability for the facilitator. Especially in terms of the avatar representing the facilitator becoming a distraction for the group collaborating in the virtual environment. This issue is also discussed by Jacobson. [35] We found that, in general, designing tools for facilitation for CSCL should aim to be at least as good as facilitating in real life. Because if the tools provided to the facilitator are more complicated or gives them a bigger disadvantage than the factors of facilitating in real life, they might become demotivated and unable to give adequate feedback.

To mitigate the risk of the tools becoming a liability, we found, through discussion with the facilitators, that instruction and training should be provided to the facilitator before facilitating in real scenarios. Helping the facilitator become more familiar with the tools can help remove the barrier of engagement for immersion described by Brown. [22]

We believe we have provided grounds for further research into the topic of MR facilitation. Our findings, albeit with limitations, suggest that there is a need for facilitators to have the capability of properly facilitating groups that collaborate in a virtual environment, be it co-located or remotely. This agrees with established theory supporting facilitation in real world facilitation of collaborative learning groups as earlier mentioned by Dillenbourg and Lee. We have also provided a suggestion for solving this problem of lacking support with our application.

8.3 Research Questions

RQ *How to use mixed- and virtual reality to support and facilitate collaborative learning in the context of EiT?*

To answer the RQ we have used the existing application IVR-Connection to explore the possibilities of facilitation in virtual reality, and developed our own version of IVR-Connection in Unity to explore the possibilities of facilitation on mixed reality platforms. We have divided the RQ into three subquestions, which combined aims to answer RQ1. To give a context for answering RQ1 and RQ2, we draw from the established theory on facilitation, feedback from the facilitators and our own reflection to establish the following requirements for facilitation in virtual environments:

- A:** The facilitator should have the ability to write down notes.
- B:** The facilitator should have the ability to grab attention when needed.

- C:** The facilitator should be able to freely observe the students in their virtual environment.
- D:** The facilitator should not become a distraction for the students.
- E:** The facilitator should be adequately introduced to the relevant medium.
- F:** The facilitator's avatar should be distinguishable from the student's avatar.
- G:** The facilitator needs to be able to distinguish the different students.
- H:** The facilitator needs to be able to observe enough body-language to accurately judge each student or group state.

A - Notes

To keep track of observations made, the facilitator needs some way to write them down. EiT also contains a lot of pre-defined documents that can help illustrate group process by filling out a form or a figure. Being able to take notes can help enable these tools to be used with the application.

B - Attention

To be able to lower the threshold for giving feedback in the virtual environment, the application should enable a way for the facilitator to grab attention from the students. This entails designing a feature that helps with focusing attention towards the facilitator. The facilitator should be able to activate this feature when needed.

C - Observation

To make adequate observation the facilitator needs tools which will let them observe the virtual environment. These tools should support manipulation of the virtual environment to let the facilitator view from a desired angle. Being able to freely scale the environment could be an advantage. The best way to do this with augmented reality is to implement a 'god mode' perspective. [38]

D - Distraction

Being in a virtual world can, if not designed properly, become a distraction to the task at hand. [35] Therefore it is important to design the tools in such a way that it does not interrupt the group process unless the facilitator chooses to do so. This entails making the facilitator partially incognito in the virtual environment.

E - Introduction

Giving the facilitator some time to get to know the application is a good idea. This can help the facilitator become more confident in using the application, which in turn can result in better facilitation. This can also enable the application to remove one part of the barrier of engagement for achieving immersion. [22]

F - Roles

The facilitator and the students have very different roles in the context of EiT. Therefore, the application should distinguish between the two. The goal is to make the different roles be afforded in the virtual environment and thus scaffold productive interactions. [33]

G - Individuality

Keeping track of who is who inside the virtual environment is important to be able to follow what is going on. If the facilitator can not follow what individuals are doing, it will be hard to infer how those individuals affect the group.

H - Body Language

Body language can say a lot about the structure of a group. Therefore it is important to support forms of body language in the application. E. g. adding hands to the avatar can effectively add gesticulation to the list of supported features. The better the application can represent the body language of the individual, the more information the facilitator will have to work with. Increasing to a better representation of body language can also increase the sense of presence for the individuals. This is because you are successfully supporting action in the environment[25] through intuitive body controls.

RQ1 *How to use virtual reality to support and facilitate collaborative learning in the context of EiT?*

To answer RQ1 we propose suggestions to how the requirements can be implemented in virtual reality.

A - Notes

For taking notes in virtual reality one could either implement a small personal drawable surface accompanied by a precision drawing tool, or have a speech-to-text feature. The latter is harder to implement properly than the former, but the latter also lets you keep your concentration towards the students. However both solution have advantages and disadvantages that require more exploration.

B - Attention

For grabbing attention one could either implement a sound cue or a visual cue. The cue would be activated when the facilitator clicks a button. The visual cue can be implemented like an indicator appearing in front of you pointing towards the facilitator. The sound cue can just be a recognizable sound cue indicating that someone

is about to speak.

C - Observation

To be able to observe the whole virtual environment and get a good overview, one could implement a separate spectating tool for virtual reality. With this tool, the facilitator is put on the outside of the virtual environment the students are in. Letting the facilitator walk around, rotate and scale the environment to get the optimal viewing angle. Much like the Hololens is doing with Holograms [20], only contained within virtual reality.

D - Distraction

As to not make the facilitator a distraction to the group process, one could make the avatar of the facilitator small and/or disappear when the visual presence of the facilitator is not needed. It could also be advantageous to enable the facilitator to mute themselves, as to not make unintentional noise.

E - Introduction

Implementing a tutorial for the facilitation tools could be a good idea. The tutorial should explain the basic tools and they are used to interact with the world. It should also explain the different elements of the virtual environment that the students will be collaborating in.

F - Roles

Implementing different avatars for the students and the facilitator can help distinguish that they have different roles. One should consider what affordances the avatar entails; like friendliness, authority, etc. What combination of these factors that would be optimal requires more research.

G - Individuality

To be able to distinguish between individuals we suggest, at minimum, adding name tags and a speech indicator. These two combined can help the facilitator, and the other students, keep track of which voice belongs to each name. Thus being able to keep track of who is who.

H - Body Language

At a minimum the avatars representing the students should capture head, body and hand movement. With these basic representations the application can replicate basic body language. The next step would be to add ways to change the configuration of the hand, either by buttons or by recording the hand orientation of the student

directly. Yet another step up would be to add facial recognition to track facial expressions.

RQ2 *How to use mixed reality to support and facilitate collaborative learning in the context of EiT*

When developing for mixed reality it enables you to take advantage of the Hololens. When answering the RQ2 we have the Hololens in mind when suggesting how to implement the requirements.

A - Notes

By using the Hololens you do not need to implement explicit support for writing notes within your application. One can simply write using pen and paper as you observe the virtual environment through augmented reality.

B - Attention

Grabbing attention concerns implementing features for the students who will be using immersed headsets. Thus the the same solution as for virtual reality can be applied here.

C - Observation

Implementing the virtual environment as a scaled down hologram for the Hololens will give the facilitator the 'god mode' perspective. Which was found to be the best solution for visualization.

D - Distraction

Implementing the same solution mentioned for virtual reality will be sufficient.

E - Introduction

Making the facilitator run the gesture tutorial for Hololens in combination with the tutorials mentioned for virtual reality, can give the facilitator a good baseline for using the application.

F - Roles

To distinguish the different roles one could follow the same solution suggested for virtual reality.

G - Individuality

Individuals can be distinguished by implementing the same solution mentioned for virtual reality.

H - Body Language

Body language can be represented with the same solution suggested for virtual reality.

RQ3 *What are the advantages and disadvantages of both approaches?*

Further study will be required to completely answer RQ3, as most of our data gathering was overly focused on the MR version, this has caused some bias towards the Vive application. Therefore the focus is more on the mixed reality aspect of this question.

Both approaches share a lot of the advantages and disadvantages. Both bring the facilitator into the virtual environment the students inhabit. This makes it easier for them to jump in and guide the students if needed. They were also less taxing on the facilitators as they did not need to keep track of multiple screens spread out over a big area, one of the facilitators was physically exhausted after trying to observe the "Give space, take space" exercise. A disadvantage observed on both approaches is the technical aspect. A facilitator would need some introduction to the technology, and many are unfamiliar with the interaction design of VR and AR.

Though we have observed that the addition of the HoloLens adds additional benefit because the facilitator can still make notes easily using pen and paper. One of the facilitators also suffered heavily from VR-Sickness after trying the VR approach, but never encountered this when facilitating in AR. If co-located the facilitator can also observe some of the students' physical mannerisms whilst they are immersed. Aschenbrenner et al. [38] observed that the 'god mode' view was better for observing objects, instead of observing them from a first person perspective. Based on these findings, we propose that MR is better for facilitation.

8.4 Future Work

In this section we will provide recommendations for future work in the context of our thesis. We will discuss improvements to the application, suggest topics for further research, and provide recommendations for future inter-campus EiT in VR/AR.

8.4.1 Improvements for The application

Improving Avatars

In real life you can observe the subjects' facial micro expressions and relate that to what the subject is saying. In MR or VR you can only rely on the vocal tone, head orientation and hand gestures, and even though this might give you enough information to give correct feedback, facilitating in MR can still be more difficult. To close this gap between real life and MR and VR, more realistic avatars and better

hardware will be needed. There are emerging technologies (e.g HoloCap[49]) in development that will let us accurately replicate the users facial expressions in MR and VR, but at the time of writing no such technology can easily be implemented into this application.

Networking

Unity Matchmaker is not an optimal solution for multiplayer in our application because of it's bandwidth cap which disconnects all users when reached. To improve upon this we propose making the server structure from the ground up, supporting the bandwidth needed to share the different kinds of data that needs to be shared(Room Data, Movement Data, Images, Models, etc.). Having an own dedicated server would also enable you to use the sharing API provided by mixed reality toolkit. This API provides tools especially for hololens to hololens communication, enabling multiple co-located facilitators to observe the same hologram.

Drawing Optimization

The current iteration of drawing is quite taxing on the CPU, and this is a problem for the Hololens, which has a rather small CPU. This is a major flaw in our application, which needs to be fixed if the application is to ever run on a Hololens without assistance from a desktop computer. We would propose looking into shader-coding. Moving the actual drawing into the shaders will move the load to the GPU, which is more powerful and suited for the task.

Add missing features

Due to time-constraints and the focus on facilitation, we never got to implement the full set of features imagined for the unity version. These features are listed as missing requirements in sections 6.1 and 7.1. These are features that improves upon what we've learned from the Unreal Version, and would provide a better platform for further exploration of using mixed reality devices for collaboration.

Add features based on new requirements

Based on the new requirements listed in section 8.3, there are opportunities for further development of the application. This would mean analyzing the requirements we have proposed in our answer to the research questions and implementing them for testing and study.

8.4.2 Suggestions for further research

From earlier research[33][34] we know that facilitation is a critical component to CSCL. Thus it would be valuable to define robust guidelines on how to best enable optimal facilitation for VR/AR/MR. The current list of requirements that we provided is based on limited research and testing, and as such we would propose further research to focus on refining these requirements.

One focus of research relating to these requirements should be to evaluate their impact on the total learning outcome. This as seen in the context of CSCL.

Further research is also required on the actual advantages and disadvantages of the different approaches.

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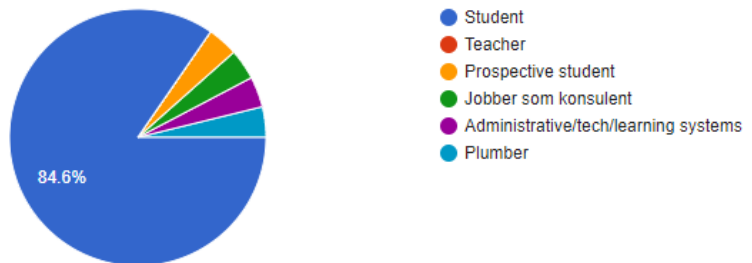
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- [46] Trello. URL: <https://trello.com/>.
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- [49] Holocap homepage. URL: <https://holocap.com/>.

A Uka Survey

A.1 Meta

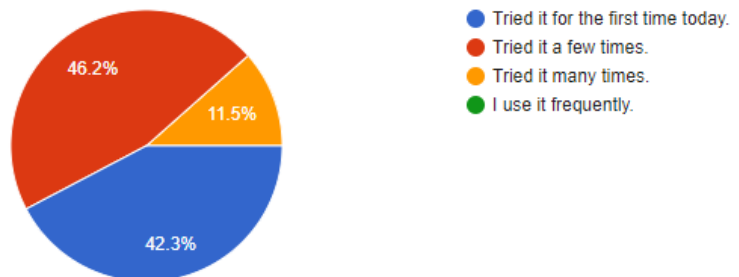
What is your occupation?

26 responses



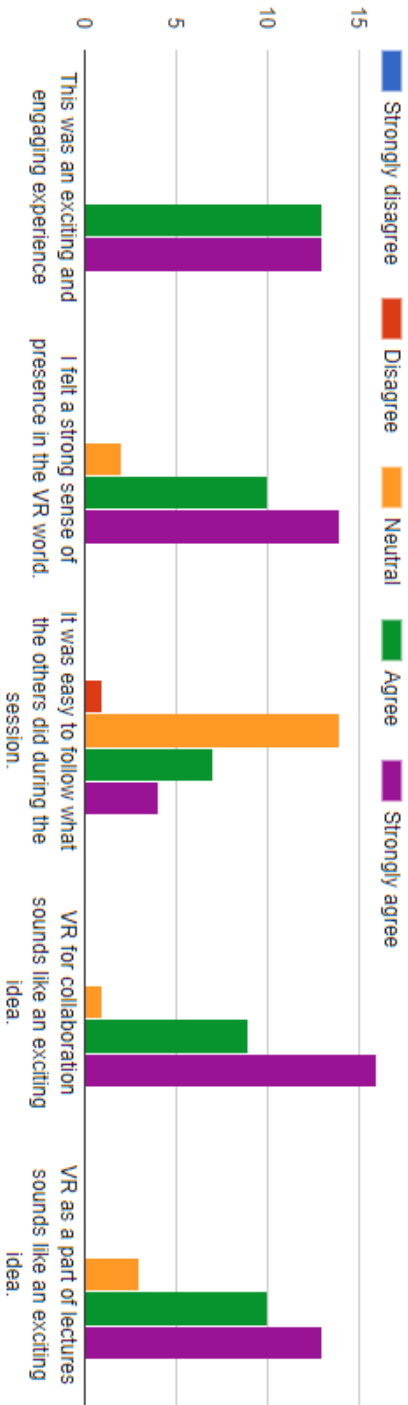
How much experience do you have with VR?

26 responses



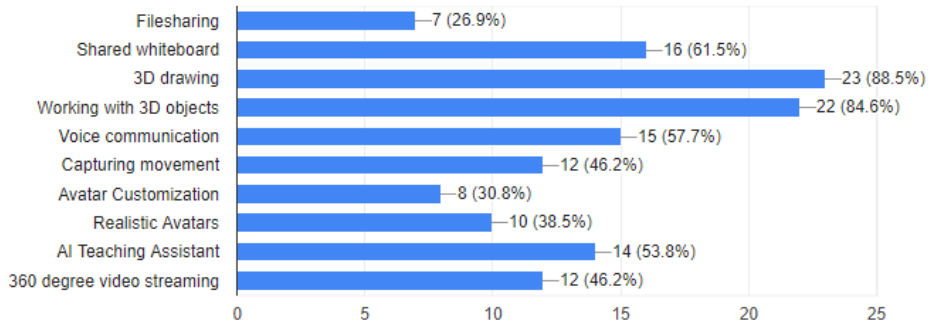
A.2 Immersive VR collaboration at UKA

Based on your experiences with, this program here at UKA, please rate the following statements:



What functionalities would you like to see in a collaborative learning VR environment?

26 responses



Feedback/Ideas?

3 responses

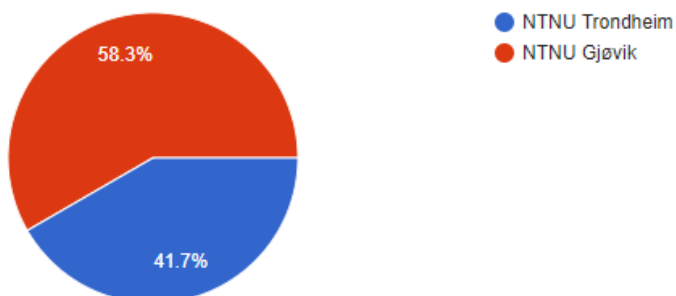
- More touch feedback when interacting with objects
- More colours
- Focus on group work! :)

B Phase 2 Survey Full

B.1 Meta

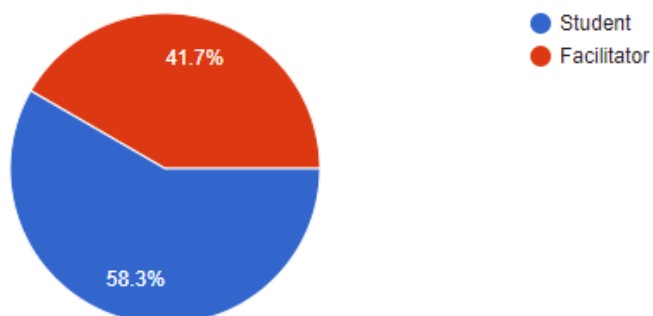
Your place of study

12 responses



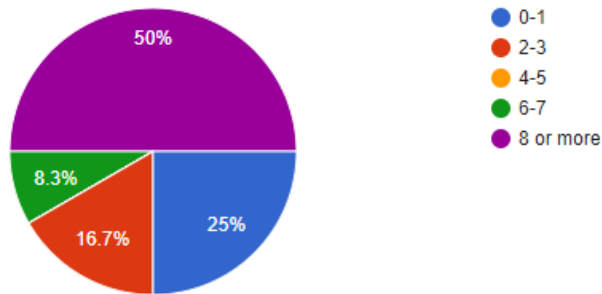
Are you a student or Facilitator

12 responses



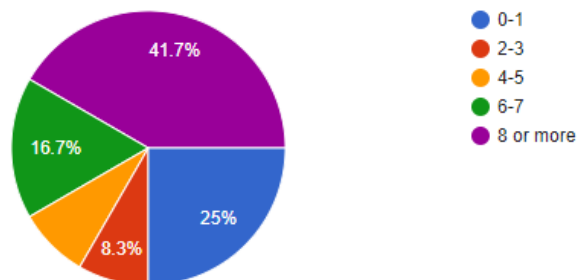
How many times did you participate in joint collaborative sessions between Trondheim and Gjøvik with HTC Vive?

12 responses



How many times did you participate in joint collaborative sessions outside Vive (via Discord, 'Spectator', Skype etc)

12 responses



B.2 Comments about the VR lab and EiT

What should be improved in the physical lab space?

12 responses

Walls to the top
More workstations
More separated cubicles for the headsets (to avoid issues with the base stations) and also maybe have it as separated rooms to block off outside sounds. PCs that could be used outside of VR use (currently there is only one). Better ventilation.
noting
There should be more Vives such that fasilitators don't have to rely on that some members of the group is not present.
Positional audio, adding a way to gain attention without interrupting
Some form of set boundaries for use of headsets. As of now it is just one room and that proved to be challenging when using the microphones.
We had only two headsets, in the same room, with poor tracking. The main problem for us was to have a decent audio setup for four people in a single room with two joining in vr and two not. The Trondheim group were often frustrated by our audio performance.
increasing the number of headsets as well as creating detached space for each individual. The reason is that when all the group members are located at the same place it is impossible to use multiple microphones because of voice reflection.
Apart from some network issues, everything was ok.
Separate VR rooms for the Gjøvik campus
To keep it as it is, in a sense that the collaborative group wouldn't have to share with offline groups would be ideal.

How could we improve Trondheim-Gjøvik collaboration in general for the next year EiT course?

12 responses

More communication and planning between the village leaders (more similar time schedules)

More Vives and better equipment in Gjøvik.

A more aligned time schedule would be appreciated, a structure for communication before course start and update about changes should happen immediately rather than a day before.

microphones

Gjøvik need more gear, Vives, microphones etc such that all of the group members can participate at the same time.

Having a fallback collaboration tool, and encouraging discord use early

On top of the answer above it would be preferable to sync up what is done on both campuses. As we missed out on things because on campus did one activity on one time and the other did it at a complete other time.

We missed a lot of content that was presented upstairs to the class by Simon, this should not be acceptable, we also had problem as the two villages were not synchronised and we would have different activities happening at different times, not to mention a different presentation day and submission date. As per the Group work a deeper collaboration should be advisable, with the group actually working together more often and not only updating each other at the end/beginning of the day.

creating the same course schedule for both groups at each location... we were struggling to find a proper time for check in and check outs because of various lecture schedules

Initially, I observed that there was a communication gap between the remote teams. Then during the planning phase itself, they started keeping a discord audio channel open at all times for real time discussions. But in the later stages, they engaged more into the "communicate when necessary" practice. This is something that the students in coming years can also do. Additionally, the EiT students at Gjøvik were pleased that they got to meet the Trondheim students in person which helped in better cooperation and understanding. However, an additional trip during the mid or towards the end of the term can help in even better cooperation.

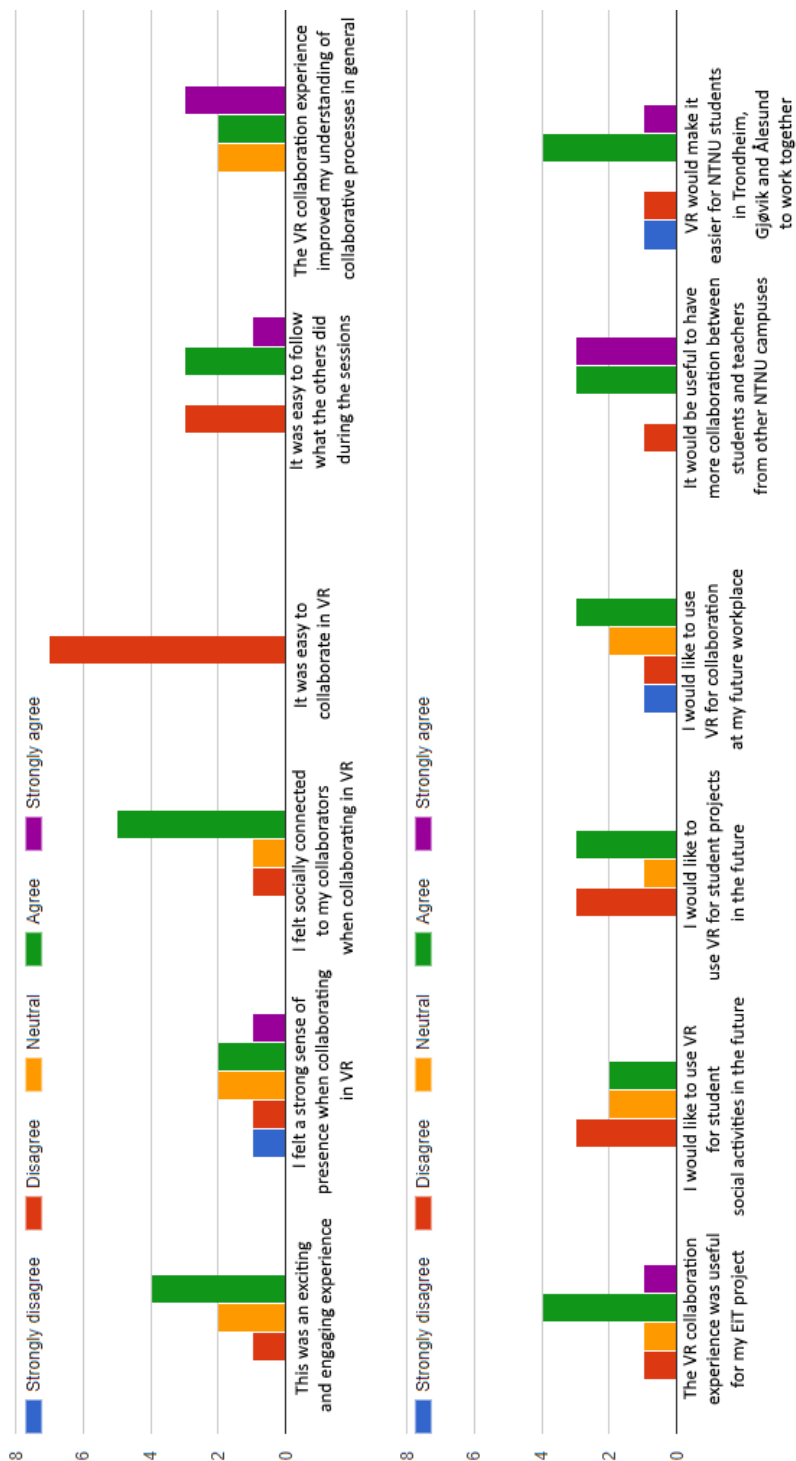
There should be a facilitator who is responsible mainly for this collaboration

I was never involved in their VR sessions (only in person), so perhaps, having a facilitator that's specifically assigned for such group is a good idea.

B.3 The Vive Application

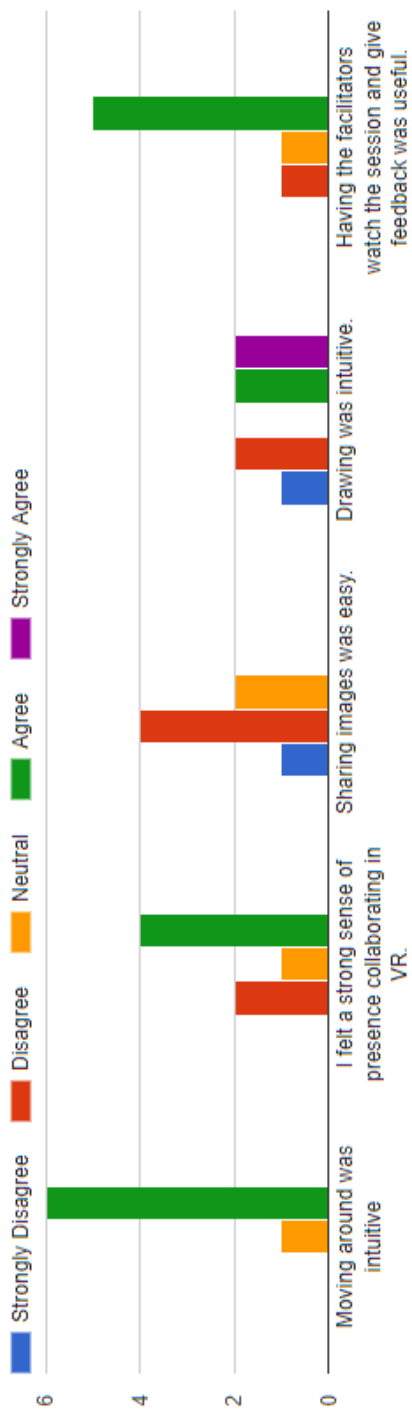
Based on your experiences with Trondheim-Gjøvik VR collaboration as a part of EIT course, please rate the following statements

7 Responses



B.4 Vive Collaboration Questions

Based on your experience with the Vive version of the application, please rate the following statements.



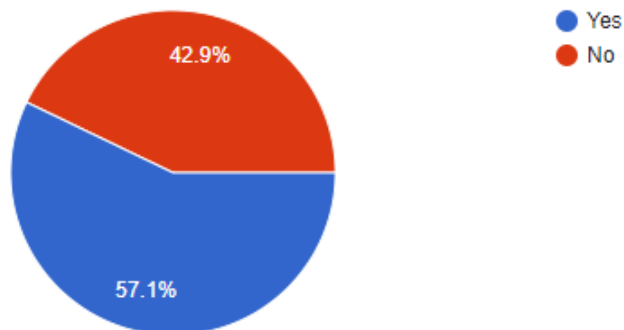
Additional comments and improvement suggestions

7 responses

- No
- Network stability.
- Movement has already been given feedback to, that it should give some type of signal that you have teleported (for example a visual trail). The UI elements with menu and etc. can also be done better so as to avoid having to remember so many buttons. Drawing simultaneously causes lag for some reason, could be problematic for future cooperation.
- It was quite unintuitive to pick up the color pencils when trying to draw. I'm not sure how to improve it, but I feel there's possibilities for improvement there.
- The futuristic look of the room is distracting and unappealing, as it is right now there is nothing I could do in the room that could not be done with google drive, sharing your screen or Skype with less fatigue.
- I want to refer to lack of physical facilities in lab again as the most important factor which was reducing the functionality
- There should be tutors for the basic knowledge of VR as most of us have no experience with the VR at all

Did you try the Mixed Reality version?

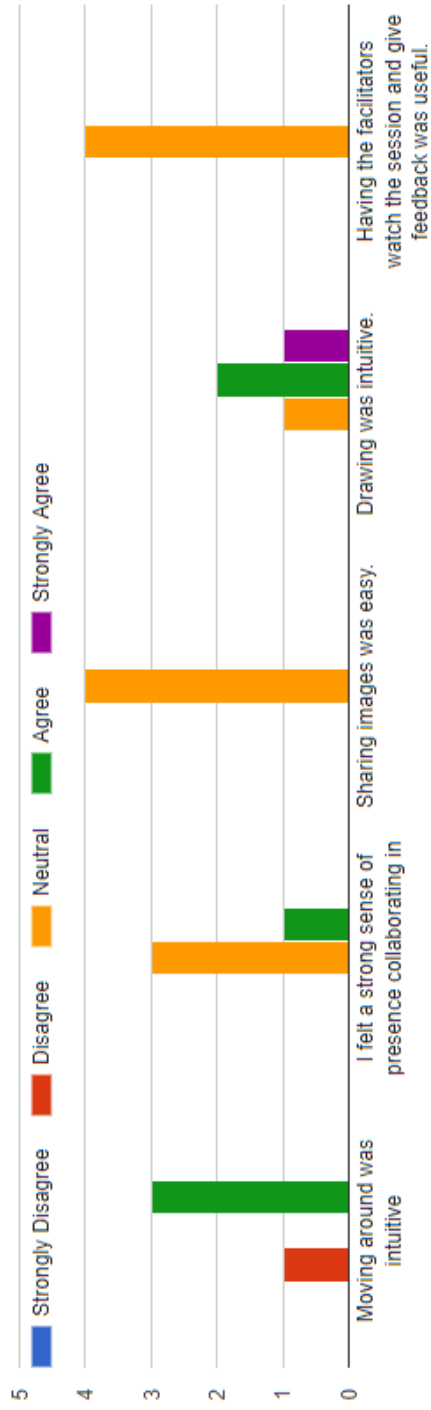
7 responses



B.5 Mixed Reality Collaboration Questions

Based on your experience with the MR version of the application. Please rate the following statements.

4 responses



Additional comments and improvement suggestions

4 responses

Did not try multiplayer or most of the features. Answered neutral on those

Sizing issues

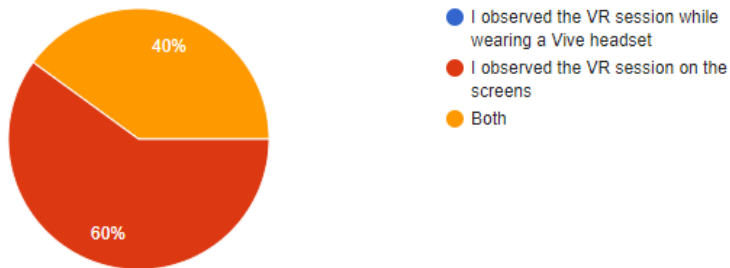
Moving here was very strange since I was already used to the Vive, this seemed like a limited version of teleportation compared to the Vive version. Rotation, specially, felt strange to do and the fade in - fade out effect was also intrusive.

Can't say much here since we didn't get to test it to the extent that we maybe should've done.

B.6 Facilitating in Vive/VR

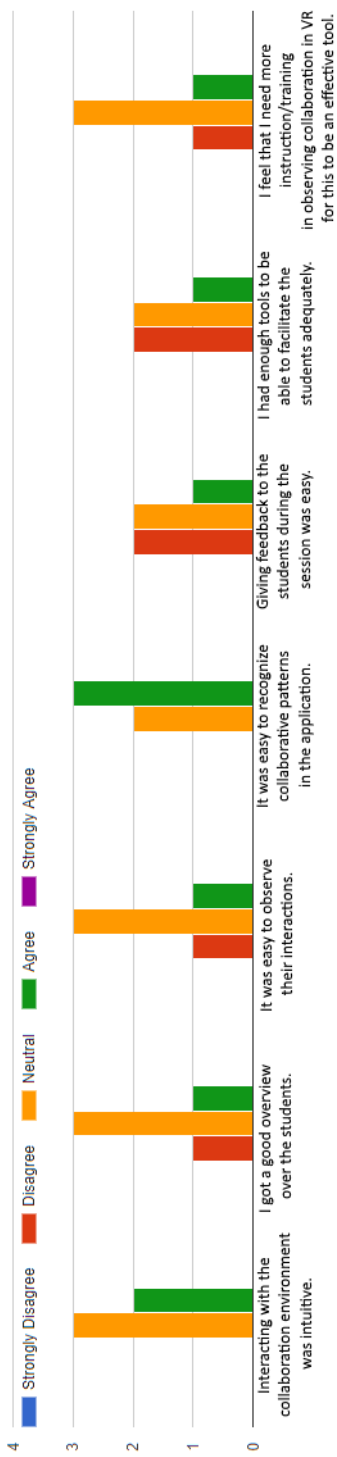
How did you facilitate in VR?

5 responses



Based on your experience with the Vive version of the application.
Please rate the following statements.

5 responses



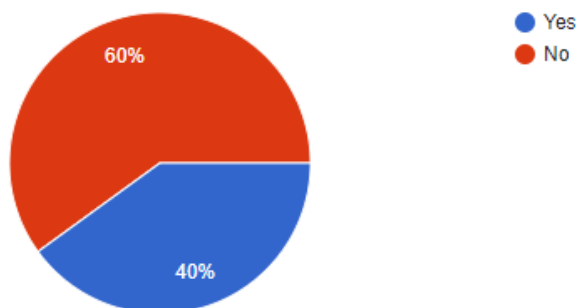
Additional comments and improvement suggestions

5 responses

- make it easy to communicate with the group (writing on a board)
- It was heavy to facilitate by only looking at the screens of some of the students. It would help a lot to be able to view the students from the "outside" and move more freely. Outside will here mean anything in addition or not through the view of the students
- I think an external viewer on laptop or tablet would be useful
- None
- I never facilitated the group in VR but only in person.

Did you try to facilitate in Mixed Reality?

5 responses



B.7 Facilitating in Mixed Reality

Additional comments and improvement suggestions

2 responses

- noting
- The gear did not work properly so I only saw one student

Based on your experience with the MR version of the application. Please rate the following statements.

2 responses

