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Using the 5G 8K-quality live stream to improve Finnish cities' functions, the school infrastructure, and the learning experience

What does the new technology have to offer for the Finnish cities and school systems?

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Abstract: The global digitalization and the rapid pace of network development have created a massive demand for technology manufacturers to develop new devices and software to improve the easiness and effectiveness of businesses and individuals. The recent launch of fifth generation (5G) networks has offered unforeseen possibilities with more efficient and powerful network. As the global pandemic of corona virus impacted heavily around the world, the school system faced a challenge on how to arrange remote schooling of the students as efficiently as possible without a decrease in the quality of teaching or the students' motivation to study. With the new technology and 5G-network, students and teachers were able to test new methods of studying and teaching. The aim of this thesis is to identify the possibilities and challenges of the 5G 8K-quality 360-degree live stream and how to use it to improve the current school infrastructure and learning experience of the students. To gain wide understanding of the current mindset of the students, the data covered in this thesis, was gathered after the experiments in participating schools. The students' answers from the question forms and technical input from the streaming site are covered and analysed in this thesis. The gathered knowledge from the experiments is also used to create a new learning theory which can be seen as a more suitable option for modern era of studying when compared to the traditional learning theories. The results of this thesis are limited but directional. They show that the students are already ready to try modern ways of studying as majority of students were interested in using the 5G 8K-live stream in their future studies as well. The participating students also gave important insight on which type of events or lectures they would be interested to watch in the future with the new technology. The identified challenges of the used technology were mainly related to the technical issues. The recently deployed 5G-network and its requirements are significantly higher when compared to the previous networks which caused several issues in the experiments of this thesis' project as well. It was discovered that the best possible outcome was achieved when the stream was sent from outdoors with stable and fast internet connection. However, the used equipment in participating schools was not on the necessary level to fully benefit from the ultra-high streaming quality of 8K. Based on the results, it was possible to build a new learning theory which better describes the current era of studying. This was made by connecting useful parts of the traditional leaning theories of behaviourism, connectivism, constructivism and humanistic learning theory. With the world heading towards more digital world, there is a massive need for improving and developing our infrastructure to meet the new requirements and achieve the full potential of the digital tools. This thesis introduces different possibilities that could be used in the future and describes the current limitations of the new technology.
Keywords: networks, 5G, 8K-quality, live streaming, remote schooling, learning theories

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LIST OF ABBREVIATIONS

1G	First generation network
2G	Second generation network
3G	Third generation network
3.5G	Improved third generation network
4G	Fourth generation network
5G	Fifth generation network
4K	4000-pixel horizontal screen resolution
8K	8000-pixel horizontal screen resolution
A.D	Anno Domini
AR	Augmented Reality
EDGE	Enhanced Data rates in GSM Environment
FPS	Frames-Per-Second
Gbps	Gigabits per second
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
IoT	Internet of Things
kbps	Kilobits per second
kHz	Kilohertz
LTE	Long-term evolution
mbps	Megabits per second
MHz	Megahertz
MMS	Multimedia messages
UMTS	Universal Mobile Telecommunications System
VR	Virtual Reality

1 INTRODUCTION

1.1 Introduction to the topic

During the last few decades, there has been a major evolution in the technology of mobile generations. Digitalization has dramatically impacted the earlier way of living and doing business, which has led to fast evolution of mobile networks and different digital tools to improve business functions in all kinds of businesses. The era of mobile communication networks started in the early 1980's when the first generation network was built. This network enabled making domestic calls with very poor quality of voice. Mobile phones were large, and they had poor battery life with very limited capacity overall. Today, almost 30 years later, fifth generation networks (5G) have become more and more common around the world. We are able to reach anyone anywhere in the world within seconds and often just via internet. Where first generation networks enabled data speed of 2 kilobits per second, 5G easily introduces data speed of over 1 gigabit per second. Especially since the third generation networks (3G) and the beginning of the era of smart phones, daily life at home and in different business functions has become more and more dependent on the quality and availability of internet connection.

The fifth generation network is expected to revolutionize the wireless mobile communication technology. Even though it is already available in many countries, it is under continuous development and there are numerous people constantly thinking of where this technology could bring advantage when comparing with the functions based on the older generations. With the highly increased demand of higher data speed and more reliable infrastructure from industrial users and private customers, 5G has ways to respond to the consumers' demands. 5G introduces more speed, more reliability and lower latency which means that it can handle the rapidly growing amounts of data better than its precursors. That is the reason why 5G also enables many possibilities for industrial users and is expected to improve Internet of Things (IoT) with massive impact. (Salih et al. 2020)

The 5G network with its high speed and improved stability is expected to play a major role in the development of Augmented Reality (AR) and Virtual Reality (VR) which require more bandwidth than traditional forms of video communication. Higher

uploading and downloading speed of 5G provide better average speed for video communication which leads to more stable connection between parties inside the video communication platform. It also means that video calls can be made with better quality in terms of voice and resolution of the video than before with slower and more unreliable connection.

In 2020, communication via different video communication applications and websites became more popular than anyone expected. The Corona virus, or Covid-19, led many countries to encourage people to work remotely from home, as restrictions around the world became unforeseen strict to prevent the virus to spread even more than it has so far. In some countries, students on all levels of education, from elementary schools to universities, have been sent home to study as schools are closed. Remote education has faced a test unlike any before, as students with different backgrounds are simultaneously all suddenly working from home. This has increased the demand for video conference system providers, as the customer base has massively increased when compared to the normal circumstances.

The Corona virus has affected the Finnish school system tremendously as most of universities, universities of applied sciences and other schools with students at an older age have been restricted to only remote studies. According to the magazine of the University of Oulu, half of the respondents report to be struggling with their motivation and feel more exhausted compared to the traditional learning methods. Many of the respondents report that the transformation to remote studying has gone quite well but the quality of the teaching has decreased. Finnish high-school students feel more stressed than usually as the teaching has become more based on individual tasks and there are fewer social contacts. (Oulun Ylioppilaslehti 2020.)

During the difficult times of the pandemic, even elementary level students started to study remotely. Finnish news was filled with issues regarding the consequences of the decision. Students' studying environment at home is not necessarily very good, children are used to a good-quality food in their schools and other side effects connected to the remote schooling of young students were discussed in several meetings with different perspectives around the country. Especially in the families with low-level salaries, issues with providing required equipment and parents being able to work remotely have been noticed. (ETK 2020).

Remote studying is becoming more and more popular around the world as digitalization and improved access to technology is increasing globally. Different tools are continuously considered and tested, as companies are trying to find new innovations on how to provide better ways for students to learn from home. Traditional learning theories and ways of learning are being challenged in high pace. Finding the right technology and digital tools itself is not enough as there are many obstacles concerning how the students are able to learn remotely. The global pandemic has accelerated the development of the digital teaching tools and led to many experiments, where enterprises, countries and individuals are trying to find suitable ways to teach the students around the world with no access to traditional contact teaching methods.

1.2 Aim and guidelines for this thesis

The aim for this thesis is to find out the possibilities of the 5G-based 360-degree live video stream in remote schooling as well as using it in cities' functions, challenges of deploying this type of technology and connecting the students' experiences with the traditional learning theories to understand more on how the developing technology will challenge the traditional learning. The research of this thesis is based on an experimental project executed by Elisa Oyj, The City of Turku and the City of Helsinki in the end of 2020. The project took place in several schools in two Finnish cities: Turku and Helsinki. This project tested the 360-degree live streaming in remote schooling and remote teaching. The goal of the project was to test the 5G-network and its capability to live stream high-quality 8K-video straight to the receiving end in different schools. According to the research covered in the topic introduction of this thesis, there has been remarkable changes in students' motivation when the school systems were globally transferred to the remote schooling. In order to understand the requirements of this new technology and its possibilities to improve the remote learning experience of the students, three research questions have been identified:

- What possibilities does the new 5G 360-degree high-quality live stream offer?
- What are the biggest challenges and obstacles in deploying the new technology?
- How does studying with the new technology challenging the traditional learning theories and the traditional learning environment?

The research questions are narrowed to three different themes since these can be assumed to be connected to the gathered data from the experiments. The feedback is gathered from the participating students to identify different perspectives and ideas on where this technology could be used. Obviously, these ideas are most likely to be mainly connected to the school environment since all of the experiments were executed in schools. Positive feedback and technical capabilities of this new technology can be used in identifying different possible using purposes in the future, also outside the school infrastructure. Challenges and obstacles from the experiments are based on the user experience of students and teachers from the schools and also from the producing site persons from Elisa and City of Turku/Helsinki. Notes from all experiments help to understand the areas where this technology still needs improvement. These observations can also help companies to prioritize certain areas where this type of equipment can already be used and where it should be forgotten or where it needs major development to work properly. Finally, as the feedback is gathered from students and the experiments are made in schools, it is important to connect these experiences and observations from all parties with learning theories. The traditional learning theories could be challenged by modern ways of teaching and learning, and this project is a great example of that. Ideally, based on the results, traditional learning theories could be modified or improved to the modern era of learning with new methods and growing access to different digital teaching tools around the world.

Results may vary since the students that participated in this experiment are studying different subjects and their age may differ. Some results came from the adult students as well, but a major part of this experiment is focusing on students from the seventh to the ninth grade, which is important since they are in the final phase of their studies before heading to the general upper secondary schools or vocational institutions. However, this research also holds experiences and observations from other parties that took part in the project in which all of the participants are adults, and most of them are professional and working in the area of business which is very closely connected to this experimental project. Based on the gathered data, we are expected to find answers to the research questions and have certain knowledge on how to move forward with this technology and have ideas of what to study related to this project in the future.

2 LITERATURE REVIEW

2.1 Evolution of networks

A history of network evolution contributes vitally with the development of an electromagnetic theory, the radio-based wireless signals and antennas that are capable of both, transmitting and receiving signals. Italian Guglielmo Marconi can be seen as the creator of a wireless telegraphy with his early experimentations in the beginning of the 20th century. Still, Marconi was mainly focusing on the wireless telegraphy and did not consider much on a wireless telephony which was the subject of focus for Reginald Fessenden from Canada. Marconi kept the Morse codes adequate enough and had no interest in developing voice transmitting. In 1894, Marconi started testing with Heinrich Hertz's equipment, which were used in his experiments before Marconi. With Hertzian waves it was possible to send signals without a wire and this led to the fact that by the year of 1896, Marconi was already able to send signals with a transmission distance of 2.5 kilometres. After five years of experimenting and testing, Marconi and his team received a signal from 3500 kilometres away in 1901. It was the first successful transatlantic experiment ever reported. Five years after that, it was Fessenden's turn. On the Christmas Eve of 1906, the first ever wireless broadcast that included music and speech by Fessenden himself, was aired. (Belrose 1995.)

2.1.1 1G to 2.5G

Approximately 80 years after the first successful experiments of the wireless networks and wireless telephony, the first generation of mobile communication (1G) was invented. It was based on an analogue system. Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS) were among the first systems in the 1980's. The first generation analog systems were very limited, and the system provided only voice communication with no data communication at all. The speed of data was supported up to 2.4 kilobits per second (kbps). However, one of the key features and improvements of the 1G was that it introduced a wireless

telephone. Still, the capacity was very low, and its voice link was poor. It also made the communication process less secure. (Agrawal et al. 2015.)

The first 1G analogue system was introduced in Japan in 1979 called Nippon Telephone and Telegraph (NTT), which was followed with the AMPS, NMT and TACS two years later in 1981. All systems were using a frequency modulation technique for the radio transmission. They used an access called Frequency Division Multiple Access (FDMA), which had a capacity of 30 kilohertz (kHz) and a frequency band between 824 and 890 megahertz (MHz) and was based on AMPS. (Kalra & Chauhan 2014.)

2G and 2.5G

The second-generation (2G) followed the first generation in the late 1980's. The 2G systems used a different access technology as the digital multiple access technology was introduced with technologies such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Besides the speech services that were already invented in 1G, the second generation had also the data support. The second generation network introduced significant improvements on the data services, roaming and spectrum efficiency when compared to the first-generation technology. The Global System for Mobile Communications (GSM) was created in Europe to enable services around Europe and to begin international roaming. GSM works with TDMA technology which supports multiple users simultaneously (Gupta 2013.)

The GSM became very popular around the world and it was the most popular cellular technology in 2009, with nearly four billion users in more than 200 countries. In the same year, its market share was almost ninety percent of the global wireless market worth of approximately 4.3 billion. The GSM introduced more bands than the previous technologies with 450, 850, 900, 1800 and 1900 MHz and created an infrastructure, which enabled it to be almost always possible to have at least one network available to connect to, wherever the user physically was at the time. With these several new improvements of the network technology, the GSM was also more secure than the previously introduced systems. All of the data it is using is encrypted, which makes it hard to hack into. All of the GSM-users have their own Subscriber Identity Module (SIM) cards which consists of a user’s identity number and an authentication key with an algorithm and the card is used to gain access to the network and features of the system. (Mishra & Poellabauer 2010, 7.)

The 2G focused mainly on providing services such as message delivering. The digital signals and the data support were basis of a new technology which allowed text messages, picture messages and multimedia messages (MMS) to be sent. However, it was the most that the 2G was able to handle. More demanding types of data such as videos were not available for 2G usage as it already required strong digital signals to cope with the pictures and the multimedia messages. The capacity was better than with the previous generation, but the 2G still needed a strong network coverage to work efficiently with the data speed capped at 64 kbps (Vora 2015.)

The second generation networking created much more possibilities with the new digital technology which created an important phase between second and third generation systems called 2.5G. The 2.5G was based on the similar technology and the same GSM-system than the 2G but it was an improved version of the previous one. New technologies were once again introduced first in the United States and Japan. In the year of 1990, Japan had created a system called Personal Digital Cellular (PDC), while in 1991, the IS-54 became in use in the United States. The new technology enabled more efficient handoff, Voice Mail Service (VMS) and Short Message Service Centre (SMSC). SMS became very popular and created the most traffic in many networks. (Gupta 2013.)

The 2.5G improved the data support up to 144 kbps with the new systems called General Packet Radio Services (GPRS) and Enhanced Data rates in GSM Environment (EDGE). A continuing improvement of the GSM technology led to many new features before reaching a new era of 3G. Phone calls were provided in a new efficient way with an improved technology. Receiving and sending e-mails became possible with the improved data support. GPRS and EDGE also enabled web browsing for the first time. Downloading music straight to the mobile phone was now possible with a download time of six to nine minutes for a song of approximately three minutes long. A camera phone was also introduced for the first time during the 2.5G era. (Vora 2015.)

The GPRS is considered as being the most important factor in the route from 2G to 3G. The GPRS used a technique called packet-switching, which means that the sent information such as voice or data was divided into the packets. Each packet was capped at couple kilobytes at most and then moved through the network to a destination based on the data of each packet. Network resources were needed only in handling the packets. Optimizing the network resources, continuous connection to the network and the flexible

data transmission rates made the GPRS a crucial part of the evolution towards the future networks (Gupta 2013.)

After the increased need of data rate regarding the voice and data traffic towards the system, the old form of GPRS was improved to the new technology called EDGE. EDGE used even more efficient coding and increased the data rate from 144 to 384 kbps. EDGE used the same technology of TDMA as the previous versions of network which made it quite easy to implement these fixes to improve GPRS to the new form of EDGE. (Gupta 2013.)

Common devices such as PC modules, phones, routers and modems were capable of using EDGE due to its simplicity with no need of software changes in GSM-networks. EDGE was used first time in 2003 by AT&T (former Cingular) in the United States and six years later EDGE was used in 181 countries with over 440 networks of EDGE or GSM. (Mishra & Poellabauer 2010, 8.)

2.1.2 3G

The creation of the third generation network (3G) started in 1980's by International Telecommunication Union (ITU) working on it. The first versions of the upcoming 3G technology were called Future Public Land Mobile Telecommunications Systems (FPLMTS) in 1990, which was revised later to IMT-2000.A task group named as Group 8/1, was a group that defined recommendations and frameworks for the IMT-2000 and the group set the evaluation criteria which included the target rates for a new technology. These target rates for a new 3G system were: 2 mbps (indoor environment), 144 kbps (pedestrian environment) and 64 kbps (vehicular environment). (Dahlman et al. 2007, 5-6.)

The 3G is a GSM-based system and it was introduced in 2000. The third generation network enables the data support up to 14 Mbps. The 3G network is still based on similar idea of packet switching than there was in the 2G. Wide Band Wireless Network improves on clarity, which makes it more efficient when comparing to the older generation networks. The 3G has a range of 2100MHz and a bandwidth of 15-20 MHz which enables the use of 3G for video chatting and internet services. With the new possibilities related to the bandwidth and data transferring, the 3G also introduced applications and audio/video files for the global use. (Vora 2015.)

The improved technology allowed sending and receiving larger email messages, video conferences and faster communication. While it took six to nine minutes to download a three-minute song with the 2G, the 3G downloaded the same song in the time range of 11 second to one and a half minute. The 3G brought new cell phones to the markets, usually referred as “smart phones”, which were often quite large with several new features such as mobile tv, gaming, high-speed internet browsing and better phone calls than with the previous versions. (Vora 2015.)

One of the technologies that emerged from the era of the third generation networks, was the Universal Mobile Telecommunications System (UMTS). The improved speed of data, better networks to support services such as video calls, streaming, gaming and improved browsing with higher speed than ever, were among the main reasons that led to the development of the new system UMTS. (Mishra & Poellabauer 2010, 6.)

The UMTS is based on the GSM-technology. It was firstly introduced in Japan in 2001. Its popularity grew rapidly and by the year of 2009, it was used by more than 330 million users in 123 different countries with 282 unique operators providing the new UMTS - technology for end users. One of the key features of the UMTS was its flexibility when it comes to the international roaming. The UMTS can use a very wide range of different bands (from 850 to 2600 MHz with future possibilities of 450 and 700 MHz) which allows its flexible use around the world with access to core networks. The UMTS can use also the previous technologies such as the GSM, EDGE, WCDMA, HSPA etc. to provide its services with the help of the local common core networks. (Mishra & Poe2010, 8.)

2.1.3 4G

History of a smartphone

The first cellular telephone was reportedly introduced by Motorola in 1973, when a company employee called from Manhattan to New Jersey. The call was made with Motorola DynaTAC 8000x, which was sold for public ten years after the first call. However, the first ever analogic first-generation phone service was launched in Tokyo by NTT (Nippon Telegraph and Telephone). Despite of the first mobile phone services launched in the late 1970's, the technology itself became popular much later. A US-based company Ameritech Mobile introduced the first 1G phone in the United States which was followed by Motorola with Motorola DynaTAC 800x within six months from the

Ameritech Mobile's first launch. DynaTAC was quite heavy with the weight of over two pounds, and it took ten hours of charging for a half an hour call. In 1989, Motorola launched a new model called 9800x which was a smaller version with flip-up mouthpiece system. (ScienceNode 2018.)

Following the first GSM-call in 1991, Nokia introduced the first GSM-phone in 1992. Nokia 1011 supported text-messaging which was a new feature for the smartphones of that era. Two years later, IBM released a model named "Simon" which can be seen as the first actual smartphone since it had features such as sending email and faxes, touchscreen with stylus, calendar, address book and other features that were not introduced before. However, even though it was ahead of its time, the web browsing was not available at all in IBM Simon. (ScienceNode 2018.)

The first 3G network was created in 2001 in Japan, which allowed people to attend video conferences and send e-mails with attachments, but the revolution of smartphones took place several years later. The most drastic change in the history of smartphones became in 2007 when Steve Jobs and Apple introduced the first model of iPhone. There were many differences between the iPhone and other mobile phones of the time. The Apple iPhone had a large touchscreen as others were mainly using keypads. The Apple iPhone was also able to browse web sites in the similar fashion than a desktop computer when the alternative phones were only able to use much more simple versions of websites. (ScienceNode 2018.)

Reasons for 4G/LTE development

A Long-Term Evolution (LTE) and the fourth generation networks (4G) were the results of the hugely increased growth of data in the third generation era of the mobile networks. Mobile data faced an explosive peak of growth after 2007, when Apple launched their first smartphone called “iPhone” which became widely popular. Apple was followed by Google a year later as Google launched their own new devices with a new system of Android. During the years from 2007 to 2011, the amount of data increased with a factor of more than a hundred. The new Apple and Google smartphones supported mobile applications in a way that was never seen before which led to a massive change in the culture of using the mobile phones. The smartphones were also much more appealing and offered unforeseen user experience, which resulted in numerous sold smartphones in the

start of 4G era. All of the changes led to a point where the rates of data consumption had exploded and the current second and third generation networks were struggling with the requirements of a new user base. Increased demand of the better data capacity was one of the main reasons to the need of fourth generation networks. (Cox 2012,8-10.)

Launch of 4G

The first commercial launch of the fourth generation mobile telephony was introduced by Finnish company called TeliaSonera in the end of 2009. The launch was proceeded in two of the company's Nordic headquarters: Stockholm and Oslo. Approximately a year later, the 4G was launched in Finland with its services available to two cities: Helsinki (capital) and Turku. (Telia.com 2020.)

2.1.4 5G

Launch of 5G

The fifth generation networks (5G) were launched in the end of 2010's. The idea and purpose of the 5G is to provide better coverage and connectivity when compared to the previous versions of networks such as the 4G. The 5G supports wireless World Wide Web (referred also as WWWW) which can be seen as wireless and limitless communication as the 4G is more about WiFi and LTE networks. The 5G provides high speed with the data bandwidth of more than one gigabit per second (gbps). The 5G network should also maintain better performance levels and have much less latency than the previous technologies. (Lopa 2015.)

All of the networks from the 1G to the 4G have brought new technology, which has led to the increasing number of mobile users and a massive growth of the whole industry. With more connected devices with different usages, the capability of the 3G and the 4G has been questioned when it comes to Internet of Things (IoT). The 5G is expected to make a big improvement on e-commerce, e-transactions and e-management due to its improved ability to provide high-speed internet and better capacity. While the 5G will improve the current possibilities with higher speed and better data handling, it needs to support the IoT which will have billions of different types of devices connected through the internet. This link between the 5G and the IoT will consist of all elements of a society with different dimensions, which means that it will likely control a massive number of

functions in all areas of life. The 5G is also expected to fulfil the wishes of several future innovations that have lacked from network requirements before. (Salih et al. 2020.)

5G and IoT

The IoT is already in a wide use with the current 4G networks. However, there are many future applications with a major need of improved networks that would support their technology. With its improved coverage and connectivity, the 5G is expected to be the solution for many of these concerns and the increasing number of requirements of the future innovations. Besides already mentioned coverage and connectivity, there is a growing need of security, lower latency, increased reliability and trustworthy for many IoT devices waiting for the actual implementation of the new 5G technology. Gartner expects over 20 billion IoT devices to be connected through machine-to-machine (M2M) by the end of 2020. Evolving 5G network has a major role in the development of the new economic and social needs around the world. The current 4G network supports the transmission speed of 1Gbps which can be improved up to 10 Gbps with the 5G technology. Where the 4G has challenges with disruptions such as signal problems, the 5G provides more stable connection. (Li et al. 2018.)

Figure 1 - 5G coverage map (Speedtest.net: Ookla 5G Map)

Picture 1 is a screenshot from the continuously updating map of worldwide 5G-coverage. From the picture, we are able to say that 5G is still mainly located in more developed

countries. For example, almost the whole continent of Africa is still without the 5G-coverage. The US and multiple countries from Europe are among the most covered areas with Japan, Australia and few others from the other continents. However, there are big differences on how crowded the countries with the most coverage are. For instance, Finland seems to have 309 locations with 5G, where Australia has about 800 which is much more but Australia is multiple times bigger than Finland. Thus, the map shows well where the technology is deployed and developed, but it does not provide that much information on whether the coverage around the country is good or not. (Speedtest.net 2021.)

According to the MIT Technology Review, the impact of 5G to the global GDP (Gross Domestic Product) can be the size of the entire economy of the country of India. The research expects this to take place before the year of 2035. It is commonly believed by scientists that the 5G could create and renew the entire ecosystem in the future. The 5G is also expected to lower the costs of manufacturing as smart factories could be introduced, and 5G's efficiency to gather and process data could improve the efficiency and lower the amount of energy consumption. (Forbes 2019.)

2.1.5 5G coverage in Finland

The three of the major network providers in Finland are Elisa Saunalahti, DNA and Telia, which are used by most of the individuals and companies based in Finland. There are also few other operators that are operating in Finland but their impact on the 5G and its future is relatively small and therefore we are focusing on the three major operators.

According to Elisa's annual report of 2020, Elisa's 5G-network is covering over 2 million people in Finland. The company also announced that they had sold over 200 000 5G phone subscriptions in the end of 2020. Elisa, Nokia and Qualcomm Technologies worked together to achieve the highest speed of the 5G networks in the world, 8 gigabytes per second. Elisa increased the number of 5G devices from four to over 50 and the amount of data used by their customers was increased by 34%. (Elisa 2020.)

The 5G-coverage of DNA in Finland was over 1,8 million in the end of 2020. The company announced that in the end of 2020, their 5G was covering over 80 different locations. According to their annual report, the customers of DNA used the most data per

person in the world with over 33 gigabytes per month, which introduced an increase of over 7 gigabytes from 2019 (25,4 gigabytes per month). (DNA 2020.)

Telia announced in the end of 2020, that their 5G-coverage was over 40% of the Finnish people. According to their annual report, Telia seeks to provide their customers a better 5G service via their new collaboration with Nokia and Ericsson, which aims to overall 5G development. Telia's 5G network covers 57 different locations throughout Finland. (Telia 2020.)

In June of 2020, Finland held an auction of the 5G-licenses for the next 13 years (until 2033). The auction consisted of three 800 MHz bands of 25.1-27.5 GHz range that could be used in Finland. All of the three bands were sold by their starting price of approximately 7 million euros each. Elisa won the frequencies of 25.1 to 25.9, Telia got 25.9 to 26.7 and DNA won the frequencies from 26.7 to 27.5. (Reuters 2020.)

2.2 High-definition video and live streaming

2.2.1 Evolution of video technology

Virtual reality (VR) and 3D technology have gathered growing interest from developers and potential end users in the recent years. A 360-degree VR-video simply means that the camera is constantly filming to all directions and forms a picture where the end user can decide what and where to look during the playback. It can be done with VR-glasses where the user can look around with head movement or using a platform where the picture can be moved by touching the screen or by mouse clicks. However, despite its advanced technology, the VR and 3D media are struggling with the video quality and resolution. As it is the most developed system so far, it has a large number of requirements. Higher bitrate needs of VR displays creates major challenges on how to transfer the heavy 360 degrees video which enables virtual reality. It is often considered that a 4K resolution is a minimum requirement for VR video. The 4K resolution (usual standard of 3840x2160 horizontal pixels) requires a major bandwidth support to make the streamed video appear with reasonable quality and the challenge will be even bigger with the evolving 8K (7680x4320 horizontal pixels) technology.(Hosseini & Swaminathan 2017.)

Even though the 360 live videos are still lacking certain things such as acceptable quality or properly functioning motions due to its requirements of the bandwidth, the 360-degree

videos have become more popular. Worldwide platforms such as Facebook, Periscope and YouTube support 360-degree videos in which their users can control the video and look around. However, these are mainly for the playback videos and live streaming of the 360 video is still rare. To run the high-quality 360-degree live stream, it requires a lot from the broadcasting site and also from the viewers point of view, as the equipment and connection requirements for a seamless video broadcast are much harder to gain than the ones with the still content or playback video. The whole process consists of three parts: a broadcaster, a streaming server and viewers. The broadcaster uses a 360-degree panoramic camera to film and uploads it to the server where it is re-encoded (in real time) in several possible qualities and forwarded for the viewers, who are able to choose suitable quality in which to watch the live stream. With several qualities to choose from, more people are able to watch the video, even if their connection is not enough for the top quality that the broadcasting site and the streaming server are capable of sending. (Xing et al. 2019.)

2.2.2 Virtual reality (VR)

The virtual reality is based on an interface which is a simulation of the environment where the video is being filmed at the certain time. The VR provides new features for users such as different camera angles, zooming, grabbing the picture and moving it to the wanted direction with just touch of the fingers. This also reduces, or completely removes, the need of all symbols and figures that take place in the traditional form of video. The basis of the VR are immersion and interactivity. Immersion can be explained as its key idea is to remove distractions and everything aims to the results wanted by the participating workers. Interactive communication between humans through the virtual world has been part of the technology development for a long time but with the virtual reality, it has taken a whole new level. The VR can be seen as a three-part technology, which includes response to the user actions, a real time three-dimension (3D) graphics and a sense of immersion. (Zheng et al. 1998.)

Despite its breakthrough during the last few decades, the VR-technology is not a new invention. In the early forms of the VR, it could be seen in the certain sectors such as automobile and military, where first VR-related applications were introduced and used in a specific use at the 1970's. Since the development of the recent years, the VR has recently become more affordable for everyone. Computers have developed massively in the recent

years, which has also made a significant difference in VR technology as the new graphic cards are much more likely to meet the requirements of the VR live video. Additionally, there has been major improvements in the VR-technology related to ergonomic use and comfort for the users. As it was mentioned before, virtual reality devices and access to the technology has become more affordable with software and devices developed by the companies such as Microsoft and HTC. (El Beheiry et al. 2019.)

The user-experience has major differences between the traditional 3D and VR. With the 3D, the user usually watches the video or picture from the monitor of the computer. With the VR, the user has access to the feeling of being inside the video, which generates more realistic experience compared to the traditional 3D. Especially in the beginning and in the first-time experiences, there are positive surprises for the users which helps the VR-products to become more popular. This can be seen in the recent development of the VR-technology used in video games and film industry, where these forms of VR have become very popular, even though there are still much room to improve in the systems and software. (El Beheiry et al. 2019.)

However, even though the VR is still not a leading force in science, the technology has a lot of potential for the science usage as well. Due to its interactive and immersive possibilities, the VR could totally change the traditional laboratory work as it provides the workers with a lot of new tools. For instance, different objects can be seen from different angles with different point-of-view than before, which could offer the scientists more insight and more data to help their work. With its hands-free technology, the VR could also help workers to be able to do something else with their hands, while having access to the object under experimentation, which reduces time and could possibly improve the effectiveness of the work. El Beheiry et al. have forecasted, based on their research in 2019, that the virtual reality technologies will have a major impact in scientific research in the future, and challenge the current way of how research is being done around the world. The forecast is based on the VR's capability with visualisation and data treatment that challenges the traditional approach to data processing. (El Beheiry et al. 2019.)

2.3 Learning theories

Learning theories are made to provide guidance and knowledge around people's individual learning. The main goal of the learning theory is to avoid unnecessary activism which does not lead to one's learning or development. Obviously, there are no exact theory that can be seen as the right one. People have different ways of learning and some of the learning methods that may work well with one, may be really ineffective for the other one. There have been discussions on whether the one theory is better than the another but due to humans' different preferences, abilities and ways of learning, this superior theory has not been found. Therefore, the common believe can be seen as that the individuals are learning in different ways and having several learning theories is the most suitable way to guide and support individual learning. (Wang 2012.)

2.3.1 History of learning theories

Learning theories are based on people's efforts to understand learning. This movement started more than two thousand years ago and is still studied. Even the Greek philosophers such as Socrates, Plato and Aristotle are told to have had debates on individuals' learning capabilities and the learning process. The history of learning theories can be divided into two major fields: philosophy-based learning theory and psychology-based learning theory. (Hammond et al. 2001)

Philosophy-based learning theory

All of the three famous Greek philosophers had quite similar thoughts on how people learn and build their knowledge. Plato was known for his rational thinking and he thought that knowledge and truth can be found individually via self-reflection. Aristotle studied the world around him to discover truth and build knowledge. Socrates used his communication with other citizens to improve his knowledge and understanding of the world. Currently used inquire methods are based on the thinking and vision of Aristotle, whereas tools with the reflection methods are formed based on the thinking of Socrates and Plato over 2000 years ago. (Hammond et al. 2001)

Romans had a different state of mind regarding the education of the people. They were more interested in studies that would improve society in a practical way, and they were not as interested in mind and meaning of life compared to the Greeks. The Romans'

mindset was that of practical studies: they would have more impact on the development of society by learning to how to build roads and aqueducts, which they found more important than understanding the truth of the world. Roman education led to a point, where the Roman Catholic Church was a very strong and powerful European institution from 500 A.D to 1500 A.D. During this period of time, the world saw its first universities built during the 12th century, where education was handled by the local priest and taught to the citizens. A similar way of transmitting information can be seen in many schools today, where teaching is approached in that sense rather than by transforming the available information. (Hammond et al. 2001)

From the 15th to 17th centuries, the era of The Renaissance started, where Greeks' way of education became relevant again. The Romans faced challenges from scientists such as Copernicus, who presented the idea that the sun is the middle of the Solar System (whereas Romans thought that it is the Earth) and Martin Luther aimed for less religion-based education and a more down-to-earth type of an approach. Individual inquiry and discovery were the basis of learning in the Renaissance era and the ideology of thinking and knowledge was the priority again, ahead of the practical skills and practical-based education purposes. (Hammond et al. 2001)

Understanding the impact of the environment to behaviour was stressed by Rene Descartes in the early 1600's. He identified the mind as a separate part from the body. His findings were the basis for many scientists when they started to research genesis or understanding human's ability to think. After Descartes, John Locke presented slightly different perspective. He described a child's mind as a "tabula rasa", which means "blank tablet" and the term is still in use to describe Locke's perception. Tabula rasa means that the child's mind will be formed by his/her own experiences. Human senses gather data and form ideas from experiences, which continue to develop to more complex ones. His approach for teaching was that schools should arrange experiences for students, who would develop their skills and improve the learning process. In the 1700's Jean-Jacques Rousseau introduced an idea where child should be given enough time to grow and develop. This means that the child could learn all the necessary aspects from life and what is surrounding him/her. This philosophy was later followed by Kant later on with the approach that the mind is a fundamental part of the thinking process and it can impact the development of thoughts. He also thought that certain knowledge exists even before

experiences which could create a basis for the data gathered from lived experiences. All of these theories and approaches to learning have showed the way for future cognitive scientists who have developed these existing theories further. (Hammond et al. 2001)

Psychology-based learning theories

At the 20th century, focus moved more towards the direction, where psychologists debated on whether humans are actually able to use their brains to create knowledge from the sense-gathered data (cognitive) or whether they are only operating by a stimulus response mechanism (behaviourism). Based on earlier researchers and their ideas, many scientists started experiments to analyse and study people's learning and to identify the best way to teach. (Hammond et al 2001.)

In the early 1900's, Edward Thorndike introduced an approach stating that people learn from experiences described as trial-and-error. His idea was that by connecting positive responses with some particular stimuli, people are able to form mental binds and learn from them. In his mind, the process was about forming a connection with sense impressions and action impulses. Teaching should be active, and the learning environment needs to be inspiring to improve the learning process. Thorndike's theory was followed by B.F. Skinner who did research on rats and pigeons where positive reinforcement was given for correct answers and he denied the possibility of any mental influence on learning. Skinner's approach was that instead of punishment and penalties, there should be rewards and allowing the students to learn at their own pace. (Hammond et al. 2001)

Jean Piaget created an idea that students learn by their own knowledge building rather than from the information given by teachers. He identified that the creation of students' knowledge was based on their own experiences and their learning from these experiences vary on their own state of development in different sectors. This was later extended by a Russian scientist Vygotsky, who believed that learning should always include social interaction. He stressed the major role of students' culture and language in advanced thinking and improving their skills and ideas with their teachers. All this aimed for the point, where teachers could be able to give responding teaching to the child's stage of mind at the particular time. This would bring out the best results in terms of child's ability

to receive and adopt the given information and transfer it to knowledge. (Hammond et al. 2001)

2.3.2 Behaviourism

The important development of science during the early 20th century led to new approaches to the existing knowledge of different learning theories. Experimentations and different tests of learning using animals and their behaviour were introduced at the beginning of the 20th century. The most famous scientist was Ivan Pavlov, whose experiments on dogs and bells were among the first ones studying behavioural actions in 1903. During his experiments, Pavlov noticed that dogs' behaviour changed over time. Dogs were able to learn to anticipate food with different stimuli such as a bowl where the food is served, sounds that were related to the fact that they are about to get food, and it was noticeable that dogs learned all these quite quickly. Since the success of these experimentations, Pavlov created a learning process where changing behaviour was paired with stimuli. This process was the key to the upcoming general advancement in understanding learning by association. (Stewart 2012.)

Pavlov's conditioning brings together every-day learning and shaping of perceptions. Stewart describes this with the following example: "Students are not born, for example with a fear of exams, but test anxiety can develop from association with previous negative experiences. Similar experimental work blossomed in the United States, deepening our understanding of learning through association, reinforcement and incremental growth (Thorndike 1898)". Pavlov's stimuli pairing -based learning was followed by Skinner's experiments in the late 1930's. Skinner's experiments were based on rewarding animals such as rats and pigeons after they had performed a task they were supposed to do. Results of these experiments showed that behaviour could be guided in the wanted direction using different tasks connected to different positive rewards. (Stewart 2012.)

2.3.3 Constructivism

The research of cognitivists consists of how we store, retrieve and process information, as well as how our thinking improves and how we absorb all new experiences to understand the world better. Researchers are seeking more insight on the unanswered questions from the behavioural experiments. For instance, they are trying to find answers on why different age groups think differently, what are moral and ethical thinking is or

how do we adapt different information to solve problems. Cognitive research also strongly focuses on how different people act and think differently than others and what this is based on. (Stewart 2012.)

The first early known researcher was Jean Piaget, starting in the 1920's, as he compared children's thinking with adults' and noticed that it seemed illogical, which was the basis on the next research on how thinking changes when humans grow up and mature. In the year of 1952, Piaget introduced his theory that children are developing different ways off perceiving, interpreting and gaining meaning in different phases of their growth. With different tests and observations, Piaget formed a sequence of cognitive levels which were progressed by children which was crucial for teaching as it stated that there are different stages in children's growth, which indicated that they are adopting the information differently and it should modify the teaching models depending on the age group in question. (Stewart 2012.)

Besides his interest in children's cognitive capabilities, Piaget also focused on maturing brains. He noticed that during growth, humans started to develop frameworks where we store knowledge and experience and as children grow, they are more and more capable of having more of these frameworks before being adults with massive amount of information and experiences that are being used in everyday life. The following was said by Piaget in 1970: "To present an adequate notion of learning one must first explain how the individual manages to construct and invent, not merely how he repeats and copies". This was his basis on the understanding that learning must be self-active which means that children need to understand and learn something themselves and they need time to process everything. With too rapid pace of teaching, children are not able to learn on their own which has negative impact on their progress. (Stewart 2012.)

2.3.4 Humanistic learning theory

Humanistic learning theory (humanism) is similar to constructivism in many ways. In the centre of humanism is the thought of self-actualization and the idea that everyone is working towards fulfilling their needs. It has been described as hierarchy of needs where self-actualization is at the top. Self-actualization means that one feels that all needs are being met - at least for brief moments. Self-actualization is the ultimate goal that everyone is working for and the environment where one is working plays a major role in either

making it easier to fulfil the needs or making it harder. These needs can be both physical and emotional and to achieve self-actualization, all of these need to be met. For instance, a safe and comfortable place to learn, enough food and support from teachers or other relevant persons to one's learning are factors that can lead to better results of learning and achieving self-actualization. (WGU 2020.)

Well-performed humanistic learning theory can lead to a point where knowledge and skill set is developing when students start to understand themselves and others better. With more understanding, students are more likely to make personal connections which also improves their learning. Meaningful and important connections are connected to more effective learning as students have already connected to the topic on some level. Despite of its many positive parts, there are also problems with humanistic learning theory. Students can suffer from teachers expecting them to be passive learners or they can be influenced by rewards, competition or they are worrying about what happens if they fail. Students can be also forced to learn in ways that are unnatural for them. With an emotional side in humanistic learning theory as well, a cold approach by the teachers or pressure to think or act similarly with the common group of humans inside this particular learning environment can cause big obstacles on a way to more effective learning experience for both, teachers and students. However, the humanistic theory challenges the traditional methods of studying where all students are expected to study in similar ways, learn the same contents and following the same path with each other. In humanistic theory, students' learning should be more self-directed and requires less guidance from teachers and the traditional curriculum. Also, the topics of the classes should be relevant for the students studying inside the classroom, and they should be interested in the particular subject to enable the best possible outcome. Students should be treated individually and by understanding that all of them are unique and have different interests and emotions. The best outcome could be produced in non-threatening environment where students are keen to learn and have been taught different ways to improve their learning. (Johnson 2014.)

2.3.5 Connectivism

Connectivism is one of the most recent learning theories. It is based on people's connections and the main idea is that people are learning through these formed connections. Connections can be between people or with hobbies, or objectives that have

influence in one's learning. For instance, using digital tools to teach students can cause positive effects on their learning and mean that they are having desired connections to learning, and thus it helps them to learn better than without these tools. Group work and working with other people creates connections and can also have positive impact on motivation and learning of the individuals. (WGU 2020.)

Connectivism and formed connections build a network where all members of the network are sharing information inside the network, which can be used to build important knowledge for the network members, often referred as nodes. Learning can be seen as actionable since all nodes of the network are working on behalf of the group as they are learning and developing the network all the time with their own actions. Interaction inside the group means that all nodes of the group are learning without a doubt through the interactive environment. (Herlo 2016.)

Characterizing connectivism can be described with three different approaches: knowledge, learning and community. All of these three are connected to each other and forming a cycle, where knowledge informs learning, our learning informs a community and the community creates knowledge. The cycle in question can also be reversed and it would work in that sense as well. (Herlo 2016.)

A precise example of connectivism in action is massive open online courses (MOOC), which were created by Siemens, Downes and Cormier who have also published important studies regarding connectivism. Downes (2014) describes the MOOC as a course, where individuals can engage, collaborate and connect with others in a specific network. Courses are arranged online with study tools such as e-books, videos, e-library and other online tools and online tasks created by the arranging personnel for the students participating in a usually free and open course. MOOC also gives students options compared to the traditional school systems. Students are able to choose only the courses they want, and they can take those courses in their free time, but they are often accepted as the school courses as well and help to move students' studies forward in addition to their learning and being able to study something that they have interest in. Connectivism has faced much criticism since it is the first approach to heavily challenge the traditional way of learning. However, connectivism and its way of learning could become more and more useful and popular since it is deeply linked with the evolving technology and Internet. (Herlo 2016.)

3 RESEARCH METHODOLOGY

3.1 Data collecting methods

3.1.1 Question forms for students

The data was collected from students and teachers from participating schools with an electronic question form. The students had access to the question form from their own school intranet called “Wilma”. Teachers were also asked to remind the students to fill in the questionnaire after the lessons and give feedback. Three of the questions were answered with numbers from zero to ten (0-10). The fourth question was answered by choosing from two alternatives: Yes or No. The example of question form (in Finnish) can be seen below in Picture 1.

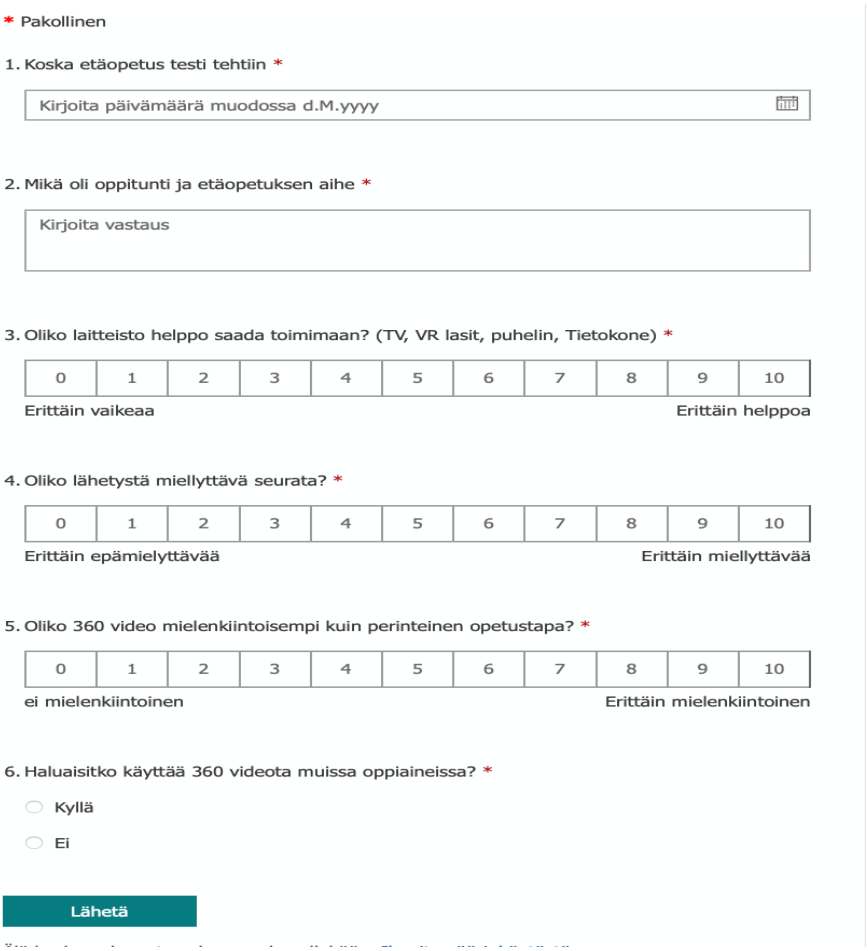

Figure 2 – Question form for students

Translated questions in the students' question form:

Question 1 – Date of the lecture

- Not included in the research part of this thesis.

Question 2 – School subject and topic of the lecture

- Used in research and very important in terms of understanding the students' feedback.

Question 3 – How easy was it to use all of the necessary equipment?

- 1 = Really difficult
- 10 = Really easy

Question 4 – Did you find the stream pleasant to follow?

- 1 = Very unpleasant
- 10 = Very pleasant

Question 5 – Did you find the live stream more interesting than traditional lecture?

- 1 = Not interesting at all
- 10 = Very interesting

Question 6 – Would you like to use 360-degree live stream in other subjects as well?

- Yes
- No

The students were also asked to give informal feedback on following topics:

- Other subjects where this type of technology could be used
- Other events where 360 live streams could be used
- What would you like to do otherwise (regarding the lecture they attended to)?
- Open feedback on anything related to the lecture.

All informal feedback was gathered in every single lecture that took part in the experimental project. All three questions used in this thesis are analysed individually with an additional part of each lecture where text feedback is discussed in its own sector. All of the answers were given in Finnish, so the results are translated as accurately as possible to English.

3.1.2 Data collection by Elisa employees

The Finnish mobile operator and network provider company Elisa was a leading force in this experimental project. Elisa provided all the necessary equipment such as cameras, laptops, virtual reality glasses and 5G routers. Where cities of Turku and Helsinki took more responsibility in finding participating schools and organizing the lectures, Elisa took care of all the technical requirements and needs for this project. Obviously, it was very important to gather information and knowledge on how the equipment responded to the cause and what issues or difficulties was detected during this project. All information was put together in a Excel-file which was shared around the employees of Elisa who took part in this project to get as much information as possible.

Before every lecture, employees tested the speed of the internet, connection, virtual reality glasses, voice volume and other factors that could cause problems if there are issues in any of these. Usually, the testing started about an hour before the actual lecture was scheduled to start, to have enough time to make adjustments or change something if there were any issues discovered during the testing phase. In some cases, when was more reason to expect issues with connection, employees took tests before the actual streaming day to know what needs to be improved or is there a possibility to send stream for certain places at all. These tests were found to be very important since there were several problems discovered in some locations and even more little issues, that were possible to be fixed before the lectures.

Since all the relevant information related to the used equipment and networks was stored and all phases of this experimental project were monitored, much of the issues were identified and if there was not a possibility to fix it immediately, it could help in the future in similar projects.

3.1.3 Other feedback and data

Several parties participated in this project, which means that there are different objectives from different parties. This thesis mainly discusses the project from the Elisa's perspective which means that there are also other perspectives where this project could be seen from. However, in this thesis, there is a purpose to understand the results also from another angles. Still, there could be different studies regarding how this project was seen in participating schools or from the cities' perspective. For this reason, Elisa also gathered more data from the participating parties to understand more on how the project was for each site that participated in it. Unfortunately, since this thesis has its limitations and the amount of data and information is large, the data and information collected from the two cities and participating schools' contact persons cannot be covered entirely in this thesis. Elisa held meetings with the other parties of the project to understand their expectations and how those expectations were met, but these conversations are not featured in this thesis.

4 EXPERIMENTS OF 5G-BASED 360-DEGREE HIGH-DEFINITION LIVE VIDEO TESTING IN STUDY PURPOSES

4.1 Introduction

The following part of the thesis focuses on the experimental project which was carried out in the end of 2020 by City of Turku/Helsinki and Elisa Oyj. Three master-level students from Åbo Akademi took part in the project including the author of this thesis. All three students participated in the project, which was executed in Turku. The gathered data and feedback from the experiments made in Helsinki are collected by other employees of Elisa. All of the participating schools are introduced in the following sections where detailed analysis of the experiments is discussed individually.

The participating schools were mostly upper comprehensive schools but there was also one vocational school that took part in the experiment in Turku. Due to the global pandemic of the coronavirus, there are differences according to the number of students that were present in the classroom or took part remotely. In total, there are five individually different experiments analysed in this thesis; three in Helsinki and two in Turku. The topics of the lessons are very different, since there are live streams sent from a fire station, a theatre and a church but also testing of the new teaching methods such as live stream for barber school students remotely watching the cut. Interaction between students and sending site of the stream was made possible via WhatsApp. Few of the streams were sent via YouTube, which enabled the possibility for the students to comment to the live chat of the stream. After lessons, the feedback was gathered from the participating students and teachers. Both had different question forms with slightly different perspective to the lessons. The students were asked about their learning experience and ideas on how to develop the technique to improve the user experience and produce better learning experiences. The teachers were asked more about using this type of technology as a teaching method. All questions were answered with the scale from 0 to 10 with the additional possibility for open feedback outside the given questions. All of the data gathered from students is included in this thesis.

The basic technology used in this project was based on the 5G -network and connection. The main object was to test how the 360-degree live stream with the 8K-quality could be send via 5G-connection, and how to use it for teaching purposes. The VR-glasses were also available for students to watch the live feed at classrooms. The sending site was equipped with the 360-degree 8K camera. In schools, the live stream was mirrored to the large screen where students were able to follow it. Two of the participating schools had a traditional system with a HDMI-cable and a laptop where the live stream was projected to a screen. One of the schools had a Huawei Ideahub, which is one of the most recent and most developed smartboards. It could be described as a really big tabloid as it has all the functions of the traditional laptop in a form of a really big screen. It is also a touch pad, so everything is controlled with finger movement.

The 8K 360-degree camera means that there are four cameras in all four sides of the device that are simultaneously recording. Four different angles are combined together, enabling that the video can be turned around and the viewers are able to watch it from any angle. However, there is a noticeable seam in the video, which means that if the video angle is right on that exact spot, that video angle could be unusable or really poor compared to all the other camera angles. The 8K resolution demands a stable and very high-speed connection with low latency to work efficiently. The required speed of the internet for the stable 8K live stream should be approximately 40 megabits per second. Even though the objective of the project was to test the 8K live stream, there was a possibility on the camera to choose lower resolution such as 4K, which requires lower speed and can perform with higher latency than 8K. Obviously, there was also an audio support for this live stream. It was arranged with an external microphone to improve the quality and volume of voice, especially when moving around and having conversations with multiple people. The external microphone was connected to the camera via an USB-cable. The actual live stream was sent through a software which was downloaded to the computers, the smart board and the VR-glasses. After the live stream is in the sending mode from the camera, there was a requirement for one employee of Elisa to execute a command from remote to enable it to be opened from the receiving ends. The same protocol had to be followed every time, also if the stream was disconnected for some reason during the experiment, which means that it took usually a few minutes to get the stream up again. One of the live streams that was sent via YouTube, with 4K-quality, followed different protocols as there was no additional software and it was aired on

Elisa's YouTube channel, which was linked to the students physically watching it at school or remotely from home. All receiving sites were tested several times by the participating personnel before sending the first live stream.

4.2 Participating schools and used equipment

4.2.1 School A / Turku

School A from Turku is an upper comprehensive school with over five hundred students (2019). School A differed from the other receiving ends as there was the only smart board used in these experiments. The smart board was located in a normal size classroom during the live streams. During the tests before the actual project, there was noticeable issues with the connection in School A. It was discovered that quite old and thick concrete walls were blocking the internet signal, which created issues on gaining the required speed. This was solved by wiring the smart board to the school internet. The speed of the internet was tested before all live streams and it was always over 100 mbps, which easily meets the requirements for the 8K quality live stream. Virtual reality glasses were also provided to this school for the students to try.

4.2.2 School B / Turku

School B from Turku is an upper comprehensive school with approximately two hundred students (2019). School B's live streams were showed in a small auditorium. The stream was opened at the laptop and then mirrored to screen with the HDMI-cable. There were no issues with the speed of the connection at School B. The download speed was about 120 mbps and the upload speed around 160 mbps. The VR-glasses were provided in School B for the students to try.

4.2.3 School C / Turku

School C is a vocational school for adults, which has eight school units around the city of Turku. School C had a similar setup with School B where the laptop was used to stream and the HDMI-cable to mirror it to the screen. In School C, there was two different internet connections available. Wired connection had similar download and upload speed with other two schools, around 100 mbps. The 4G-connection was also tested in this

school with similar download speed but with very poor upload speed. The upload speed was only around five megabytes per second, which is very low for this video format.

4.2.4 School D / Helsinki

As mentioned before, this project took place in both cities, Turku and Helsinki. In Helsinki, School D was the only participating school. School D is a high school which has around 860 students. The used equipment was similar with School B and School C.

4.3 Helsinki 1 (18 students)

The topic of the lecture was 3D modelling, 3D printing and teaching with virtual reality. It also had a virtual introduction to the university of applied sciences called “Metropolia” which is a University of Applied Sciences in Helsinki with over 16 000 students. This lecture was part of art studies in School D. The survey received answers from 18 students.

4.3.1 Question 1

How easy was it to use all of the necessary equipment?

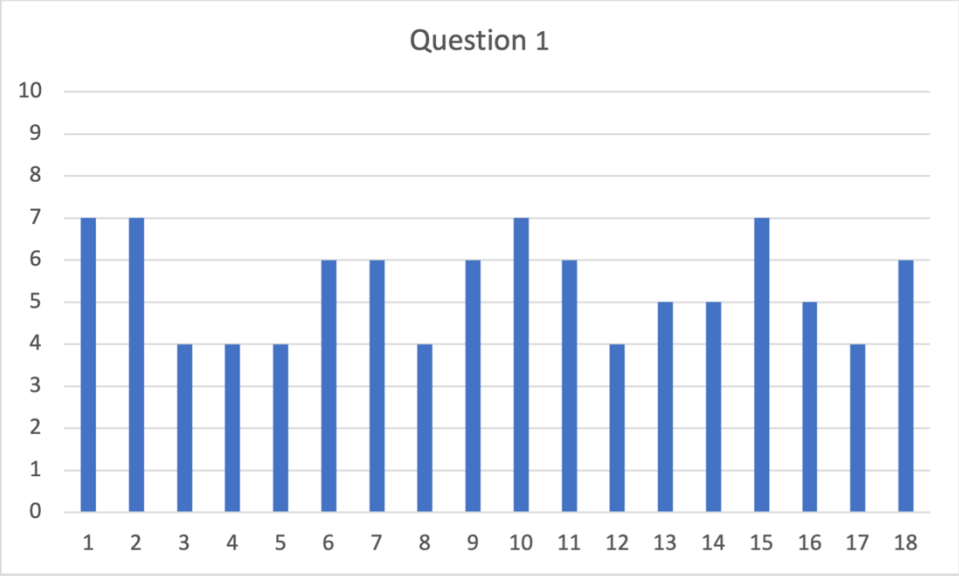

Figure 3 – Question 1 of Helsinki 1

Helsinki 1 was the most popular experiment of all in terms of received answers from the students. The total amount of answers was 18 and the average for the first question was 5.38 with the scale from 0 to 10.

Despite of the scale from 0 to 10, all answers in Question 1 were between 4 and 7, which shows that not that much fluctuation existed between the respondents' answers. However, four of the respondents gave a grade 7 and five of the respondents gave grade 5, so even though the results were all divided between four grades, there were some differences between students' reactions on how easy it was to use the needed equipment. Having the average over 5 when asked about how easy it was to use all the necessary equipment could seem low, but in this type of project with new technology, it could also be seen as decent. Results show that there were no answers under a grade 4 which most likely indicates that none of the students were facing major issues with the technology. However, all of the grades were under seven and this could mean that the highest expectations from the students were not totally fulfilled.

4.3.2 Question 2

Did you find the stream pleasant to follow?

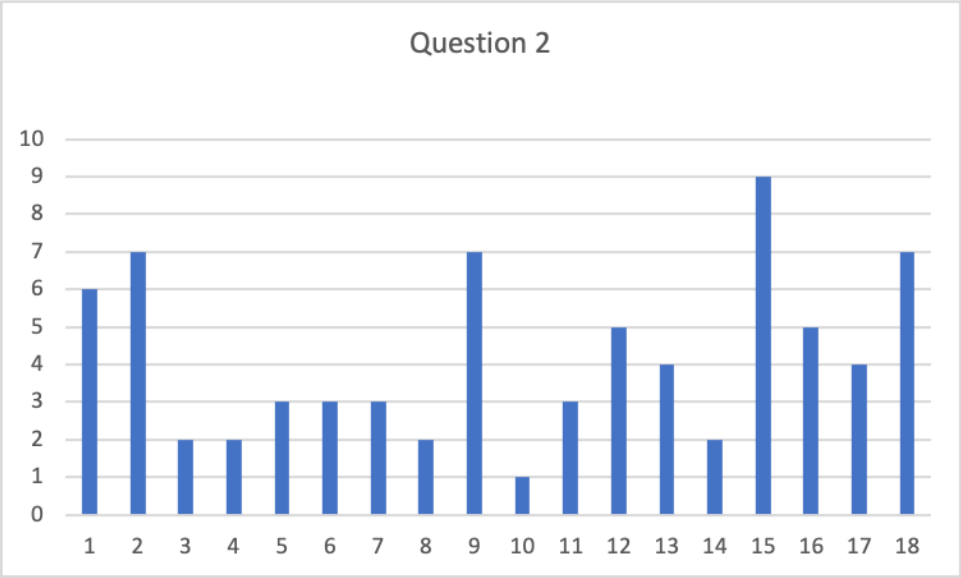

Figure 4 – Question 2 of Helsinki 1

The second question was answered by 18 students, just as the first one. The average of these 18 answers was 4.16 with the scale from 0 to 10. This question, showed a wide scale of answers. The largest margin between the answers was eight grades as respondent number 10 gave a grade 1 and respondent number 15 gave a grade 9. One remarkable notice is that respondent number 10 was among one of the three respondents in Question

1 with the best overall grade of 7. However, respondent number 15 was also among those three in Question 1.

In the second question, only four answers provided grades of 7 or over and seven answers gave a grade of at least 5. 50% of the respondents gave a grade of 3 or lower and more than 55% with grades of 4 or lower. The scale of answers was wide in Question 2 which might be connected to the fact, that Question 2 is more concerned with students' own opinions of the lecture and less with technical "facts" such as how the equipment worked. This might also explain the wide scale of given grades with many lower-level grades, but also a few high ones. Students' attitudes, interests and expectations are likely to be important factors when giving grades which means that a student with less interest in such a project might give lower grades if something is not working perfectly, while a student with high interest can still really enjoy the lecture.

The average of 4.16 is quite low and lower-level grades are more common than higher scores. This could implicate that some issues have existed that have made the experience less enjoyable than the students would have expected.

4.3.3 Question 3

Did you find the live stream more interesting than a traditional lecture?

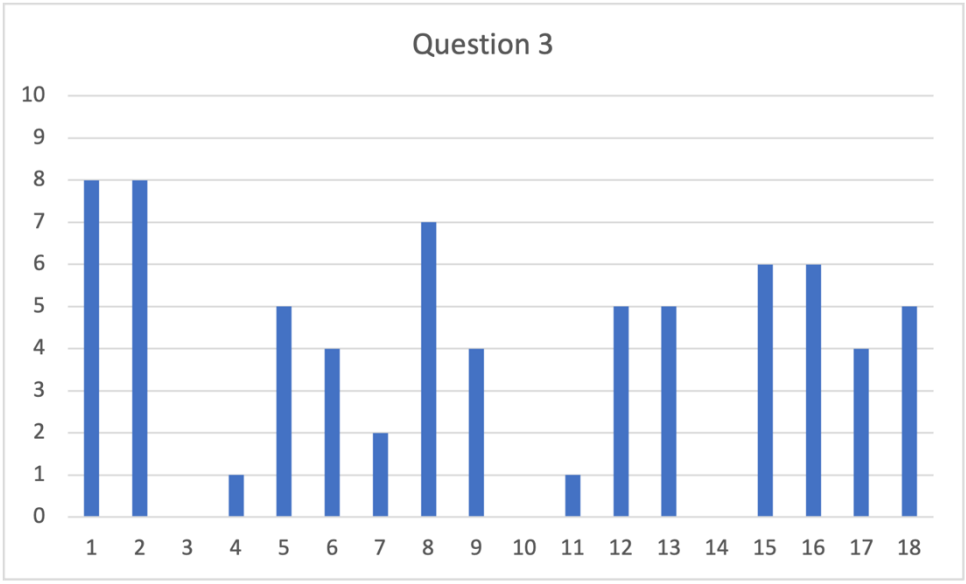

Figure 5 – Question 3 of Helsinki 1

Question 3 had 18 answers with an average of 3.94. Question 3 could be seen as the most important of these three questions as it measures if the students are more interested in this type of lectures than in traditional ones.

There are three grades of zero among the answers which could be a result of one of two factors: either the respondent has not answered at all, or the given grade is actually zero. In this case, the first of these respondents has given grades of 4 and 2 in the previous two questions. The second respondent has given grades of 7 and 1. The third respondent gave grades of 5 and 2. This could implicate that all of the respondents may actually have given grades of 0 to the Question 3, as both of their answers in Question 2 were really low. Also, there were two other answers with grades of 1 so this could also implicate that these are actually given grades from these respondents. If we assume that these answers were actually blanks, the average of 15 answers would be 4.73 which would obviously be a considerable improvement.

The answers in Question 3 fluctuated much. Five answers provided the grade of 6 or higher and nine answers with 4 or less. Also two grades of 8 and one 7 existed, which indicates that there were also students that would be clearly interested in this type of lectures.

The average of 3.94 is the lowest average in all three questions in Helsinki 1. However, several answers show inspiring grades as well. Remarkable is, that most of the respondents who gave good grades in Question 2, gave good grades in Question 3 as well which might be a result of these students' interest in the topic and their less strict approach to this type of technology and its possible issues. In Question 3, students' learning processes are also very important to consider as the question concerns their preferences on how they would like to learn: with traditional methods or with the new technology and modern teaching methods.

4.3.4 Feedback and summary

The combined average from Question 1, Question 2 and Question 3 in Helsinki 1 was 4.49. All three questions were answered by 18 students, which resulted to 54 unique answers when combining all three questions. The combined average of the three questions was lower than in any other experiments. However, Helsinki 1 was the first lecture given with the new technology and it can have significant impact on students' answers, and how

the actual stream worked in terms of equipment and connections and other key features that are making the stream enjoyable to watch.

Feedback

The students were able to give feedback of their opinion on how the stream worked and how they feel on if this technology could be used in the future studies. Below are the most frequent comments from the students:

- 1st: Problems regarding the voice of the stream

The most common problem among the students' answers was that there were significant problems with voice of the stream. There were comments on how the quality of voice was very poor and unstable. This is strongly connected to the second recognized problem.

- 2nd: FPS (Frames Per Second)

The FPS measures frame rate. If the frame rate of the stream is too high for the equipment such as portable screens or laptops that are mirroring the stream for the students, it will cause an unstable stream with many possible problems. In this case, the video and voice have not been totally synchronized, which resulted to that the image was moving ahead of the voice and has made the watching experience less enjoyable for the students in the classroom.

- 3rd: Unnecessary teaching method

There were few answers by the students that this teaching method is not needed to replace the traditional methods. It is very difficult to find reasons behind this feedback, but most likely it is connected with the first two as the whole experience has not been on a level the students would like it to be.

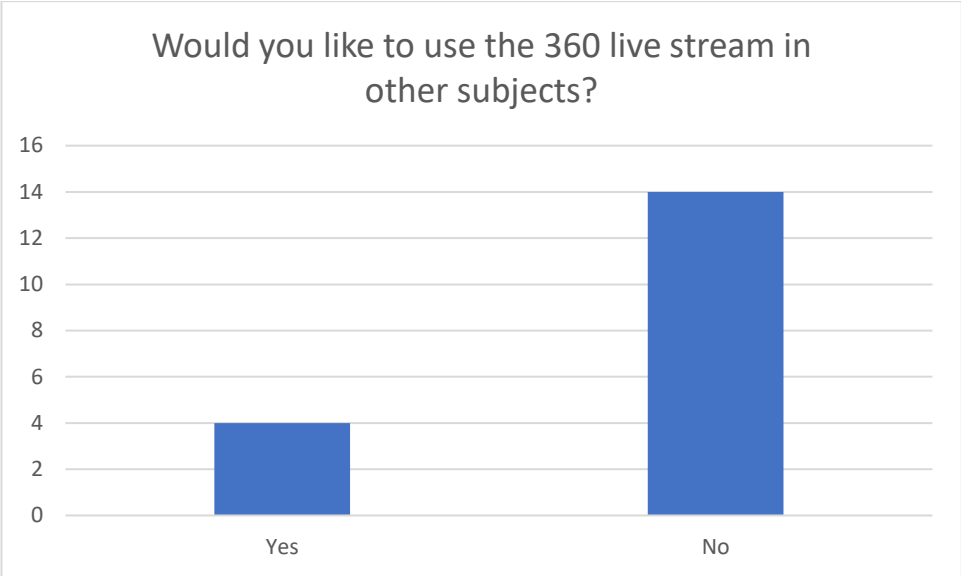

Figure 6 – Question 4 of Helsinki 1

When asked on if the students would like to use this teaching method in the future in other subjects, the results are clear. 14 of the 18 students answered "No" which means that over 75% of the respondents would not be interested in using the 360 live streams in the future. Obviously, since the first experiment was not that big of a success in terms of the stream quality, it is definitely noticeable in these results as well. We can see in the upcoming analysis of other experiments that there is a clear connection between the learning experience and how the stream worked.

Summary

All of the results presented above are clearly stating a fact, that several technical issues existed in this first experiment. Since there were no previous experiments, no gathered results, no student feedback and other data that could have been used before the first stream to improve the numbers, there are no reason to think that this experiment was not successful. In terms of the students' learning experience, it might not have been the best lecture, but it gave important data on how to improve in the future live streams.

The problems with voice and unstable stream caused many students to give out low grades which is totally understandable. Most of these young students have used all kinds of devices for their whole life and they are used to a well-functioning technology. Even though the average of 4.49 can be seen as a bottom-level result, it is not that poor of a result. If there were nothing but issues, and students were completely frustrated

with the stream, the average would be much lower. Also, there were approximately 25% of the students that would like to use this technology in their lectures in the future, despite of its technical problems during the first experiment. Improving the issues with the voice and FPS, the results are likely to look a lot different.

4.4 Helsinki 2 (10 students)

The topic of the lecture was to virtually introduce Aalto University and its different possibilities for the upper comprehensive school students. This lecture was part of media art studies. Aalto University is a respected Finnish university with over 17 000 students. Since the watching students are studying in school, which is mainly focusing on media studies, it was also a virtual presentation of Aalto University's media studios and other working spaces.

4.4.1 Question 1

How easy was it to use all of the necessary equipment?

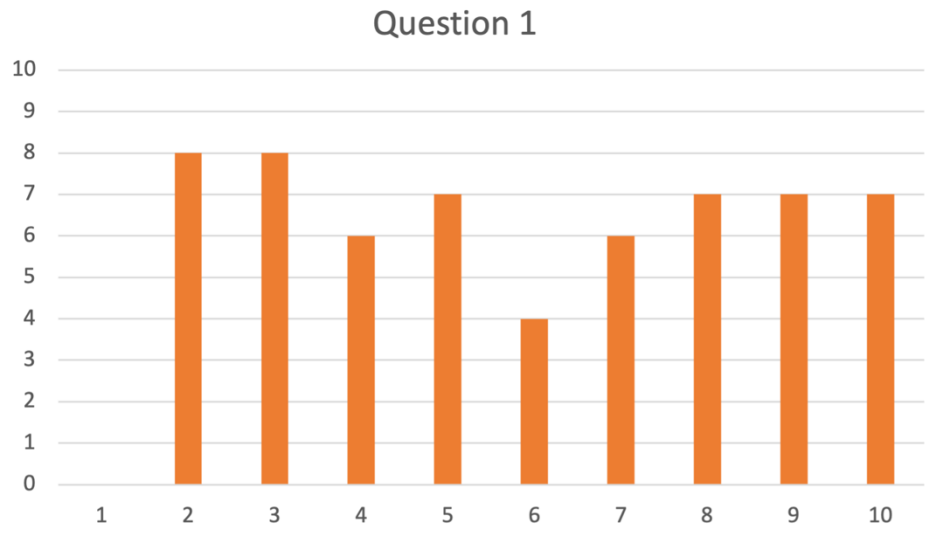

Figure 7 – Question 1 of Helsinki 2

In this experiment, a total of ten students gave answers to the questionnaire. It was among the most popular experiments regarding the number of answers. The average from these eight answers in Question 1 was 6.0 with one zero, which can be either blank or an actual grade.

If we forget the one zero, all answers are between 4 and 8. The most popular grade was 7 with 4 answers out of nine grades. There are also two eights, two sixes and one four and without the one grade of zero, the average would rise to 6.6. Overall, when students are asked about easiness of using the new technology and equipment, they are most likely unfamiliar with, having the average over 6 is an excellent result. However, there are also couple grades of 4, which indicates that some of the students have not found it as easy as most of the other students have. Obviously, with the technology, which is much based on connection and internet speed, there can be some kind of interruptions or disconnects which can explain the lower grades in certain situations.

Apart from the one zero, there are no grades under four and only two under six. The results indicate that there has not been significant issues with the equipment, and everything worked quite smoothly in terms of adapting the different teaching method.

4.4.2 Question 2

Did you find the stream pleasant to follow?

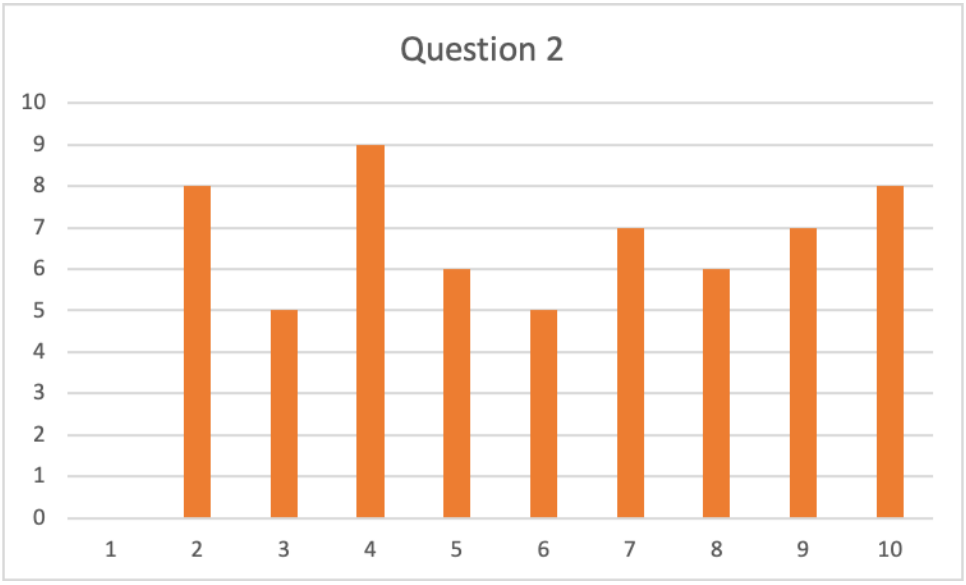

Figure 8 – Question 2 of Helsinki 2

The same number of students answered to the second question of how pleasant it was to follow the live stream. The average out of ten answers was 6.1 with one grade of zero from the same respondent than in the previous question. The respondent has given an

actual grade in the Question 3, which could indicate that these zeros in the first two are also grades. Still, it can also be possible that the respondent has just skipped the first two questions or forgot to give out grades for those two. Again, without the zero, the average would be 6.78.

Question 2 followed a similar pattern with the Question 1. In Question 2, all the answers were between the grades of 5 and 9 excluding the one zero. Nine answers consisted of one nine, two eights, two sevens, two sixes and one five. From these results, we can clearly see that the students were able to enjoy the stream, as almost all of the grades are closer to the top grades than they are to the bottom ones. The level of the average in this case is decent as we must remember that most likely, it is the first time the students are trying this kind of learning methods and it could be confusing or difficult to follow for many if the stream was not working that well. Therefore, we can assume at some level that the flow of the stream has been really good and there have not been many problems that would have affected the stream and the students' learning process.

4.4.3 Question 3

Did you find the live stream more interesting than a traditional lecture?

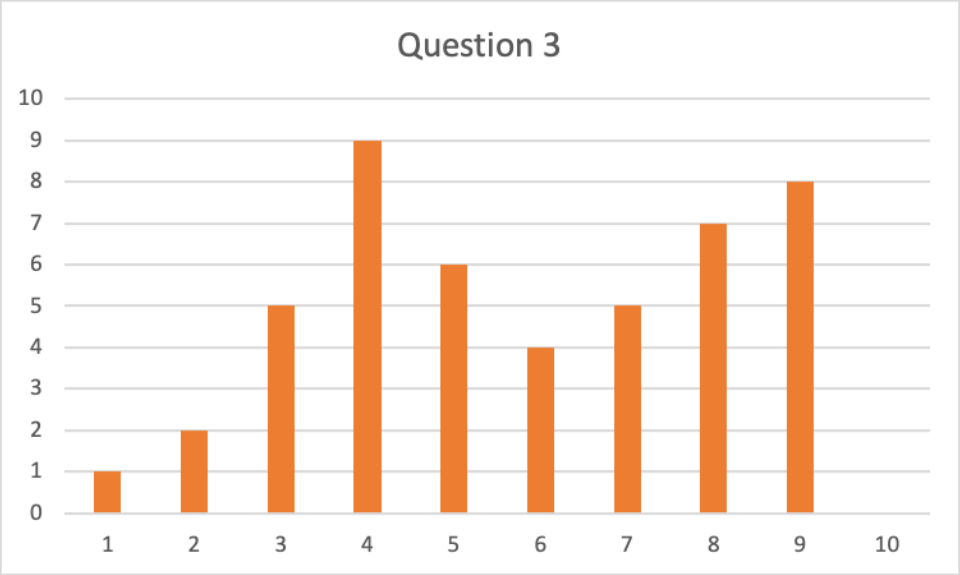

Figure 9 – Question 3 of Helsinki 2

In Question 3, there was one zero as well, but it was from another respondent so in this case we cannot be sure if it is an actual grade or if the respondent just left it blank.

The average of the answers for Question 3 was 4.70 with a zero and 5.2 without it. Typically for Question 3, the grades are more spread around the scale than in the Question 1 and Question 2. Question 3 is more about the students' own opinion on whether they like this teaching method more than the traditional lectures. The bottom-half grades consisted of one 1, one 2 and one 4. There were also two fives followed with one 6, one 7, one 8 and one 9. When comparing to the Helsinki 1's Question 3, similar fluctuation can be seen also in Helsinki 2.

When analysing the results from the Question 3, the important factor is to compare the third grade with the previous two grades from Questions 1 and 2. Often it seems to follow the same pattern, where good grades in first questions are followed by a good grade in Question 3 but it is not necessarily so. For instance, respondent number two gave two grades of 8 in previous questions and gave a grade 2 in third and thought that this type of teaching method is not better than the traditional teaching methods. However, the other respondents who gave good grades in the earlier questions seem to be more interested in using the technology in their future studies.

Again, the average of Question 3 is also remarkably lower than the averages of Question 1 and 2. Similarly with the results of Helsinki 1, it was common that students who gave better grades in first two questions were more interested in this type of lectures and it also backs up the thought from Helsinki 1 that these students could be more receptive to the minor technical issues if they are more interested in learning with new methods than their fellow students. Obviously, both Helsinki 1 and Helsinki 2 are quite similar experiments with a little different topic, which can mean that these results are somehow following the similar patterns.

4.4.4 Feedback and summary

The combined average of Question 1, Question 2 and Question 3 was 5.6 in Helsinki 2. The questions were answered by the total of ten students so there are 30 unique answers included in the combined average.

Feedback

The students were able to give feedback and Helsinki 2 produced a lot of comments by the participating students. Three of the most frequent comments are showed below:

- 1st: Quality of voice

Similar issues appeared in Helsinki 2 than which existed also in Helsinki 1. The students gave most feedback on how the quality of voice was changing during the stream and some of the students just mentioned a poor quality of voice.

- 2nd: Unstable connection

This follows the same pattern than Helsinki 1 and is connected with the voice problems. There has been issues with the connection, which has caused changes in the stream quality and made the experience less enjoyable for the students.

- 3rd: Nice lecture with interesting topic

Despite of the issues showed above, there were several comments of that the lecture was nice and the topic was interesting. One student also added that it was nice to be able to watch the tour remotely and see all the premises with this technology.

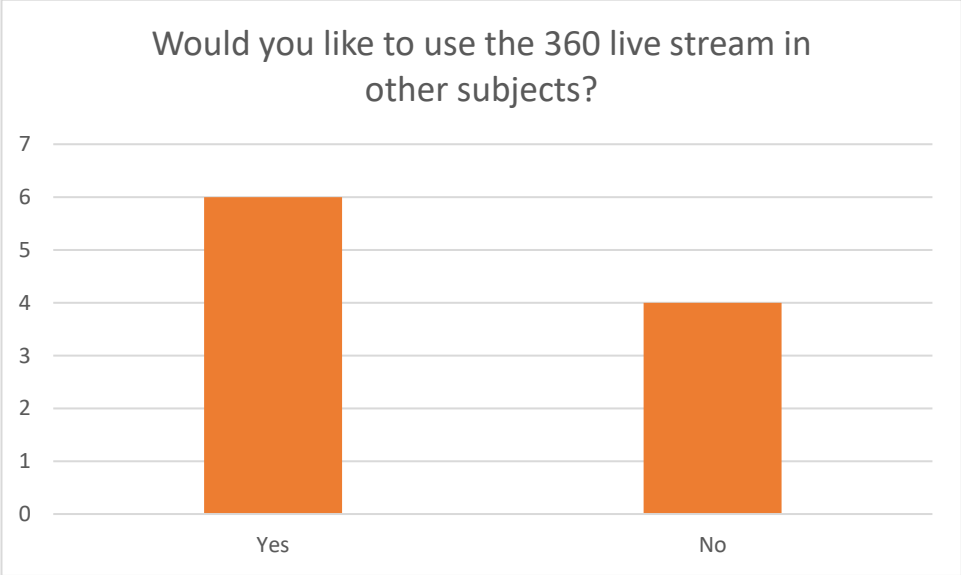

Figure 10 – Question 4 of Helsinki 2

In Helsinki 2, more students were willing to use this method in the future than ones that would not. 6 out of 10 students answered "Yes" when asked about their preference on whether they would like to use the live stream in other subjects. In Helsinki 1, 75% of the students were not interested in participating to the future lectures with live stream teaching, which means that there was a complete turnover when comparing these two

experiments, as 60% of the students in Helsinki 2 are interested to use the live stream also in their future studies.

Summary

The average of 5.6 indicates that there was an improvement of more than a grade when compared to Helsinki 1 (4.49). Despite of the similar issues with the quality of stream and voice, the results were better than in the first experiment. Therefore, it could be assumed that the problems were not as major as in the first one. Obviously, the difference might also be that there were different students with different opinions on this technology but either way, it is a great improvement from the first one.

A noticeable point seems to be, that the topic of the lecture seems to have a significant impact on how the students feel about the lecture. In the first experiment, there were few comments on how the topic was not interesting, which most likely had an effect on the grades of these students. In Helsinki 2, the effect was completely opposite as there were multiple answers on how interesting the topic was. This seems to be a reason on why the results were better in Helsinki 2 than the results in the previous experiment. It also shows that there seems to be more factors on how the students are giving out the grades than just the actual factors of the stream itself. Obviously, these assumptions make the analysis even tougher since the answers are not seeming to be completely related only on the different factors of the stream and used technology.

4.5 Helsinki 3 (8 students)

The lecture of the topic was very different when compared to the other two live streams since it was streamed from an atelier of a Finnish artist and the main idea was to introduce the workshop of the artist and the students were able to ask questions and interact with the well-known Finnish artist. There was also an introduction to clay and ceramic art.

4.5.1 Question 1

How easy was it to use all of the necessary equipment?

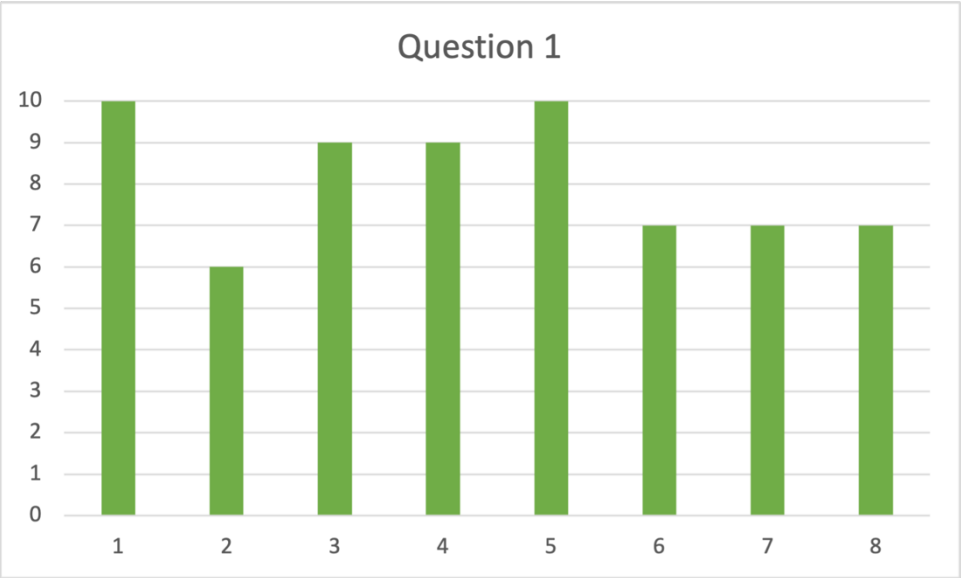

Figure 11 – Question 1 of Helsinki 3

Helsinki 3 was answered by eight students and all students answered in all three questions. The average of Question 1 was 8.1 which is an excellent result. The average consisted of one six, three sevens, two nines and two tens, with no grades under 6. The average of Question 1 is so high that we can assume that there were only minor issues with equipment in this experiment, if any issues at all. Two grades of nine with two tens cover half of the respondents, so at least 50% of the respondents had their equipment working as well as it should.

Since the equipment is used for the virtual reality and live streaming, having such a high average grade is even better than in many cases as the technology and equipment is almost entirely based on how the connection works and even small issues can cause major disappointments in the following live audience. An important fact is also that much of the millennials and young students are very used to different devices and technology, which can lead to the higher expectations as they are used to the well-functioning systems and devices. In this sense, the results are on a remarkable level in this experiment.

4.5.2 Question 2

Did you find the stream pleasant to follow?

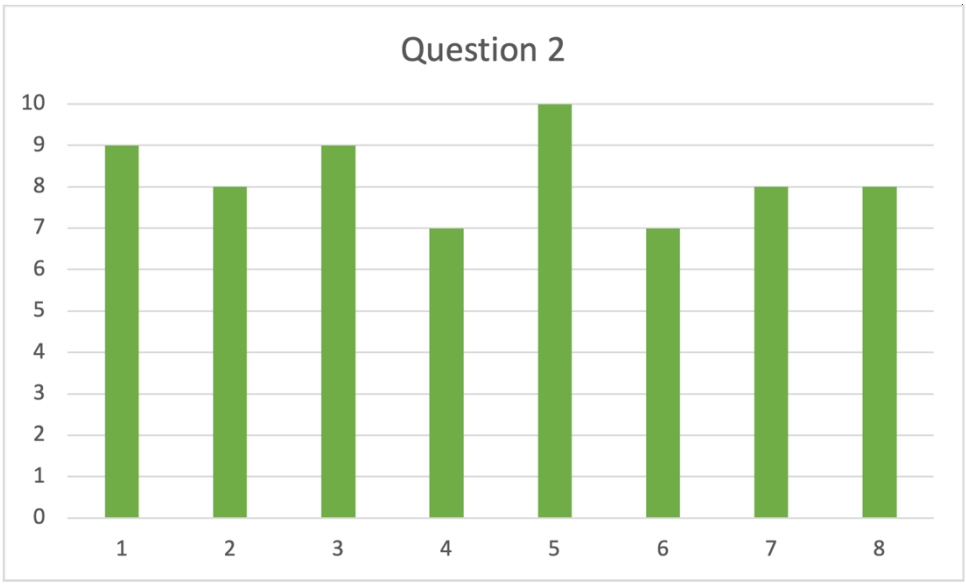

Figure 12 – Question 2 of Helsinki 3

The total average from the eight respondents in Question 2 was 8.25, which means that the average was even better than in Question 1. The average consists of one ten, two nines, three eights and two sevens. Obviously, after receicing great results in the Question 1, it was most likely to receive such results in Question 2 as well since these questions are proved to be connected together.

Without having a working infrastructure (Question 1), the results would not be this good in Question 2. It can be seen from the previous Helsinki 1 and Helsinki 2 that if there have been some issues with the equipment, also Question 2 often follows the same pattern. This can be seen from the fact that it varies between the respondents, as ones with better experiences in Question 1, have usually given better grades in Question 2 and vice versa. Similar pattern is not necessarily there between Questions 2 and 3, as even if the respondent thinks that the stream was easy to follow, it does not mean that the student thinks that it is a better method to learn than the traditional lectures are. Having such a high average is also a good sign in terms of the students' learning process. If they find the live stream easy to follow, it could mean that they are also following it with more caution, which could produce better learning experiences when compared to the situation where everything is not working that well, stream is difficult to follow, and they lose their concentration to the lecture due to these issues.

4.5.3 Question 3

Did you find the live stream more interesting than a traditional lecture?

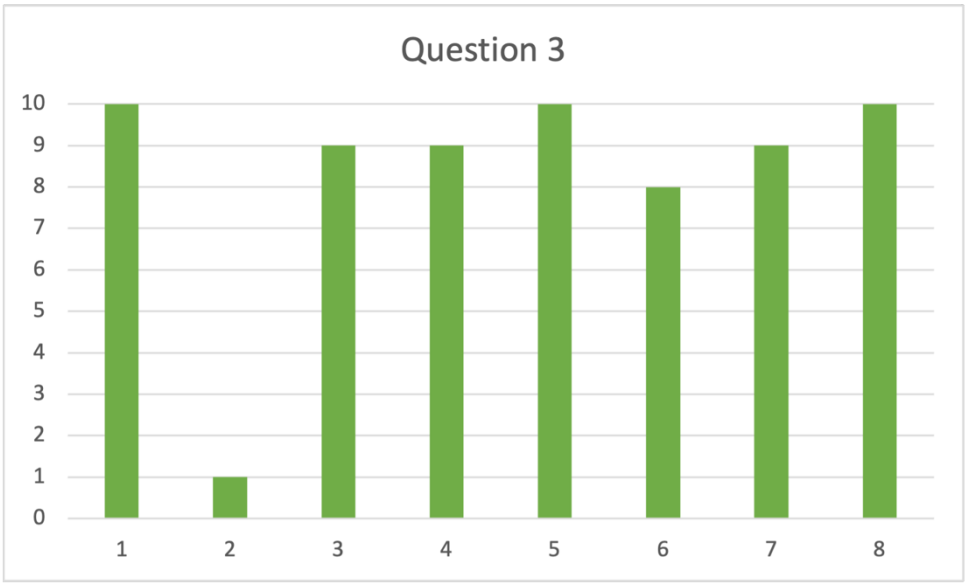

Figure 13 – Question 3 of Helsinki 3

The average of Question 3 is exactly the same than in Question 2, 8.25. However, the biggest difference between these two questions is that in Question 3, there is a grade of 1 which is by far the lowest grade in any of the three questions of Helsinki 3. The third question of if the students prefer these teaching methods over the traditional ones has been the most fluctuating question in all experiments in Helsinki.

However, this is the first where a gap of this size between respondents appears. There is one grade of 1 and all the other grades are 8 or higher. The respondent who gave the lowest grade has given a grade 6 and a grade 8 in the previous two questions, which could imply that the respondent is simply not that interested in using these teaching methods over traditional ones, even though it seems like everything worked quite well for this student as well.

If we leave out the one grade of 1, the average would be 9.28 which is close to perfect, and it is very hard to find any flaws in terms of how students felt about the lecture and if they are interested in using similar methods in their learning processes in the future. Even if the average is the actual 8.25, it is so high that we can say with confidence that these students are definitely ready to use the methods in their future studies. Whether their actual learning is better or worse with these methods than it is with traditional methods,

that information might be available in the future after gathering more data with bigger samplings.

4.5.4 Feedback and summary

The combined average of Question 1, Question 2 and Question 3 in Helsinki 3 was 8.2. Eight students gave answers in each question so there were 24 unique answers in total.

Feedback

The open feedback section was not that popular in Helsinki 3, but it gathered some interesting feedback to look at. Three feedbacks are introduced below:

- 1st: Quality of the video could be better

Despite of the excellent combined average in Helsinki 3, there has still been some room to improve in terms of the video quality. It is not totally clear from the feedback according to the quality of video, that if it was about the video resolution or some other aspects in the video. However, we can assume that it is about the screen resolution. In all of the other experiments, there has been comments on how the voice and video are not totally synchronized. In Helsinki 3, there is only a few comments on how the video quality could have been better.

- 2nd: Interesting and enjoyable lecture

This feedback was received as many times as the first one. It is completely in line with the great results that were noticed already in the answers of the first three questions.

- 3rd: Possibility to use own devices (missing)

A student gave feedback that it would be nice to use own devices to watch the live stream. As we know, there has been experiments where this has been possible, and these experiments have gained excellent results. A proactive feedback from the students only backs up the fact even more, that this could be the most popular form of the live stream teaching, at least at the moment.

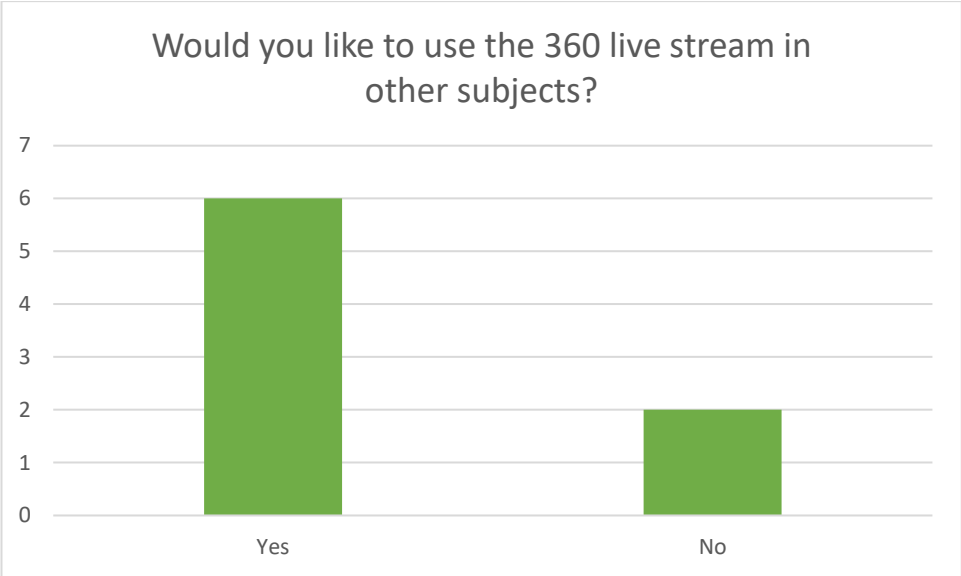

Figure 14 – Question 4 of Helsinki 3

Similar results followed in the fourth question. Six of the eight total students (75%) answered "Yes" as they would be interested in using the technology in other subjects as well. Two of the eight (25%) students answered "No" in the same question. It is the highest percentage when comparing with the first two experiments of Helsinki (Helsinki 1 and Helsinki 2). Obviously, there are also fewer answers in Helsinki 3 but when comparing the percentage, it can be considered as the most successful experiment in the city.

Summary

The results of Helsinki 3 are remarkable. When comparing the combined average of Helsinki 1 (4.49) and Helsinki 2 (5.56), there is a massive improvement in the results of the third experiment of Helsinki. The combined average of Helsinki 3 was 8.2, which means that there is an improvement of 2,64 grades in the results. Also, the average of 8.2 is already in the level where it might be very hard to improve it even more, as there seem to be always a few students in the classroom who are not that interested in certain method of teaching. However, in this experiment, there were even couple comments on the quality of the stream which means that there are still ways to improve the learning experience. According to the results, major issues with the voice and video quality are not showing up in this third experiment. These problems were mainly covering the first two experiments' feedback section and it clearly stands out in the averages as well. Fixing these problems seem to have a positive impact of over 2.5 grade, which can be considered

as a major improvement in the results, and also shows how the overall experience of the students was much better than in the previous two lectures.

4.6 Turku 1 (11 students)

The topic of the lecture was a virtual tour from the Central Fire Station of Turku. The purpose of this tour was to introduce the used equipment, services and personnel from the department. The actual tour was held in approximately 50 metres high as cameramen, city workers, equipment and fireman were lifted up with the fire truck. The students were able to see the fire station from above and it was a unique opportunity to explore city of Turku from air.

The live stream was sent with a wireless 5G-router, a 360-degree 8K camera and a portable microphone and it was sent via Elisa's streaming software to the participating schools.

4.6.1 Question 1

How easy was it to use all of the necessary equipment?

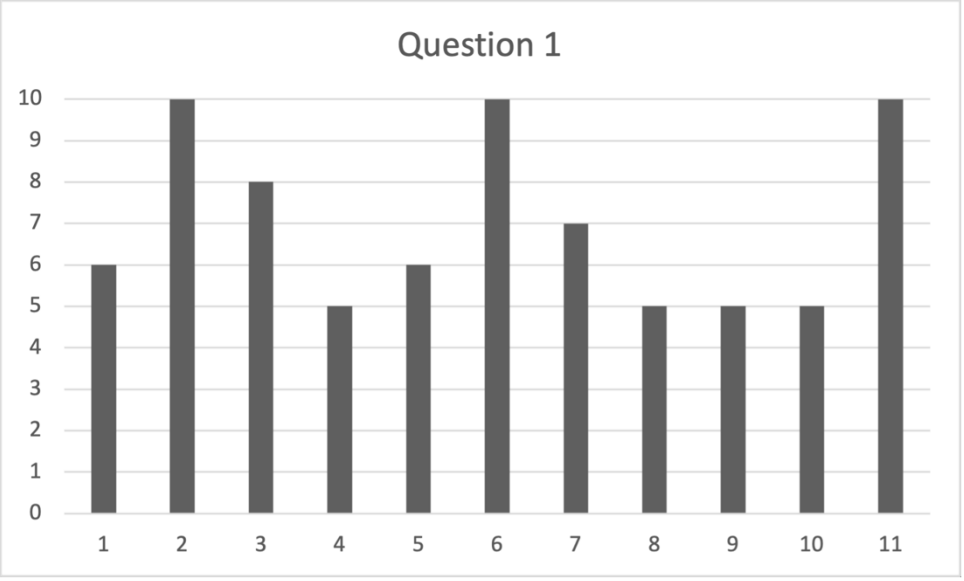

Figure 15 – Question 1 of Turku 1

Turku 1 got answers from total of 11 students. The average of the Question 1 was 7.0 which consisted of three tens, one eight, one seven, two sixes and four fives. All eleven students answered to all three questions.

The first thing that pops up from the results of the Question 1 is the three tens, which is more than in any other experiment from Helsinki. However, results of this question have some more fluctuation than we have seen in previous results from Helsinki regarding the Question 1 as there are three tens, but also four fives, and these two grades are the two most popular selections from the respondents.

Even though there are three tens given by the respondents, there are more grades below seven than over it, which means that all the students have not been as thrilled than the others have. This could be explained by the factor that maybe the used equipment such as the VR-glasses have not worked as well for all the students to encourage them to give higher grades. These devices are connected to the network, which always means that there is a possibility that the connection is not as stable for everyone and there might be network problems that do not affect all of the students in similar ways.

Overall, the average of 7.0 is a really good number. It was the first experiment made in Turku, so despite all the testing before the stream, there can always be something that the team has not prepared for, or what was working well in the testing phase before the lecture.

4.6.2 Question 2

Did you find the stream pleasant to follow?

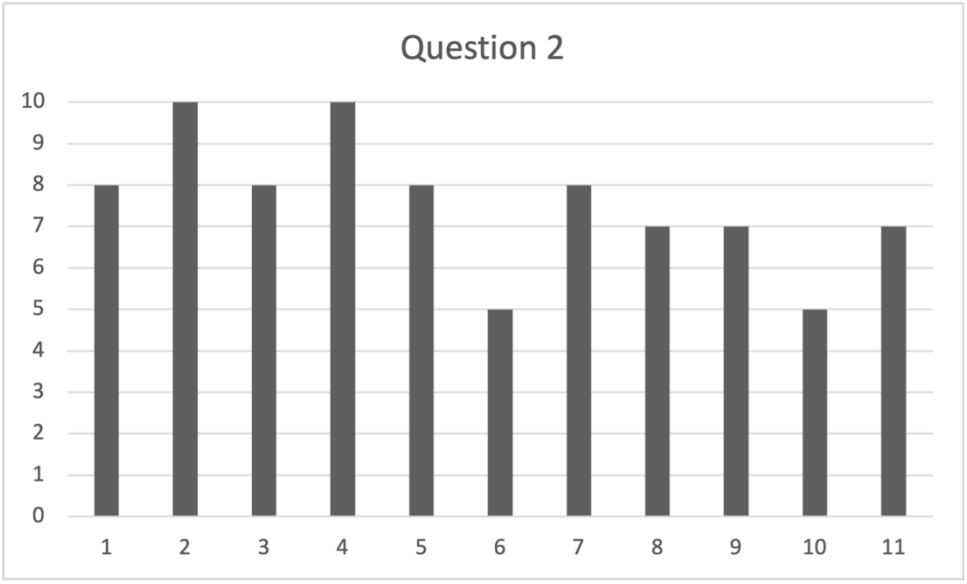

Figure 16 – Question 2 of Turku 1

Second question of Turku 1 was answered by eleven students and the average of this question was 7.54. The individual grades given were two tens, four eights, three sevens and two fives.

Out of the eleven individual answers, nine of them were grades of 7 or over which is a remarkably great result. Question 2 is about how much the students enjoyed watching the stream, and from the results it is clear that most of the students did enjoy it. There were no grades under five so even the lower grades were in the middle of the scale.

When comparing the results with the ones gained from Helsinki, the results of Turku 1 are really good. Only the third experiment from Helsinki did slightly better in Question 2 than Turku 1, which was a first experiment done in the city. Obviously, there are many reasons behind students' opinions on whether they enjoy the stream or not, and all of the reasons are not necessarily connected to the actual stream and its performance, but with the students' own thoughts on this kind of streams and their own personal interest on the topic.

4.6.3 Question 3

Did you find the live stream more interesting than a traditional lecture?

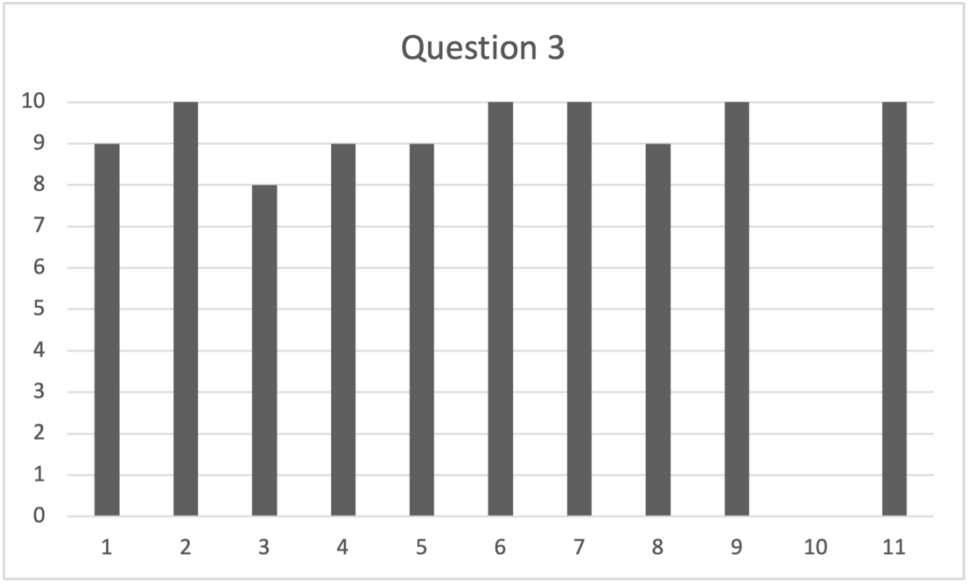

Figure 17 – Question 3 of Turku 1

The average of Question 3 was 8.54 from the eleven grades given by the students. It is the highest average of all questions in all experiments so far. The average consisted of

five tens, four nines, one eight and one zero. Without the one zero, the average would be 9.4, which is almost as high as it could be. However, it could be assumed that in this case, the respondent has actually given the grade of zero since the first two grades from the same respondent were both fives, and the respondent has given the lowest grades in the previous two questions when compared to the other respondents.

Overall, there is not much to analyse in the results of this question. Ten students out of eleven gave excellent grades and would clearly be excited to use this teaching method in the future. All of these students found it more interesting than traditional lectures. One student did not feel the same way with the others, which can be assumed as a personal opinion towards this technology and way of teaching, since there should not have been many issues with the equipment or other parts of the stream as all the other respondents were enjoying the lecture.

4.6.4 Feedback and summary

The combined average of the first three questions in Turku 1 was 7.69. Eleven students gave answers in all three questions so there are 33 unique answers in total.

Feedback

Turku 1 received some answers in the feedback section, even though it was not really popular. Three of the most popular answers are introduced below:

- 1st: Good / ok

Having positive feedback as the most popular comment is always a great sign. It can be assumed, that if there were some issues or room to improve in the experiment, these have not been that major that it would have created a negative experience for the students.

- 2nd: Slight interruptions in the stream

There have been some problems with the voice and video quality during the live stream. In this experiment, the equipment was lifted approximately 50 meters up in the air as the fire station was introduced from the air. This type of test brought out interesting results when discussing about technology and equipment, and its effectiveness. These are analysed more deeply in the section of technology analysis later in this thesis.

- 3rd: This technology to be used in geography studies

This comment appeared three times in the feedback section from the participating students and it is something to consider. The geographic studies with a possibility to watch something from your own device and being able to control the directions to watch to and so on, could be a really interesting and effective learning method for the students. There are a lot of interesting things around the world and in the nature so it could be something to try in the future.

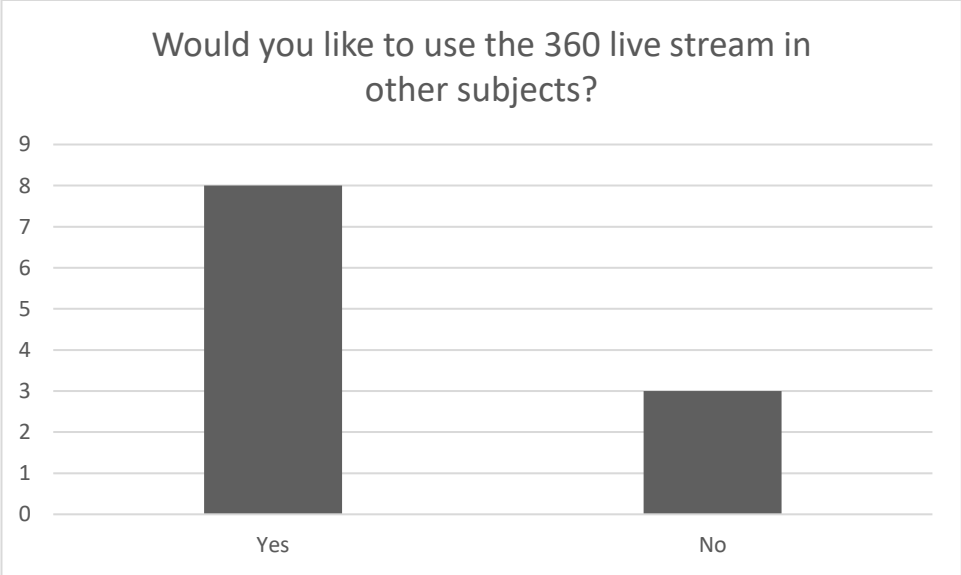

Figure 18 – Question 4 of Turku 1

Eleven students gave answers in the fourth question. Eight of the respondents (73%) were interested in using the method in other subjects in the future. Three of the eleven students (27%) were not interested in further experiences with the technology. As this is the first experiment of Turku, the results are really good. The combined average of 7.69 and 73% of the students interested in this teaching method compares well with Helsinki 3, which was the best experiment in Helsinki, in terms of the results and grades.

Summary

Turku 1 achieved excellent results as a first experiment done in the city. Obviously, it cannot be fully compared with all the previous experiments, as the camera and other equipment was lifted to the air with the fire truck, which strengthens the signal very much and was not the case in other experiments. However, it is very important to have such

experience and to be able to compare the results to find out which kind of actions can be carried out to improve the quality of the stream.

4.7 Turku 2 (8 students)

The topic of the lecture was to introduce a historic church in Turku, "Turun Tuomiokirkko". A worker of the church gave a tour around the church and explained all the relevant facts about the church's history and events during the last 900 to 1000 years.

The live stream was sent with the wireless 5G-router, the 8K 360-degree camera and the portable microphone. However, in this experiment, the quality was lowered to the 4K resolution and the actual live stream was sent via YouTube. With YouTube, the students were able to test and watch the tour with their own devices such as tabloids and mobile phones.

The link to this live stream was also spread out around the schools of Turku and it was also published in the city's web site. The feedback was still gathered only by the participating schools and personnel in this project.

4.7.1 Question 1

How easy was it to use all of the necessary equipment?

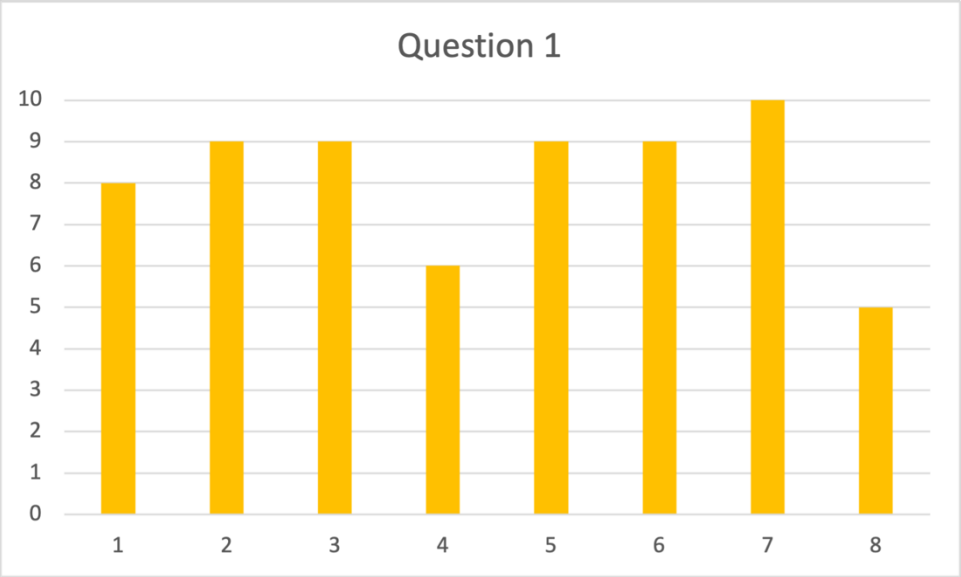

Figure 19 – Question 1 in Turku 2

The second experiment of Turku was graded by eight students. All of the students were older than in the other experiments as the participating school was a vocational school, which means that the students were at least 16 years old. The average of Question 1 in Turku 2 was 8.125. The average includes one ten, four nines, one eight, one six and one five.

The average of the Question 1 is on a respectable level. This experiment differed from the others as some of the students were watching the stream from home and some were physically in the classroom. There is no data on whether the student that answered to the question was watching remotely or in the classroom, which means that we cannot compare these two factors in their answers. However, when the average is this high, it most likely indicates that there were no major technical problems among the group of students.

In this experiment, the students were able to use their own devices to watch the live stream. Therefore, comparing the results with other experiments is slightly different. Luckily, the overall grades in other streams have been quite good as well, as if the grades would have been worse, it could mean that the reason is the equipment provided by the team working for this project. Now, we can assume that the equipment has worked well enough in all of these different circumstances.

4.7.2 Question 2

Did you find the stream pleasant to follow?

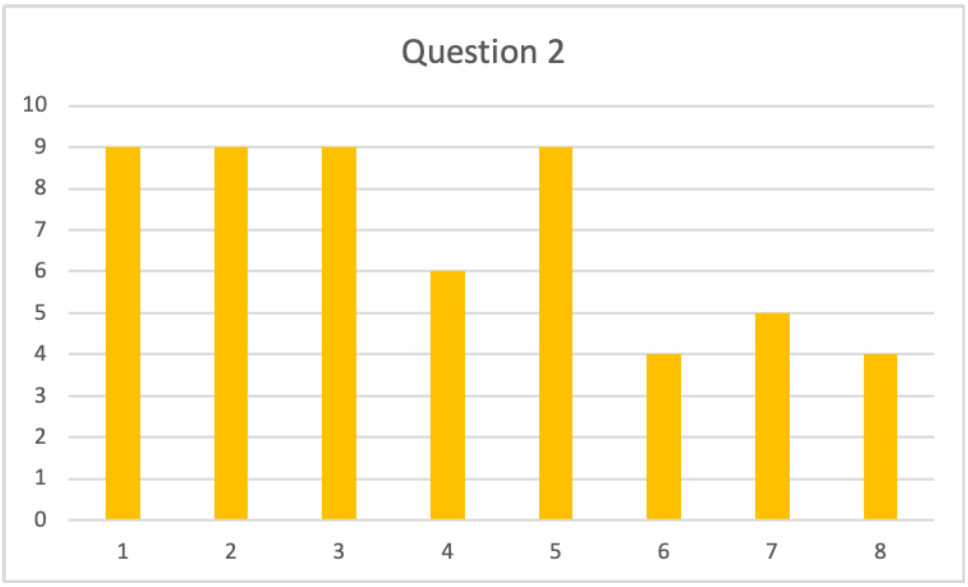

Figure 20 – Question 2 of Turku 2

The same eight students gave grades for Question 2. The average from these eight answers was 6.8. The average included four nines, one six, one five and two fours. It is lower than in Question 1 but still a decent number.

As usual, the second and the third question are showing more fluctuation between answers. All of the answers are between five grades in both of the questions, but in the Question 2, there is four excellent grades (9) and four lower grades (4 to 6). The important notice is that the respondents 6 and 7 gave grades of 9 and 10 in the first question, but these grades were then followed by grades of 4 and 5 in Question 2. This could indicate that even though the equipment and the live stream was working as expected, they did not enjoy following the stream that much for some reason. Both of their grades were better in Question 3 and it could be connected to the fact that they think that the setup is good, and this teaching method is usable, but it was not a right lecture or an interesting topic to teach this way.

All of the other grades were similar with the first ones and most of the students seemed to enjoy the stream if they had given good grades in Question 1.

4.7.3 Question 3

Did you find the live stream more interesting than a traditional lecture?

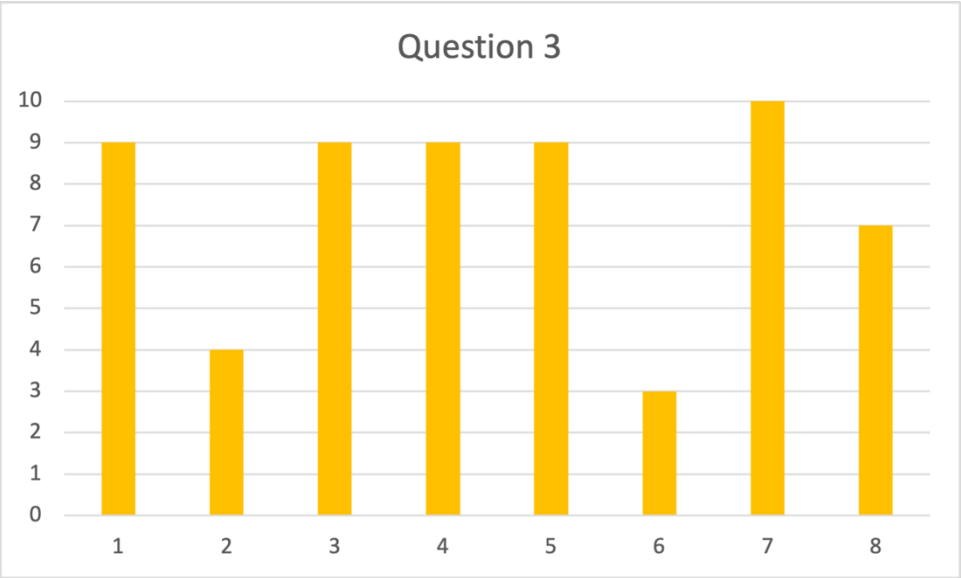

Figure 21 – Question 3 of Turku 2

Question 3 had the average of 7.5. It consisted of one ten, four nines, one seven, one three and one four. Overall, the average is higher than in Question 2 and six of the eight students gave grades of at least 7, which is an inspiring result.

As it was already mentioned in the previous sector, there were big differences on how some of the students were answering between the first two questions. Apart from the respondent number 7, all of the grades were following similar patterns with the previous question. Remarkable is, that most of the students gave good grades in all three questions. Gaining good results in all questions in this kind of experiment indicates that the live stream has been well produced and executed and there have been only minor problems, if any problems at all.

For the few lower grades, it must be remembered that some of the students might not like this teaching method when comparing to the traditional methods or they are not interested in the topic of the lecture, which can have effect on their grades.

4.7.4 Feedback and summary

The combined average of Question 1, Question 2 and Question 3 in Turku 2 was 7.475. There were total of eight students that gave answers to all questions so there are total of 24 unique answers in Turku 2.

Feedback

Turku 2 got a very few answers to the open feedback section, but still a few comments that should be pointed out.

- 1st: Good and well-functioning system

Among the total of eight students, five of them gave answers that were related to the good and working teaching method. It is an excellent result as this experiment was made in the vocational school and part of their studies to the profession, and if there were many problems with the teaching method, it can be assumed that the results would look very different.

- 2nd: Could be used in the remote studies

Several students thought that this technology would suit the remote schooling purposes really well. These comments are really promising since this is one of the main ideas behind the whole project that this equipment and knowledge could be used in remote schooling purposes in the future. Especially, during these times with the pandemic, these are very promising comments from the students as they are proactively saying that this could work well in remote studies. Some of the students were already following this stream remotely, but we are not able to identify these students from the answers/grades.

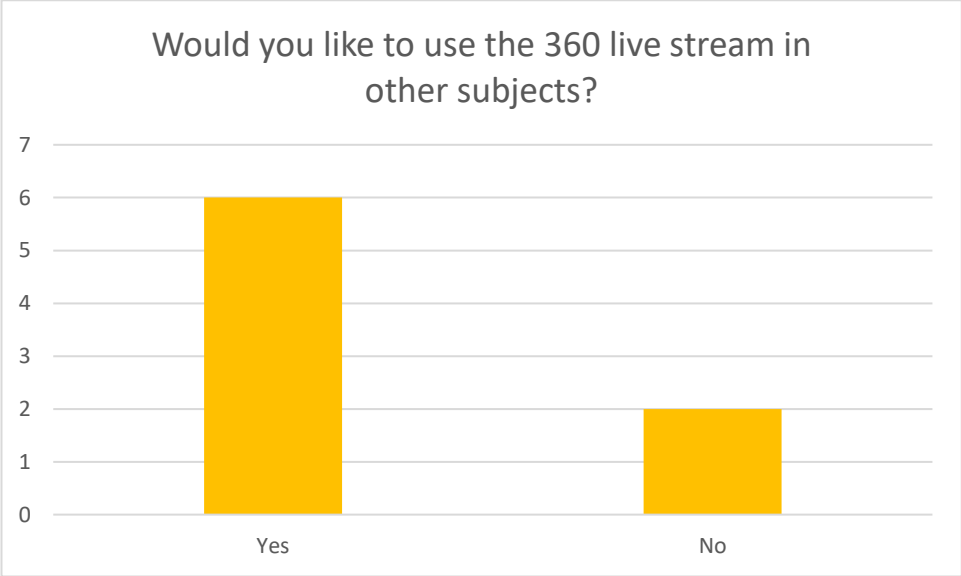

Figure 22 – Question 4 of Turku 2

Total of eight students answered in the fourth question. Six of the students (75%) would be interested in using this teaching method and technology in other subjects and two

students (25%) are not interested in similar future experiments. Once again, the results are excellent in terms of the percentages. It would be interesting to find out, how the small number of answers is impacting the percentage, and if there more answers, would the results be better or worse. Unfortunately, in this experiment, we do not have a possibility to gain more answers. Overall, the results can be seen as great since the experiment was made in the vocational school and the students are older, more experienced and chose to study this subject, which most likely also means that their interest is more likely higher in all lectures than it is in a compulsory level of school.

Summary

The combined average of approximately 7.5 and 75% of the students willing to participate in similar lectures in the future, is an impressive result. In this case, it must be considered that these students are already studying for the profession, which means that they are more likely also more interested in the lectures and could also have slight impact on why they enjoy the lecture. With the younger students, there has been some results indicating the fact that they are giving lower grades as they are not that interested in the topic of the lecture. To some distance, we could be able to assume that this effect is lower in this particular experiment and therefore the lecture and its results should be seen as really successful.

4.8 Analysis of used technology and equipment

In this section, we are trying to identify the different issues and problems during the live stream experiments. We are also attempting to solve these issues by finding reasons causing these problems and suggesting solutions for the future experiments. All of the issues gathered in this section are related to the used equipment, connections or other technology-related factors.

THE ISSUE: Voice and video problems (not in sync, interruptions etc.)

SOLUTION:

The issues with the voice and video were faced in several experiments, especially in Helsinki 1 and 2, and also in the experiment in Turku, which was not featured in the question form analysis since there were not enough answers to use. When comparing

these three experiments with the successful experiments, there are few solutions to these issues.

The internet connection must be very stable and big differences in the connection speed during the stream can cause several problems. This was identified in Turku, where we had to cancel the planned experiment since the connection was not stable enough. An unstable connection caused total disconnections and major issues with the voice and video.

These problems also appeared in the experiments where the 8K-quality was used, and the receiving devices were not able to handle the continuous requirements of this high-definition live stream. The best example of this was in Turku, where Huawei IdealHub (portable screen) was used. Screen's FPS was not high enough for the 8K live stream and it caused major issues with the quality of voice and video.

The issues were much lower in Turku 1, where the live stream was sent from outdoors and the equipment was lifted up in the air. The signal and speed of the internet in the sending site was much better. An opposite example was the cancelled experiment in Turku where the signal was too weak in the indoor building and it was not possible to send the live stream for more than couple minutes before it got disconnected. This backs up the basic assumption that outdoor objects are much easier for the current equipment and technology.

THE ISSUE: Virtual reality glasses did not work (disconnections and other problems)

SOLUTION:

There were some issues with the VR-glasses in several experiments, but these were mainly connected with the issues of connections and internet speeds. However, in one of the participating schools, the VR-glasses needed to be taken completely off from the students as the glasses did not work for more than a minute at once. This issue was tried to be fixed with internet speed tests, software updates and other actions but we were not able to identify the reason to this problem. Internet speeds were similar with others and software were up to date but still the glasses did not work as they should. The most likely explanation is that there was something wrong with this pair of glasses, even though it was not anything obvious.

THE ISSUE: Issues with the FPS

SOLUTION

Frames per second -issues appeared in several experiments. In some schools, the mirroring devices were not able to completely meet the requirements of the stream and it caused issues where the stream was delayed or buffering. These issues were also identified in one school in Turku, where Huawei Idealhub -screen was not able to keep up with the 8K- live stream due to its lower FPS. In this case, there is a simple fix. The problem is solved by using the device with enough capacity to meet the requirements of the high-definition live stream. At the moment, it is not that easy, especially in the educational environment as many of the schools do not have that type of equipment.

THE ISSUE: Video quality (low resolution)

SOLUTION

There were several comments in the feedback sections that the quality of the video was not as good as it could be. We identified this as a low resolution -issue, which means that the video quality is lower than it is expected to be. In this project, the idea was to send the 8K-quality, which is extremely high when it is working as it should. The devices that are able to mirror the 8K-quality as it is sent, are still quite rare which we can also see in this experiment. In many experiments, the quality of the video was really good but not necessarily in the level of the 8K, as schools' devices were not able to completely mirror that quality.

These comments are still more likely related to the issues with the changing connection when moving around the sending location, which caused issues with stable connection and led to the lower quality video and the voice problems. This could be solved by finding and testing a proper location with a high signal and a stable connection. The perfect result would be achieved by a good location, a strong and stable connection and a receiving end with devices that are able to meet the requirements of the high-definition live stream.

Summary

When discussing the functionality of the used technology and equipment in all experiments, the results are really inspiring. Obviously, there were some flaws and issues,

especially in the first couple experiments, but overall, the technology worked well considering that this was probably the first time in the world, that something like this was tried. As we can see from the results, the best overall experience for the students was still achieved with the 4K-quality and the ability for the students to use their own devices, as the current equipment in the participating schools were much more ready to receive the live stream in 4K-quality than they were to receive it in the 8K-quality, which is still extremely high and demanding quality for current equipment.

Some issues with VR-glasses and FPS were detected, which are most likely a result from the lack of stable high-speed internet connection as well as the devices that are not entirely build for receiving such high-quality video than the 8K-video is. Still, it is an important result to find out that the actual system and software are working reasonably well since the devices are getting better and better all the time as they are being developed by the manufacturers. Due to this development, we can expect major improvement in this technology in the upcoming years. However, issues with the FPS in certain locations caused major problems for the students trying to follow the lecture and that is something that needs to be fixed as the objective is to challenge the traditional teaching methods and if the students miss out some of the sentences, or other important aspects, it will not be ready to use on a daily basis. These issues are simply fixed by the connection of devices with the necessary capability in both ends, sending and receiving.

The changes of the equipment in the different locations and the different experiments which gave us important insight on which of the combinations worked really well and which had the most issues. Using this data and knowledge from the experiments, we can create suggestions on what type of equipment and what kind of crucial aspects we have to consider to be able to create a live stream with the best possible outcome. Later on, in this thesis, we are discussing more on the identified working solutions for the live streams to be sent in the future and also on how to improve the results even more.

5 CONCLUSIONS

5.1 Possibilities for the 5G high-quality 360-degree live streams

The research question 1 was “What possibilities does the new 5G 360-degree high-quality live stream offer?”. Through the results we gained from the experiments made in both cities, we are able to identify successful experiments and reasons behind them as well as the possibilities on where this technology could be implemented in the future.

Teaching and learning purposes

The ultimate purpose of the research was to gain insight and feedback on how the students feel about the technology as a teaching method, if they are willing to continue with these methods also in the future and obviously, if the technology works well enough to be used in the lectures.

Due to the global pandemic of coronavirus, most of the students were aimed to the remote learning, which has caused a massive impact on educational systems and future learning methods. Teachers, students and other members of the school society were forced to perform a quick transformation to the remote studying, which also led to a growing demand for the useful and effective remote-teaching methods. An education theory professor Eero Ropo from the University of Tampere believes that the remote studying will remain as a big part of the study program also after the pandemic. He also mentions that the technology is already capable of transferring the information effectively to the students, but the school lectures are also a big part of the growing process of the students, and it brings out the new challenges of the remote schooling. Testing and choosing the different remote teaching methods is very important to remain the same level of education than in traditional lectures. (University of Tampere 2020.)

The experiments were executed in the perfect time, in terms of the global need of developing the new teaching and learning methods. In four of the five experiments, the students were more interested in using these methods in the future than to not use, which is a promising basis for the future development of the teaching methods. From these results, we can make an assumption that many of the students are interested in challenging

the current methods with new and modern technology. The feedback section also received many comments that the students would like to follow the lectures with their own devices such as laptops, tabloids or mobile phones, which most likely would be quite easy to manage, especially in the future when the used technology evolves more into the devices in the common use.

Often, as a part of the study schedule, students are taking trips to the certain locations to visit different places connected to the certain subject. Obviously, these trips are usually not free, and they require resources such as money and logistics to perform, which means that it varies between schools that how often students have the possibility to have such lectures. In this experiment, there were multiple different locations that were introduced for the students. With this technology, students are able to visit the locations virtually without moving away from home or school. This could bring decreases on costs as the only investment is to acquire the necessary equipment for the students. It would most likely improve the number of different lectures arranged for the students which could cause increased learning motivation or increase students' interest to certain subjects. For instance, students could have access to explore world's most famous locations in geography with the virtual reality glasses or take a virtual tour around the most visited museums from their home.

The experts from around the world are expecting virtual reality to become more and more popular as a part of the teaching and learning process. Microsoft, Google, Amazon and other companies are investing to their development of the VR, which indicates that the overall costs are likely to be lower in the upcoming years as more people will gain access to the VR around the world. Many universities have already taken steps towards to an approach where students are taught via different experiences instead of the traditional theory lectures. (EHL.edu 2021.)

The similar technology (lower quality or 4G) is already known to be used in study purposes, especially in the medical studies. The doctors are able to send the live stream over the network to the students watching real-time at their home or school. With the new improved technology with the 5G and the 8K-quality, the quality of these remote lectures could be improved a lot, which could have impact on their results on how the students are learning without them actually being in a procedure room themselves.

The virtual reality and its massive potential are expected to be a groundbreaking transformation to the global school system. The results of these experiments are indicating that the students are mainly ready for the change and the required technology is already on a decent level. However, the implementation of such technology into a school infrastructure requires resources and a lot of tests before it can be actually considered to be a permanent part of the study program.

Possibilities in Finnish cities

The cities of Turku and Helsinki were the two participating cities where these experiments were executed. The results of the experiments in both of the cities have introduced several possibilities that could be developed further in the future and used to improve different functions with the help of the new technology.

As the development of devices with the 8K-technology and high FPS is continuous, and will be more common in the upcoming years, it is likely to introduce many different options where cities are able to use modern digital tools to improve their functions, or at least give out an option to the traditional methods that are currently used. With widen coverage of the 5G-network, desired internet speeds and requirements for smooth 8K-technology can be soon reached. The modern technology provides another perspective to the traditional methods and ways of doing.

Events

As the term of "Virtual Reality" already indicates, the idea of the system is to be somewhere without actually being there. We have already seen VR-based traveling where people are able to virtually visit cities and other locations using their smart devices. Similarly, this idea could be implemented to the events that are arranged by the cities.

Due to the global pandemic situation of Covid-19, one of the main celebrations of the year for Finnish people, the May Day and its parties around the country were not able to take place in 2020. From VR's point of view, it introduced a new way to celebrate and arrange events, even though people were not allowed to move physically from their homes. The best example was introduced by Finnish rap duo called JVG as they performed a live concert with a green screen technology. The city of Helsinki usually celebrates the May Day at the market square. With the green screen technology, the

Finnish duo performed in a way that it seemed like they had been outside at the market square as they were actually in large hall with the green screen. The hashtag #virtuaalivappu was seen over 11 million times in social media which is nearly twice the number of Finland's population. There were over 54 000 unique viewers on the website and through all the attention in media, the event reached possibly over 18 million readings. (PingHelsinki 2020.)

In a similar sense, all this could be done without the green screen technology. Having the actual high-quality 360-degree camera in the city event would mean that anyone could follow the event from home and feel as close to being present as one possible could without physically being there. This could be also used as an assistance for people who have disabilities or movement restrictions and are not able to physically go to the certain event. With the live stream, VR-glasses and working infrastructure, it would definitely be more enjoyable experience for many viewers compared to just watching it from the television or website.

In the future, popular live events such as concerts or sporting events could be streamed over the 5G-network with the 360-degree 8K camera. This could mean that fans could be able to watch the final of FIFA World Cup of Football from their own sofa with the camera placed somewhere in the stadium. For example, watching a football game where the camera is placed on a good place and being able to feel the atmosphere and watch the game with your VR-glasses in a similar way than actually being at the stadium, could become quite popular. However, this requires that the infrastructure is ready and able to meet all the requirements in terms of speed, latency and other necessary equipment. Similarly, music concerts could be streamed with several cameras placed in the audience and the fans could watch their favourite band or singer from anywhere in the world, just with their own laptops.

Tourism and traveling

The virtual tours for tourists and travellers are already a very common thing to see in many tour operators' websites. However, the current stage of virtual content for tourists planning their trip is nowhere near its full potential. Most of the attractions are offering videos and images at their websites but virtual reality is still quite rarely used. Obviously, using the virtual reality videos when most of the potential customers or tourists do not

have access to the working VR-glasses is not necessarily worth a while just yet. As consumers are becoming more familiar with the VR-technology and when common people get the access to the 8K-ready devices and higher internet speeds, there is a massive possibility to introduce Finnish cities and attract more tourists to visit Finland. One could argue that many tourists could be quite interested in visiting Finland after successful virtual introduction to the Archipelago of Turku at summer, snowy nature of Lapland at winter or intellectual tour around the museums, libraries and other interesting locations of Helsinki. With such virtual tours, there is a big possibility that the potential tourists would think that this is something that I need to see myself. Even though the current YouTube-videos and pictures can also be appealing, it could be assumed that an actual virtual reality experience would have greater impact for possible tourists.

5.2 Identified challenges and issues

The research question 2 was "What are the biggest challenges and obstacles in deploying the new technology?". The results of the experiments showed us several issues and challenges that need to be taken care of before being able to maintain the high-quality live stream and making the experience enjoyable for its sending site as well as its viewers.

Many of the issues reported by the students or the sending site were connected with the lack of stability of the internet speed or other issues with the internet connection. Obviously, the live stream relies completely on the internet connection and with fluctuation or other interruptions during the live stream, the quality of stream decreases and the effects are inescapable. In this project, all of the participating receiving ends had the needed speed of the internet. However, the actual fluctuation of the connection and the speed was an issue in certain locations in the sending site. It was also verified through the results and tests that outdoor locations were providing better and more stable connection than when filming indoors. As it is widely known, the connection is usually strongest when there is a minimum number of buildings or other obstacles blocking the signal. This was also verified in Turku 1 with a massive improvement of the quality when the camera and router were lifted up to the air while streaming. While 5G-network is still being built and strengthened, these issues with stability of the connection were expected but we can be happy with the small amount of these issues appearing.

When discussing the results of the experiments and the whole project, there was a big challenge with the required equipment to be able to experience the actual quality of such a high-definition video as the 8K. As the 8K-technology is still quite new and there are only a few devices that can actually meet the unforeseen requirements, it had to show up also in the results of the experiments in this project. For instance, in the participating school that I took part personally, many of the students were asking about the quality of the live stream as it was nowhere near the actual quality of 8K as was expected. This was mainly about the issue of FPS of the smartboard and the low resolution of the classroom's screen, but it describes the issue that was identified in several experiments that the receiving devices were not able to introduce the 8K-quality in a way that is expected when talking about ultra-high resolution. Obviously, it is a common issue as the equipment is still mainly in the development process and not available in a sense that we are used to with many other devices. To indicate this, Finnish price comparison software shows 11 results with keyword "8K TV" where "4K TV" gives out 649 results (Vertaa.fi 2021). Prices of these 8K TVs are starting from 1000+ euros and most of the devices have prices of several thousand euros which well emphasizes the rarity of these devices.

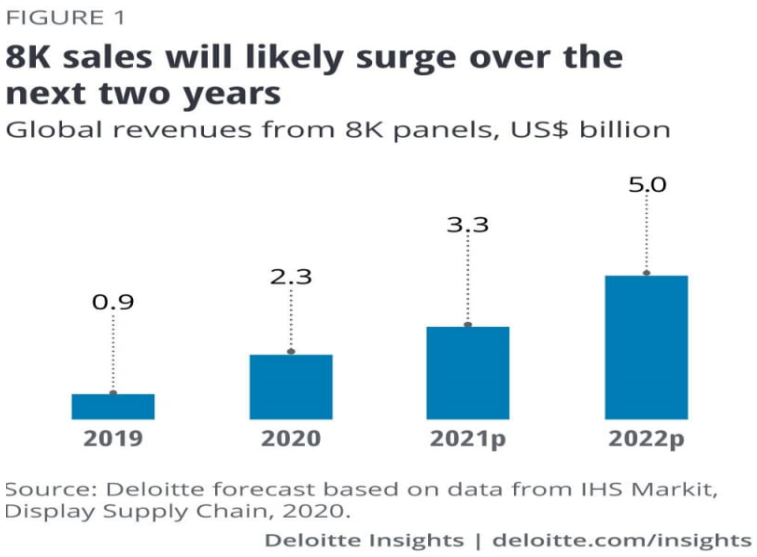

Figure 23 – Deloitte's 8K predictions

The figure shows Deloitte's prediction of 8K sales for the upcoming years. From the figure we can see that we are most likely facing a major increase in 8K sales between the years of 2021 and 2022. Additionally, Deloitte is predicting that 8K won't be that popular in the year of 2021 as the amount of content created in 8K-quality is still very low and

the costs of the devices are extremely high when comparing to the 4K-devices. (Deloitte 2020.)

According to the forecast of ABI Research, the 5G-network is expected to overtake the 4G at 2021 (RCRWireless.com 2021). Since the 8K-quality and its overtake of the 4K-quality is expected to be years away, it can be predicted that the issue of finding the right devices for such technology can last for few years. Due to the high costs and lack of content in the 8K-quality, we can expect that the 5G-network will be there for the 8K-quality well in advance, at least in Finland where the 5G-network is already covering a major part of Finland. When considering the live streaming, the development of the network before the devices could be seen as the right order, as the devices could be quite useless if the network is not powerful enough for offering the enjoyable user experience. Based on these forecasts and the results of the experiments of this thesis, we can assume that the 8K-quality live stream could be sent flawlessly via 5G in the few years' time after both of the factors have faced more development, especially the sector of the 8K-devices.

5.3 Students' changing learning experience

Research question 3 was "How does studying with the new technology challenging the traditional learning theories and the traditional learning environment?". Based on the results and the feedback of these experiments, it is possible to discuss on how the new technology and new learning methods challenge the traditional way of learning. The question is approached from the perspective of four different learning theories: Behaviourism, Constructivism, Humanistic learning theory and Connectivism. The analysis of changing the learning experience and environment should also be considered based on the results.

The new approach to the traditional learning theories

Behaviourism is an old and very traditional learning theory where learning is connected to positive experiences. The famous experiences of Ivan Pavlov's dogs and how they were able to widen their skillset with positive associations and rewards is a well-known experiment around the world. Despite of the theory being discovered over a hundred years ago; its basic idea can be connected to the modern way of learning as well. Actually, the question form provided to the students after the lectures, had a question, which measured

the willingness of students to try this technology again in other studies. It is deeply connected with behaviourism, since students with a positive experience are more likely to be willing to try the technology in future studies. This is also the main reason on why the results can be seen as very promising as approximately three of the four students were interested in trying the new teaching method again. When connecting this feedback with the behaviouristic approach of positive experiences, there is a considerable potential for such teaching methods to be used in the future.

The learning theory of constructivism focuses on students' different phases and different ways of learning. The children and youth have different ways to improve their knowledge and their skillset, and it is often based on finding their own way to learn. It is also proved by researchers that teaching with too quick pace can cause significant decrease in students' ability to learn. The new technology of 5G and 8K challenges the theory of constructivism in several ways. Are the students of the modern era of digitalization all familiar with technology and ready to use it as a teaching method? Based on the results of this project, many of them are, and with developed infrastructure, the numbers could be even higher. However, we are only able to measure the students' feedback on how they felt about these lectures and do not know much about whether they are actually learning more than with the traditional methods. As constructivism focuses on the different phases and stages of learning of the students, it needs to be considered when using the new technology as a part of their studies. Understanding the right phase of their development where this type of methods could be used is crucial in terms of creating a positive learning environment and improving the results of their learning. The children of today have been surrounded with different types of technology nearly their whole life, which might indicate that as the world moves more and more towards digitalization, finding the right phase of deploying technology as a part of the studies could also become easier.

The humanistic learning theory is based on one's ability to fulfil the individual needs and reach the part of self-actualization where one can feel that all needs are met, at least for a brief moment. The theory indicates that knowledge and skillset of the students will develop as soon as they are able to understand themselves and other students better. Leaning on this belief, they are able to build personal connections to their studies and to the certain subjects. The usual challenges are identified by wrong ways of learning (or by

the wrong teaching methods) and passive teaching. Humanistic learning theory seeks new ways to learn and believes in the self-guidance of the students. If we compare this basic purpose of the theory with the deployment of the new 5G 8K-technology, it could be seen as a potential match. The new technology offers a completely new way of learning and it could also be pointed more towards to the direction where students are able to use their own devices and control their own learning. This was also noticed in the comments by the students that participated the lectures and the best results were from the experiments where students were able to use their own devices. The humanistic learning theory is fairly recent, and it fits quite well in the ideal learning theory for this technology-based learning.

Connectivism is a learning theory where the connections between students are crucial in terms of their learning. Sharing thoughts and knowledge between the group of students can be a very rewarding and positive experience when executed rightfully. Encouraging students to use digital tools as a part of their learning process could have major positive impacts as we can see also from the results of this thesis. The majority of students thought that these types of lectures were more interesting than the traditional ones which indicates that they enjoyed the learning experience and the learning environment when comparing them with the usual ones. If the students feel that studying with certain devices or technology is more interesting, it might have positive impact on their motivation towards the studies and by that, towards their development in their studies. Having several students using their devices in a different way, could lead to more discussion, opinions and different perspectives to many matters which could also improve the learning environment for the whole group.

Based on these comparisons, a new approach to the learning with modern technology can be created. Below, these findings are brought together into an ideal learning theory for the way of learning that was covered in this thesis:

- A positive learning experience from the lectures indicates that the student is more likely to be interested in using such technology again. (Behaviourism)
- Finding the right phase for the students when to apply such technology as a part of their studies is crucial to prevent negative outcome (Constructivism)

- Future students are likely to be more and more responsive to the modern learning environment and methods as they are more experienced in using such technology also outside the educational environment (Constructivism)
- Finding the right (and new) learning methods for individual students to improve their learning and motivation towards their studies (Humanistic learning theory)
- Understanding the students' interest on using new methods to learn and using it to improve motivation and create positive learning experiences (Connectivism)
- Freedom for the students to be able to use digital tools in different ways to encourage discussion, opinions and different perspectives (Connectivism)

Combining all of these learning theories to build up a model which is more responding to the needs of the new learning methods of the modern era is very important, as societies and educational systems are facing drastic changes of digitalization. As the world moves forward, the traditional theories of learning need to move in that direction as well and become more suitable for future ways of learning. Using this new approach towards the learning of students will help to understand the individual way of learning and overcome challenges when all students are not responsive to the similar methods.

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