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Virtual reality for teaching geography

MASTER THESIS

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Abstract

This paper examines the use of virtual and augmented reality in teaching geography. The investigation is divided into several parts and was focused on the preparations for such activity, the selection of the appropriate applications, possible technical issues and limitations, side effects, and the improvement of geographical competencies. For the data collection, quantitative and qualitative methods were chosen. Quantitative research consists of several questionnaires and for quantitative research, interview and observation were used. The results show that this technology is interesting for students, and could help them in understanding some geographical processes and with visualization and imagination, and students would like to use this in the future during teaching.

Keywords	Virtual reality, augmented reality, teaching geography, virtual reality in geography, augmented reality in geography
Language	English

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Abstrakt

Táto práce zkoumá využití virtuální a rozšířené reality ve vyučování geografie. Výzkum je rozdělen do několika částí a byl zaměřen na to, jak se připravit pro takovou aktivitu, na výběr vhodných aplikací, možné technické problémy a omezení, vedlejší účinky a zlepšení geografických kompetencí. Pro sběr dat byly zvoleny kvalitativní a kvantitativní metody. Kvantitativní výzkum pozůstával s několika dotazníku, a pro kvalitativní výzkum byl použit rozhovor a pozorování. Výsledky ukazují, že tato technologie je pro studenty zajímává, může jim pomoci v pochopení geografických procesů, s vizualizací a představivostí, a studenti by uvítali její použití ve vyučování v budoucnosti.

Klíčová slova	Virtuální realita, rozšířená realita, vyučování geografie, virtuální realita v geografii, rozšířená realita v geografii
Jazyk	Anglicky

This thesis has been composed by Bc. Tomáš Krajňák MSc. for the Master's Degree Program in The teaching of Geography and Mathematics for Secondary Schools for the academic year 2021/2022 at the Department of Geography, Faculty of Science, Palacký University Olomouc.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

18.04.2022, Olomouc Tomáš Krajňák

Prohlašuji, že jsem diplomovou práci vypracoval/a samostatně s vyznačením všech použitých pramenů a spoluautorství. Souhlasím se zveřejněním diplomové práce podle zákona č. 111/1998 Sb., o vysokých školách, ve znění pozdějších předpisů. Byl/a jsem seznámen/a s tím, že se na moji práci vztahují práva a povinnosti vyplývající ze zákona č. 121/2000 Sb., autorský zákon, ve znění pozdějších předpisů.

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Zásady pro vypracování

Hlavním cílem práce bude popsat možnosti nasazení virtuální reality pro rozvoj geografických kompetencí žáků. V teoretické části práce bude provedena rešerše relevantních informačních zdrojů, jejíž hlavní náplní bude v obecné rovině popsat přínos technologie virtuální reality pro výuku a na konkrétních příkladech ukázat silné a slabé stránky využití této technologie ve výuce geografie. V praktické části práce bude vybrána vhodná aplikace pro virtuální realitu, pomocí které se student pokusí na žácích empiricky ověřit poznatky zjištěné v rešeršní části. V poslední části práce dojde k syntéze poznatků z předchozích dvou částí, na základě které budou navrženy určité postupy, jak pracovat s virtuální realitou pro dosažení co možná nejefektivnějšího rozvoje geografických kompetencí žáků.

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Freina, L., & Ott, M. (2015). A literatrure review on immersive virtual reality in education: State of the art and perspectives. In Proceedings of the 11th International Scientific Conference „eLearning and Software for Education" (eLSE), 1, 133-141.

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http://www.classvr.com

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AR	Augmented reality
VR	Virtual reality
HMD	Head-mounted display

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1 Introduction

When teaching geography, the lesson itself should be not only instructive and informative but also a bit cheerful. The teacher can choose various teaching methods or forms. Some of them are more interactive than others, in some cases, students even use some teaching aids which help them in learning and understanding. When the teacher does not want the students to be bored during class, it is possible to choose specific methods which could be helpful. This is also the case when the topic could be hard to understand. On the other hand, in some situations, it is a bit challenging to use standard methods and forms. When teaching things that are very hard for the imagination, the teacher does not have that many options on how to proceed. Description could take a long time, books did not provide many details in photos, and preparation of presentations could be demanding. Especially, in such situations, a teacher could choose virtual or augmented reality during the class. However, this technology is not new, in education, it is not that common, because specific devices are needed and a good preparation too. But it has many more advantages than a classic lesson. This thesis focuses on the possibility to use AR or VR in teaching geography.

Nowadays many people already heard about AR or VR, but usually, it was connected to the gaming industry, cinema, or driving schools. This technology is still not that known in education. It is slowly finding its way in the universities, but in elementary or secondary schools it is still an unexplored area. This is supported by Freina and Ott (2015), who found only one paper that described VR in elementary school between 2013 and 2014. But, in the last several years, AR and VR found their place in education and also in geography teaching. Some authors developed their geographical applications, some of them focuses on the existing ones and some concentrated on the comparison between classical teaching and teaching geography with AR or VR.

The teacher could choose from many various applications which provided detailed information about a particular topic not only in written form but also in 360° photos or videos. Students can travel to many different places around the world or even visit places that are impossible or very hard to visit. But, to use this technology, it requires very good preparation and knowledge of the technology. The selection of applications is crucial. Some are designated for AR, some of them only for VR, and some for AR and VR. But both types of applications have some strong points. Augmented reality is easier to use and

except for the mobile phone does not require any particular devices. Such applications can picture virtual objects in the real world on the mobile screen. On the other hand, the VR experience is only in the virtual world. A special headset as a holder for a mobile phone is needed. Such applications allow users to move completely outside of the real world into a virtual one. This, however, could cause some health issues and the teacher should take into account these possible side effects. In this thesis, I will also discuss several areas that are important to think about in advance, when including AR and VR in the teaching process.

Authors in the previous papers found a positive contribution of this technology in the teaching process. The most frequent were possibilities to switch between various types of maps, overlaying of virtual information in real-time scenes, control of the environment (see a specific situation from different angles, travel to various places), better visualization and imagination of some processes, in field studies, more effective teaching process, or in situations where students could observe environmental changes over years. Students were also more curious and were thinking more about the discussed topics which lead to more analytical and interesting questions. On the other hand, the authors also noticed several cons. Usually, they were connected to the technology itself – bad internet connection, technical problems with mobile phones or with applications. These problems then lead to stress or to a higher pressure on the teacher to manage everything during selected time slots. Last, but not least are also possible health issues revealed during the research. These side effects were mostly nausea, blurred vision, dizziness or eye pain, etc. In the thesis, I will concentrate on both pros and cons. The main goal of this thesis will be to investigate the use and the impact of VR and AR during the geography class, if this technology will have an added value for students, and if it will help them better understand particular geography topics. The secondary goal will be to describe some recommendations on how the teacher should proceed during the preparation and also observe if students will experience any side effects.

The rest of the thesis is organized as follows. Section two describes the history of AR and VR, the literature review, and the overview, of how this technology developed over the years and in which area it was used. Section three provides information about the methodology, data collection, applications, and devices selection, and the teaching process in the school. In section four I present results from the investigation and the last section provides the summary of the thesis.

2 Literature review

2.1 The definition of virtual reality

Nowadays, when we are talking about virtual reality (VR), we can simply imagine it as an environment, which is simulated on the computer or on a mobile phone, designed for an interaction between the person, who uses the VR and the computer itself. The main point of VR is to create a visual environment or experience for the person. The definition of VR is however not that unambiguous. At first, it is necessary to distinguish between two terms – augmented and virtual reality. According to Crofton, augmented reality (shortcut AR) is "an illusion where both virtual and real objects coexist in the same space"[1] (Crofton *et al.,* 2019). On the other hand, Crofton describes virtual reality as "an immersive human-computer interaction in which an individual can explore and interact with a three-dimensional computer-generated environment" (Crofton *et al.,* 2019), so we can say a complete replacement of the real environment. We can imagine augmented reality somewhere in the middle between the real world and the virtual environment. In some publications, authors also mentioned the term "mixed reality" – a situation, where fictive objects are inserted into the real world. Another author mentioned another term – "augmented virtuality" (Jerald, 2015). It is the opposite to augmented reality – it inserts real objects into the virtual world. Jerald also explained, that the whole concept was first described in 1994 by Milgram and Kishino and is called "The virtuality continuum".

Many authors define VR in many different ways. For example, "the ability of the user of a constructed view of a limited digitally-encode information domain to change their view in three dimensions causing update of the view presented to any viewer, especially the user" (Fisher & Unwin, 2002). Another author explained VR as:

"VR is characterized by the illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on three-dimensional (3D), stereoscopic, head-tracked display, hand/body tracking, and binaural sound. VR is an immersive, multisensory experience" (Gigante, 1993).

[1] Example of augmented reality could be a special display, which pictures some information that overlay the real world. So, the user sees two different types of images – real and virtual. Nowadays a typical example could be specific mobile application, where you use your mobile camera and on the display the application adds desired effects.

According to Blade & Padgett (2002), virtual reality (or virtual environment) is a "three-dimensional data set describing an environment based on real-world or abstract objects and data". They also explained that the name virtual environment is sometimes addressed to an artificial environment – because the user interacts with this environment.

2.2 The history of virtual reality

The term virtual reality (VR) is nothing new nowadays. We can find it in gaming, the real estate industry, movies, medicine, construction, education, or aviation. Many people got in touch with virtual reality when trying to get a driver's license. Many lectures started with driving simulators – a person sits in the box with the complete interior of the car and drives in a particular environment with particular conditions (rain, wind, fog, etc.). However, the term virtual reality is a well-known buzzword nowadays and we can see it in many different sectors, the origin of this term is almost two centuries old.

The history of virtual reality goes back to the middle of the 19th century and is connected with the machine called the *stereoscope* invented by Sir Charles Wheatstone. The design of this device consists of two mirrors, which reflected two images in the view of a spectator (Sherman & Graig, 2018)[2]. This device used only stable images and was stationary – it was mounted on the table. That is why it was not that serviceable for an ordinary user. Later, another famous inventor improved Wheatstone's stereoscope. Jerald (2015) explained, that David Brewster used lenses instead of mirrors and therefore was able to minimize the stereoscope to the size of a small block, which a spectator was able to put on his/her head and therefore it was portable and it could be used not only at one place. This device looks more like devices used nowadays.

Another breakthrough in VR came at the beginning of the 20th century and it is connected with US patent number 1183492 in 1916 by Albert B. Pratt for the so-called "head-mounted display (periscope)". Sherman and Craig (2018) described this device as something which was not a typical VR machine as we know it today, but it was more like a gun mounted to the top of the helmet with a small circle – some kind of a "display". While moving his head, a soldier was able to aim the gun (but also to fire). But still, there was no interaction between the user and the machine.

[2] More details about Wheatstone and his invention are possible to find in the Guest editorial by Nicholas J. Wade published in Perception, 2002, volume 31, pages 265-272, available online: https://journals.sagepub.com/doi/pdf/10.1068/p3103ed

Later in the 20th century, in the 1950s Morton Heilig described the "Experience theatre" – a theatre that simulates all of the senses of the viewer. Based on his visions he started a new project and in 1962 he built a device called Sensorama (Burdea & Coiffet, 2003). It was a simulator (arcade machine) in which a spectator could watch particular films with the ability to sense the smell, hear a sound, and feel. Earnshaw (2014) described one of the possible movies that a spectator could choose: a ride on a motorcycle in New York with the smell of the city and the wind. Although it was an interesting device at that time, it was not a typical virtual reality machine. However, the spectator could choose a particular movie, it was the only interaction that a person was able to do during the experience. Movies were prepared in advance and the viewer did not have any options to change something while watching them. But the spectator had the opportunity to see something, which could be impossible without this machine.

Heilig also had one very important invention "Stereoscopic-Television Apparatus for Individual Use", which he patented in 1960 (Sherman & Craig, 2018). It was similar to the head-mounted display patented in 1916, but more improved and included a special mechanism to see, hear, and also to feel something.

Jerald (2015) mentioned one very important milestone – the first telepresence system. A system introduced in 1961 by Philco engineers was compound of two parts – a head-mounted display with the orientation sensor and a camera that provided the final image. These two parts were separated and could also be in two different rooms and they used video signals for communication between them. When the user moved the head, the camera also moved and the spectator was able to see the video provided by the camera. Another important breakthrough was one year later when IBM patented the first glove input device (Jerald, 2015).

A big breakthrough came with Ivan Edward Sutherland. In 1965 he described the so-called *ultimate display* as a display in which the spectator can interact with the environment in a fictive world (Sherman & Craig, 2018). One year later, he and his student Bob Sproull followed Heilig's invention and created a new head-mounted display. Burdea and Coiffet (2003) explained, that their construction was, however, a bit heavier and therefore they attached the display to a mechanical holder. Because of such

construction, many authors started to call this system "the Sword of Damocles"[3]. It has on the other hand one big advantage – for the first time, they were able to install motion sensors so they can calculate the viewer's direction. In such a case, when the spectator moved with his/her head or whole body, the machine reacted to the movement and provided new particular images[4]. The device was also interesting because they used cathode ray tubes and because of this, they were able to provide separate images for each eye. Sutherland also predicted that new features will be added to similar machines, especially the haptic sensors[5].

At the University of North Carolina at Chapel Hill, Dr. Frederick P. Brooks followed Sutherland's invention and tried to adjust it for chemistry purposes (project GROPE). In the beginning, he was able to provide visual images of molecules, but later, as Sutherland predicted, he incorporated haptic sensors so he could feel the force feedback from the interactions of docking of simulated protein molecules (Sherman & Craig, 2018, Jerald, 2015). The scientist who operated the machine could watch the display and at the same time could feel the interaction between molecules. At first two-dimensional, but later also three-dimensional forces using robotic arms. Burdea and Coiffet (2003) pointed out that many of today's VR technology with haptic sensors use robotic arms but in a miniature version.

Not only individuals and universities were trying to bring new modern devices providing virtual reality, but the military was also interested in that field. The biggest issue at that time was to find a way how to train pilots – not only commercial but especially fighter pilots. In 1929, Edwin Link built the first flight-simulation machine for pilot training. This device provides the ability to train new pilots in the cockpit of the plane inside the building (without the necessity to fly for real). So, the training was much more secure for the pilot and the instructor, but also much cheaper (Sherman & Craig, 2018). Since becoming a fighter pilot could be very dangerous and stressful, it is not that

[3] Jerald (2015) explained, that the Sword of Damocles is named after the story of Damocles, who was a courtier in the court of Syracuse in Sicily. His king Dionysius offered Damocles to switch places for one day, so Damocles could try to be the king with every advantage of it. But since the king was vigilant and during his reign, he met a lot of bad people, he arranged a big sword hanging about the throne held by a single hair of horse's tail. This symbolized the power of a king but also the caution during the reign. At the end, Damocles begged the king to switch places back and realized that the higher the power, the higher the danger.

[4] In this case, the image was provided by computer graphics and did not need a camera, not like in Philco engineer's invention, where they used video signal to move the camera.

[5] According to an Oxford Dictionary, the haptic sensor is "a technology that stimulates the senses of touch and motion" (https://www.lexico.com/en/definition/haptic)

easy to train such pilots for real fighting situations. Therefore, armies were trying to bring a new technology, where pilots could be trained without really getting into fighting situations – something like virtual reality based on head-mounted displays.

The big break in that field was made by Tom Furness from the US Air Force Armstrong Medical Research laboratory (Gigante, 1993). He was motivated to work with VR because of the complexity inside the fighter jets. It was not easy to control the jet and fly and at the same time fight. He wanted a device in which the pilot would be able to aim just with the movement of his head (something like an invention by Albert Bratt). That is why he followed the previous work on a head-mounted display but focused more on the helmet. He also worked on a special cockpit for pilots' training (similar to Link). His "Super Cockpit" was introduced and operational in 1986 and included also display mounted on the helmet. The display provided much information based on the direction, where the pilot was looking in various styles – 3D maps, radar images but also information about the plane itself, like how many missiles are left for fighting (Sherman & Graig, 2018).

NASA was also interested in VR mainly because of two reasons: the training of the astronauts and the simulation of microgravity. NASA had two possible ways how to do it, but both were not completely ideal for such training. Therefore, they focused more on VR. They developed a system called VIVED (Virtual Visual Environment Display) in 1984. Jerald (2015) explained the construction: a mask for scuba divers adjusted for this use and equipped with two pocket TVs. In later development, they added also gloves for the ability to control the simulation. NASA also specialized in visualization in specific situations. They constructed a Virtual Wind Tunnel which allowed us to watch the flow of the smoke around many different digital objects, mostly airplanes, and space-shuttles (Mazuryk & Gervautz, 1999). Later in 1990, NASA's two employees founded a new company and two years later they released a new VR system called CAVE (Cave Automatic Virtual Environments). Visual execution, in that case, was completely different than in other systems, because the system projected images on the walls. But still, the user had to wear special glasses to see the projection. The big advantage of this system was that more than one person could watch the projection (Sherman & Craig, 2018).

Virtual reality in the following years spread also into the culture, architecture, and adventure parks. In 1997, a special CAVE virtual reality system was opened in the Electronic Art Museum in Linz, Austria. It was available also to the public, where people could see virtual worlds made by artists. Similar technology was also used next year at the Swedish Royal Institute of Technology, or in Orlando, where Disney opened DisneyQuest, which was a special center for families. They planned to open three such parks, unfortunately, the second one in Chicago was closed so the opening of the third one was canceled (Sherman & Craig, 2018).

Another big and very important area of virtual reality is the gaming industry. Playing games was part of life since ancient times. Games were popular among all people, especially children, and adolescents. People used to play mostly board games like chess, card games like poker, role models games, and many other types. Since the 1950s, with the expansion and improvement of computers, a new type of interactive entertainment was created – video games, or computer games. Inventions like cathode ray tubes, microchips, or minicomputers helped big companies develop new and more powerful PCs. From the beginning, special-orientated firms started to produce games designed for such computers, like for example a company Atari and her game "Pong" was introduced in 1972 (Sherman & Craig, 2018). At first, it was built as a cabinet, but later in 1975, Atari built also a home version/console (Montfort & Bogost, 2009). Atari was founded by Alan Kay and the priority of the firm was to focus on especially video games and their future (Jerald, 2015). In 1977 the company announced a game console designated for home purposes.

Nintendo, another famous game company, started in the VR industry by producing the so-called "PowerGlove" introduced in 1989 for the Nintendo entertainment system (Burdea & Coiffet, 2003). This special glove was appointed especially for games and was designed to evaluate the position of the hand relative to the computer itself. With such a possibility, the spectator could control the situation in the game by just moving his hand and bending his fingers (this glove had special sensors to measure the fold of each finger). Gloves were also equipped with buttons on the top side so the user could input various commands during the game. Williams and Green (1990) mentioned one big advantage of these gloves, the price. At that time, they cost just $80. On the other hand, they also described one issue with the connection and signal receiving. The system had three different receivers and there should be a direct line between the glove and receivers. In

some particular conditions, it was a bit complicated to set everything up in the correct way. That is why the glove had a problem with the determination of the correct position. Another disadvantage mentioned also Burdea and Coiffet (2003) – is a lack of proper games for such technology. That is why the device was only produced till 1993.

PowerGlove, however, was not the first attempt at the connection between VR and gloves. Its ancestor is called DataGlove[6] and was firstly built in 1985 by the company VPL[7], which was founded by Thomas Zimmerman and Jaron Lanier who left Atari in 1985 (Jerald, 2015). Jaron Lanier is often called the person who popularized the term virtual reality the most (Jarald (2015) mentioned, that Lanier used this term for the first time). This company has many interesting inventions, but not all of them were famous and mass expanded. VPL also constructed their version of a head-mounted display called "EyePhones". Unfortunately for VPL, the display had a really bad resolution, was a bit heavy (almost two and a half kilos), and was extremely expensive (at that time it cost around $11,000). Even this failure did not stop VPL from developing new devices. In 1989 company introduced a new system for virtual reality – "Reality built for two" (Shermana Craig, 2018). It was created by putting together two previous inventions: EyePhones and Data Glove. It was the first system suitable for two persons at the same time. The system worked in real-time and collected all the data about moving heads or hands and at the same time, both audio and video were also updated in real-time so the users had a real virtual experience.

During the next years, VR in the gaming industry oriented also on multiplayer games. Companies wanted to provide VR devices and games not only to individuals but also to a group of people. One of the first companies which provided games and VR for two persons (beside VPL) was W-Industries. This company produced around 20 different products related to VR[8]. One of the famous VR systems is called "Virtuality". Sherman and Craig (2018) described their system as a dual-player VR arcade system. In other words, we can imagine it as a virtual world, where more players could play the same game at the same time. Virtuality 1000 SD, a specific product from the "Virtuality" series was a specially designed console for users to sit down in it, and the system provided a virtual race against other players on different consoles. The system consisted of a head-mounted

[6] More detailed information could be found under the patent number US4988981A
[7] Jerald (2015) explained, that the shortcut VPL means „Visual Programming Language"
[8] Most famous products are Virtuality 1000 SD, Virtuality 1000 SU, Space Glove, Space Joystick etc. A complete list could be found in IGIC Inc. (1992)

display (in W-industries they called it “Visette”) and “Space joysticks”. The company wanted to provide this system to the public and they planned to install it in big shopping centers across the US. IGIC Inc. (1992) wrote about the conditions of use - $5 for a five-minute experience. Kreuger (1991) describes the system as quite faster than other systems in that time, with no big lags between the movement and the reaction of the graphics. On the other hand, he also mentioned some bugs and problems – audio contact with other players did not work correctly, bad graphics in such situations, etc.

Based on such prototypes and especially in situations, where time is really important (like in pilot training as mentioned above), inventors started to realize that virtual reality should meet some requirements. Gigante (1993) describes some of them, for example, a number of frames per second (he recommended at least 30), the time between the movement and the image (so-called lag time) - should be as small as possible or visual defects. Therefore, the development of technology was a need to present a better VR system.

At the beginning of the 21st century, there were already many various companies well established in the field of virtual reality. Quick improvements in computers and technology especially reducing the size of various components led to a faster development also in virtual reality and such technology started to become affordable for the public and individuals. The big competition was in the gaming industry. Many companies already had a VR system and everybody wanted to gain as many users as possible. In 2000, Sony introduced the second version of their popular console PlayStation. The biggest competitor for Sony was a well-established company, Sega. Sega already provided the system Saturn and its new version Dreamcast (Wolf, 2008). A big advantage was however on Sony’s side – all the games were provided on DVD. Another big technology company, Microsoft, wanted also to join the battle. A couple of weeks after the release of PlayStation 2 Microsoft announced, that they have been developing their own VR system. It was presented next year under the name Xbox. Both Sony and Microsoft developed their products in the next years and provided new features. For example, the first online console Xbox Live in 2002, or Microsoft Kinect, when the user did not need any controller to interact with the game. The system provided a device that watched the user’s movements, voices, and gestures. Similarly, Sony introduced their PlayStation Camera in

2013 – a similar device to Microsoft Kinect with almost the same functionalities. In 2016 both companies presented special displays for a better experience[9].

Nintendo, the company which already had good results in VR, also brought its system to compete with Microsoft, Sony, and Sega. They named it Nintendo Wii and the system used a remote device (wiimote) to control the movements. Sherman and Graig (2018) highlighted, that this was one of the most famous low-end VR systems among the masses.

Not all companies focused utterly on games. Some of them were interested in the business or common life of the masses, like for example Skype, which released its first communication tool in 2003. It provided peer-to-peer and video chat. Jerald (2015) explained, that people and big companies started to realize the future of virtual reality. Some companies even changed their primary focus, like Facebook, which acquired Oculus VR in 2014. Oculus became famous especially because of the headset called Rift designed especially for video games in 2012[10]. This device became one of the most famous and widespread among the public not only because of its compactness (small and light) but also because of its relatively low price. The device itself used a LED display that projected two images, one for each eye (Desai *et al*., 2014). The main purpose was not for games but the application of it could be found in many various areas, like medicine, architecture, developers, etc.

A bit later, another two big companies enter virtual reality with their products similar to Oculus Rift, Samsung, and HTC. Both organizations were familiar especially with the production of mobile devices and their participation in VR went in parallel ways. Samsung, in cooperation with Oculus, introduced "Samsung Gear VR". This system was designed to use a smartphone as a display (without a phone the system was unusable). One small issue was, that the device was just compatible with Samsung smartphones. On the other hand, HTC together with Valve presented HTC Vive Kit with HMD (with two OLED panels) and two hand controllers (Sherman & Craig, 2018). Both companies released also special software for developers to develop various applications or games. Therefore, both systems became very popular amongst the masses, because in just a

[9] Microsoft Xbox History Walk: https://www.xbox.com/en-US/xbox-history-walk
PlayStation Through the years: https://www.playstation.com/en-gb/explore/ps4/playstation-through-the-years/

[10] The founder of Oculus, Palmer Luckey, made a prototype of Rift in 2012. But to start a production, he needed entry capital. Therefore, he launched a Kickstarter crowdfunding, where he collected around US $2.5 million

couple of months users could download many interesting applications specially designed for virtual reality.

2.3 Virtual reality in education

As was already shown in the previous chapter, virtual reality found its place in many different areas, which we can divide into two big domains – entertainment and education. Both of these fields can be separated into various areas. In education, computers started to be used in schools many years ago. And since the development of VR went hand in hand with the development of personal computers, VR also step by step found its place in education at schools. The main reason for such a popular evolution could be in the definition alone. VR is the possibility to substitute the real environment with the virtual one. And in a virtual environment, everything could be possible. And since in education many times it is not easy for students to understand a new subject, imagine something, or see something, which is not possible to see in real life, with virtual reality it could be much easier. Therefore, VR got well established in the learning process during the last couple of years.

A nice summary of previous papers focused on the application of VR in education was made by Pantelidis (2009). She identified more than 800 various articles or reports related to this field since 1989. Authors in their research focused on different areas, beginning with the advantages/disadvantages of the use of VR, the unique capabilities of VR during the training process, and also on effectiveness in learning. The author later in detail described the main pros and cons of VR in schools or circumstances, under which to use/do not use VR during the learning process. An author named several appropriate situations, especially when it could be dangerous to use real things when a simulation could be used, or the students have to travel to see/experience something. On the other hand, since using VR could be emotionally or physically dangerous, she did not recommend VR during the classes. The author also described a 10-step model to find out, whether using VR in education could be helpful and suitable.

Similar research was made by Freina and Ott (2015). The primary period for their survey was however just two years – 2013 and 2014. During that period, they identified 93 different papers linked to the term “Immersive Virtual Reality Education”. Most of them were written in USA and UK. More than 60 percent of the papers were in the computer science area, but other areas like medicine (almost 12% of all papers),

mathematics, neuroscience, materials science, or nursing had also a strong representation. Most of the papers were targeted at university students, and just one paper describes VR in education in elementary school. Authors argued that younger people are still under development and therefore the use of such a system does not have to be appropriate for them[11]. The authors also identified some papers that targeted to the application of VR for disabled people (especially in rehabilitation). Similarly, as Pantelidis (2009), they mentioned many different situations in which using VR had a positive educational impact, like pilot training, or using the CAVE system for Mandarin teaching.

As was mentioned by Freina and Ott (2015), many papers studied the application of VR in the medical fields, like surgery, nursing, dental medicine, laparoscopic examination, and so on. The success of VR in that area has one very important reason – the safety of the patients. Students have to practice, so they can become more skillful, unfortunately, not every time they can practice in the real world. Therefore, they can improve their skill in a virtual environment, where many specific situations could be simulated.

Halluck and Krummel (2000) described the situation in surgical education. They advocated that studying in a real situation (operating room) could be very stressful and sometimes unpredictable. The main point is still the care of the patient. They mentioned also another important point as a disadvantage of the real environment – costs. They examined, that operational costs of operating rooms in the US are almost US $53 million annually. Virtual reality has an advantage because the environment is controlled and could be fit to everybody's needs, or can cover just particular problems or tasks (so not the whole procedure is needed to be prepared). Students can repeat the same problem several times and therefore improve their weak spots. Also, with the computers, students can see more details of many different organs, because many schools still provide only plastic models, or drawings in books, which are not described that thoroughly. Silva *et al.* (2018) wrote in their paper about similar findings. Also, they proved, that using virtual reality in some special examinations could be much faster and therefore more effective[12]. The effectiveness, as a key factor especially in the phase of pre-preparation, mentioned

[11] Many companies also state, that using their system should not be used by children under the age of 13 (Samsung Gear or Oculus Rift)

[12] Silva *et al. (2018)* compared two different ways to examine the patient's condition who undergone computed tomography angiography by traditional way or by 3D display. The difference was 9 minutes (13 vs. 22 minutes).

also Joda *et al.* (2019). During the consultation before the maxillofacial surgery, a patient very likely would like to see the targeted state of teeth after the operation. VR is the best tool to use in such cases since the simulation could be prepared for each situation individually. Similarly, the number of needed training lessons decreases significantly for students using VR. They became more skillful in a shorter period (both undergraduate and more experienced students). Also, during the educational training, students see the real situation of the patient and they can practice using special software in a virtual world.

VR got established in medicine quite well and it is expected to be more popular in the future because of its advantages. This can be supported by Grand View Research (2017). They estimated that the VR market in medicine and healthcare could be around $5.1 billion by 2025.

However, VR is becoming more and more popular, some authors stated also the disadvantages of a particular technology, which could have a significant impact on its popularity and its use during classes. Some authors compared education using various types of VR, like Hussein and Natterdal (2015), or Polcar and Horejsi (2015). Polcar and Horejsi showed that stereoscopic projection is not as good as monoscopic. Many users experienced cybersickness symptoms (like nausea, dizziness, blurred vision) during the stereo projection compared to PC (88 versus 3). But using Oculus Rift was also not that comfortable – together 71 symptoms, were experienced by two times more users compared to stereo projection. They argued that Oculus Rift was still in development and for many users, it was a new way how to experience a reality that could cause so many symptoms. On the other hand, in the study by Hussein and Natterdal (2015), most of the students preferred VR technology (Samsung Gear VR), because it was more interesting, more effective, and more useful. The environment was so interesting and therefore students were more concentrated on it. Students were part of a virtual world, they feel like they were involved in the simulation, which is something new, something unimaginable. They did not need anything to read because they could experience everything. And it is easier to see something that cannot be seen in real life than just read about it. But also, in their case, some students have problems with headaches and motion sickness.

Similar results found also Natsis *et al.* (2012), but they observed virtual sickness just among two students when using VR during the lesson about Greek pottery. The authors

compared two possible types of VR, monoscopic (the scene was projected on the wall using a special projector) and stereoscopic (using special types of glasses). From their study, they summarized that the monoscopic type is a little better than stereoscopic when looking at learning outcomes. Mikropoulos (1997) mentioned that some students had difficulties while using VR and manipulating it (especially power glove), or some of them had a problem with disorientation and are a bit confused by using the mouse and gloves at the same time. On the other hand, after a while (around 10 minutes), students used to new technology, and the students' interest in a specific field could overcome possible problems of the system.

Yap (2016) also used Google Cardboard in his research focused on students from elementary school (ninth grade). Information produced using VR was just supplementary to the text used in the class. Of 26 students only four had previous experience with this technology, but in the end, most of them were very happy to try it and used it during classes. They learned how to use it and the tool itself was so interesting, that they were happy to use it also out of school in their free time. More than 80% stated that this technology helped them in understanding the curriculum, especially because of its 3D factor and everybody would recommend using Cardboard also in different classes.

Stojšic *et al.* (2016) made a nice summary about the use of Google Cardboard in education. One of the biggest advantages is its low cost and many various available applications (like Expeditions, Google Street View, Cardboard application, etc.). Also, teaching new topics could be easier for students with VR, because it is more interactive, and funnier and it increases the interest in the topic. Traditional tools in teaching geography (atlas, maps, pictures, texts) cannot compete with VR and its ability to be part of the virtual environment. On the other hand, Google Cardboard is not compatible with every mobile device and sometimes schools do not have appropriate devices. The truth is, that nowadays almost every child has a smartphone, but the teacher cannot rely on this information when preparing the lesson. Another limitation is the internet connection or the ability of the teacher to know how to use this special technique during the class. It is not easy to prepare, since the teacher has to take into account many various things, including the topic of the class, if there is an appropriate application to use, or if the topic is suitable for using virtual reality, how many children are in the class and so on. And also, as was mentioned before, the big issue could be some physical problems, like dizziness or sickness problems, especially when this tool is used for the first time. That is

why it is also recommended to have more teachers available during the class, so they can take care of students.

Augmented reality can also stimulate memory (Billinghirst and Duenser, 2012). In their research, they compared two types of stories – classical text stories and augmented books[13]. They did not observe significant results in an understanding of the stories between high and low-ability students in the case of augmented books. But with plain textbooks, high-ability students remembered more from the story. As the authors stated "children referred to the augmented books as games" – and games are very interesting for students because they are part of it and they have to interact with various types of things in the game and they can be more competitive, so they want to be the best.

2.4 Virtual reality in Geography teaching

Virtual reality got very well established also in geography in the last several years. Many times, under the term geography, a lot of people immediately imagine names of states or cities, rivers, climate, etc. But the main object of geography is the Earth, its features, and the relations and interactions between such features. And during the study of some special fields of geography, like lithosphere, atmosphere, or human geography, it could be a bit complicated to imagine particular features, like various types of geomorphology landforms, glaciers, climate, or education in the field.

A nice survey about the existing mobile AR applications was made by Wang *et al.* (2017). They tried to prepare input for developing an application for geography fieldworks called GeoFara. To design the application as best as possible, at first, they made research about existing mobile AR applications designated for geography. Together, five applications were compared and tested in real situations. They identified some potential pros, like overlaying virtual information in real-time scenes, the possibility to switch between various types of maps in the application, and mixed types of information (text, sound, videos, etc.). On the other hand, one big limitation was, that for participants it was impossible to view a higher area on one single screen in comparison with a physical map. They had to move to see a different part of the map. During another experiment, they run into a typical possible problem with AR or VR – technical issues. During the task (to get to know better the area based on the physical map or a map on a

[13] Augmented book is a book with a text widened with graphics animations.

mobile device) one group of students had a technical problem and they were not able to complete the task. Also, the authors observed that such issues caused distractions and stress from the main task among the participants. Such failures could be problematic for both, students and teachers.

To imagine the universe, the Sun, the Earth, or other planets, is not very easy for students, especially for undergraduate students. Therefore, Shelton and Hedley (2002) wanted to improve the understanding of the relation between the Sun and the Earth by using augmented reality. Thirty-four students were first given the questionnaire to find out their knowledge of the relation, the rotation, solstice, or the amount of light falling on Earth, etc. After that, they used AR to see the situation in the augmented world. In the end, participants had to fill up the same questionnaire with the same questions so the authors could compare both results. They found out that there was a significant difference in the knowledge before the AR and after that. Students improved in the understanding of all particular areas (rotation, solstice, and so on) because with the AR they could play with the situation – speed up/speed down the rotation of the Earth around the sun, they observed the position in particular times (equinox, solstice), they saw the tilt of the earth towards the Sun, they could rotate images and so on. They were able to examine all the situations in a more detailed way because they could control the environment and they had free hands in what they wanted to explore. The most significant improvement was among the weakest students in the knowledge before the use of AR. The authors both agreed that AR could be a very powerful tool in education, especially in situations that could be really hard to imagine. But they found small problems too. Since AR is just the projection of virtual objects into the real world, some students were confused to identify particular virtual shapes in the real-world background.

Kerawalla *et al.* (2006) did similar research with 10-year-old students. In their study, however, they found out, that in some cases the AR is not that interesting for students. In their situation, just teachers had the ability to control the environment and students were just able to watch, like in front of the TV or in the cinema. Therefore, it was not that fascinating for them, students were not that active and thus they did not ask that many questions about what was going on. But still, they recognized AR as a nice tool that can help students to understand some relations easier and faster. But teachers have to identify particular situations when it is appropriate to use AR and the preparation for the lesson should also be quite detailed and organized.

In some specific situations, VR could be very helpful, especially, when teachers and principals are afraid of field study because of the safety of students, or just a small amount of time spend outside. Minocha *et al.* (2018) and Minocha *et al.* (2017) focused their research especially on using VR during fieldwork education, where they used Google Expeditions[14]. This application provides two types of expeditions – places that you can visit (cities, historical buildings, etc.) and places that you are not able to visit or it could be very dangerous to visit (planets in the Solar system, International Space Station, Chernobyl, etc.). During the normal geography lesson, they gave students and teachers Google Cardboard. The lesson then continued as usual, but teachers used this tool during the class – the topic was the environmental change in Borneo. The big advantage for students was the possibility to see more details on a mobile screen, change the view angle of the scene, or watch historical (environmental) changes in a particular area.

In the end, students were asked a couple of questions, for example, if VR facilitated the lesson and the process of understanding the new topic. Authors in their research summarized, that using VR during the class brought out many more different and analytical questions because students could imagine and saw more in detail particular things or expeditions. That is why they were more curious about it. Also, they could choose specific expeditions which they liked the most and then focused on their features. Authors also explained, that VR could be good preparation for the real field trip because the teacher could prepare in advance – what expeditions/experience is the most interesting among students, what they would like to see, what questions they have etc., and therefore the fieldwork will be more effective. Also, VR is helpful after the expedition, because it is possible to revisit the place to do the summary or visit another similar place to reuse knowledge from one place to another. Sometimes, however, even the fieldwork is not possible and therefore VR is the only way how to as best as possible experience specific situations.

Billinghurst and Duenser (2012), Brown and Green (2016), and Defanti (2016) also see the potential in mobile AR applications in the field study. When students go outside, they can use their mobile phones to hear or see interesting facts about specific locations, when using Google Expeditions. This can be very helpful for them since they do not need

[14] Google Expeditions is a mobile application developed by Google. It provides various expeditions which can be downloaded into the mobile device and using Google Cardboard (or any different similar tool) you can travel around the world, see historical events, etc. and by moving your head you are moving around the objects etc.

books, maps, or other requisites, the only thing needed is a mobile device. Also, anybody can turn their mobile phone into a tool that can picture several information on the device's display, like GPS coordinates, compass, elevation, etc. The only thing needed is the application called Geocam Free (Defanti, 2016). Besides Google Expeditions, Brown and Green (2016) saw a potential for the beginning in the application Street View by Google. Everybody could upload a photo which then could be viewed by any user around the world. This app also allows students to travel to many various countries and many famous places on Earth. On one hand, the only use of this application is to see the world around, but on the other hand, it provides an almost never-ending exploration of famous places like museums, historical buildings, and famous landmarks (White House, Eiffel Tower), etc. Nowadays, it is even possible to compare a specific place (area) for several years and watch, how the area has changed over time.

Although nowadays there are many various VR applications designed for mobile phones available, some authors developed their own applications to study the suitability of such applications in geography teaching (Ramírez *et al.*, 2013). They developed an application called Explora México according to prescribed modules for 4th grade from Public Education Bureau. The main idea was based on the game with creative features like colorful images, funny main characters, or interesting scenarios. As was explained before, game techniques are motivational for students and awake an interest in the study. This caused that the attractiveness of the application was increasing and therefore also the interest in geography. A similar application, but focused on Europe studying is GeoAR. Iftene and Trandabat (2018) explained, that using a game in the education process is very helpful since a game is a more interactive and funnier way than just reading or listening to new things. It also exercises the memory of students and they can remember more from the new topic in a shorter period. In the end, the educational process is much more effective. Using VR or AR during the class also showed that students are not that stressed and feel more relaxed, so it is easier for teachers to explain new topics.

3 Methodology

In this chapter, I will explain the methodology and the methods which I use to investigate the use and the impact of the VR and AR applications during geography class teaching.

As was already mentioned in chapter 2, many researchers focused on the application of virtual reality in education. But, just some of them focused on geography, and only a limited number of researchers focused on geography in elementary schools. In some cases, researchers used their own developed applications, but some of them also used applications that were already at their disposal (and are free to download). Some authors mentioned technical and health problems when using virtual reality, but on the other hand, there were also authors who explained, that VR helped students to better understand the topic and some processes. Some researchers showed, that in some cases VR/AR was not that interesting for students.

Because of these ambiguous results in the past, I will investigate the use and impact of VR and AR during the geography classes, if they could help students during the class to better understand and imagine specific topics, if it helps in the development of geographical competence and if there are some side effects when using this technique.

3.1 Types of devices

There are several various types of devices for virtual and augmented reality and they differentiate by several parameters. For teachers and schools, it could be hard to decide, which type is the best one. They should take into account several aspects – price, mobility (easy to transport), quality of the resolution and image, size of the class, internet connectivity (if it will be used only in one particular class or in various classes, Wi-fi or ethernet connection), if the device itself has a display or if it is only the holder for a mobile phone or how many devices they need/want – the more devices, the better (more students can use it at the same time), but the expenses are much higher.

For some schools, the most important thing will be the price. There are expensive virtual reality devices, which contain several controllers and sensors and have a better quality of materials and a display. In some cases, you have access to a specific store where you can download many various applications. Unfortunately, not all of them are free so a

school has to pay additional money to download desired applications and they could be really expensive. For expensive devices, there is also a need to have a computer/notebook where special software is installed and you will not run the virtual reality without this software. This device is connected to the headset, controllers, and sensors by Bluetooth/Wi-Fi or by cables (this could be again a big limitation).

Fortunately, there are also cheaper equivalents – basically, only the headset where the phone is put without any other components or controllers. Again, for such devices, there could be big differences in the price, the quality, or the features that particular headset has. In this case, VR/AR apps are also needed, most of them are free but for some of them, it is needful to pay. Another thing to keep in mind is the difference between mobile operating systems. Nowadays, there are mainly three big companies with their systems – Apple with iOS, Google with Android, and Huawei with HarmonyOS. Each operating system has its store where all the applications are available. Sometimes it can happen, that some of the apps are not available in each store. For example, the application Earth AR is only available in Google pay store, not on iOS and HarmonyOS. So, it is also important to think about it in advance and to find out, which operating systems are mostly used in the class and if there are corresponding applications available.

Another thing is, whether the device itself has a display or not. Some devices automatically contain special glasses/headsets for virtual reality already equipped with the display. Usually, they have really good resolution and the image itself is sharp and clear. On the other hand, some of them, mostly those simpler and cheaper ones, contain only the headset without the display. For such a device, it is necessary to use a mobile phone as a display. In this case, the resolution and the image quality depend on a particular mobile phone. If the display resolution is not that high the image itself has a bad quality and the feeling from the virtual reality could be bad and in the worst-case scenario, it can cause health side effects. This also means, that either the school has enough mobile devices at disposal (with the same/similar quality), or students have to bring their own mobile phones. This could bring other problems or limitations, students with more expensive phones could have a better experience. Cheaper phones could be technically limited and some applications will not run-on old systems with not enough power (processor, physical memory, or RAM).

Additional equipment is another important aspect of the VR device. Especially devices designated for mobile phones usually do not have any equipment or controllers. Everything is organized through the mobile phone and in the headset. More expensive devices usually contain also special cameras and sensors. They should be installed in specific places in the room and after that, they can better control the orientation of the person in the space by capturing the position of your glasses. If the VR includes also special hand controllers, sensors and cameras are checking the position of your hands in real-time which is then more precise. But this is especially useful for games designated for VR/AR and is not necessarily needed for education. Hand controllers are also used for better orientation in the application and with buttons, it is easier to control the functions in the application and for example to change settings, confirm activity through the application, move to another scenario or another photo/information, and so on. If a user uses only the headset with a mobile phone without such a hand controller, the orientation in the environment is more complicated and, in some situations, not that easy. It is necessary to put down the headset, move to another scene in the app and then put the glasses back on the head. In some headsets, it is possible to find a specific button for confirmation in the application. It works based on the magnetic connection and unfortunately, it is not compatible with all mobile phones.

Nowadays, there are also applications that have incorporated a special small point (dot) that is pictured directly on the screen and is used for navigation and conformation – if you point the dot on the specific button in the app, the button then does the programmed steps (it is similar as using the mouse with the notebook). So, a user can control the app only by focusing this dot on specific buttons.

The third important thing to take into account is the need for the PC/notebook when using device for virtual reality. Headsets designated for mobile phones do not need any PC/notebook – you only need your mobile phone (and enough space to install the app and sufficient processor and RAM). On the other hand, more complex devices usually need a notebook where you need to install the special software. This could be problematic and more complicated in some cases especially if you need to carry everything and prepare the device in a different place. For teachers, this could be limited, because either you need one room, where everything is installed or you have to transport everything to another place. Also, there are specific requirements for the system in notebook and hardware parameters.

The last, but not the least important thing is the internet connection. In some cases, and for some applications you need to be connected to the internet all the time. This could be difficult to arrange in some schools (Wi-fi speed, quality of the connection, stability). Fortunately, there are still applications, when the internet is only needed to download the app – unfortunately, this is true only for mobile phone devices not for a more expensive system where the internet is a must.

Based on the explanation, limitations, and pros and cons in previous sections, in this thesis, I will use only one type of device – a classical headset, where the mobile phone is needed as a display. I will use a virtual reality box called VR Box VR-X2 from the company CPA (Fig. 1). It is one of the cheapest ones but it is compatible with all the mobile phones with the size of the display between 3.5 to 6.5 inches. I will also use probably the simplest headset from Google called Google Cardboard (Fig. 2). It is made from cardboard and provides a magnetic button for the orientation in the application (working only with some mobile phones).

I decided for such devices because of several reasons:

- These headsets are easy to manipulate and easy to use,
- Ideal size for many different types of devices (display size from 3.5 to 6.5 inches),
- Easy to transport them from one class to another so there is no need for a specific room where the device will be placed.

Figure 1 Headset VR box VR-X2

(a) Fully folded headset. At the top, there are two moving controls so the user can adjust the lenses inside especially for herself/himself. (b) The same headset but with removed holder for mobile phone.

Figure 2 Headset Google Cardboard

(a) Fully folded headset Google Cardboard. (b) The holder for a mobile phone is holding with the headset using Velcro. After removal, mobile phone can be put there (c) and then with Velcro the holder is connected to the main part of headset (d).

- Price – they are not expensive so it is possible to buy more headsets and more students can use them simultaneously. I had together 13 headsets (two Google cardboards and 11 VR boxes),
- Almost everybody in the school nowadays has their own mobile device.

I decided for such devices also because of the availability of appropriate applications for mobile devices and most of them are free.

3.2 Applications selection

There are many various applications that can be used in teaching geography, some of them are focused on the imagination (how to imagine complex relations on Earth, or the size of the Earth, planets, etc), others are oriented on the possibility to travel all around the world to see various places, some have the gamification or a story incorporated

directly in the app and so on. Some of them are only for augmented reality (only a mobile phone is needed), and others (for virtual reality) are dependent on mobile phones and headsets. It is always very important, which applications to choose because some are a bit hard to use, some, on the other hand, are only limited to only one or two functions, etc. The language of the application is also an important thing to think about. In my thesis I decided to use three different applications:

3.2.1 Earth AR

Earth AR is the application for augmented reality which means it can draw virtual objects into reality – in this case, it will draw planet Earth. It uses the camera of the mobile phone. When starting the application, at first a user sees the room where the camera is pointing (it is necessary to have an empty place in the class/room). Then, the user will use circulated moves with the phone, and the application display several dots on the screen which will represent the Earth. Then pressing the only button in the app, planet Earth will be drawn on the display in the class/room, where the user uses this application (Fig. 3).

This application could be very helpful when introducing the topic about the shape and size of the Earth, and geographical location determination or to understand where continents or seas/oceans are located. Sometimes it could be hard for students to imagine the size of our planet. This application can picture various sizes of the Earth and it is similar to looking at the globe. The big advantage is that students can resize the Eart – it is possible to zoom in and out or to walk around. Unfortunately, the portrayal of the Earth is not very detailed – the application pictures only continents (green colour) and oceans/seas (blue colour). There is also no information about states (no boundaries), rivers, mountains (no 3D representation), or other information that students can find on the globe, or on the map.

Two disadvantages of this application are that it is only supported on mobile phones with Android (there is no equivalent application in the Apple store) and it is only in the English language. But, since there are no specific texts or information written, this language is in the end not that big a limitation. For this application, no headset is needed.

This application is in my opinion the best way how to introduce AR or VR to students. This technology will usually be new to many students and the best way how to arouse an interest in it will be to start with something very easy to use, where a teacher could

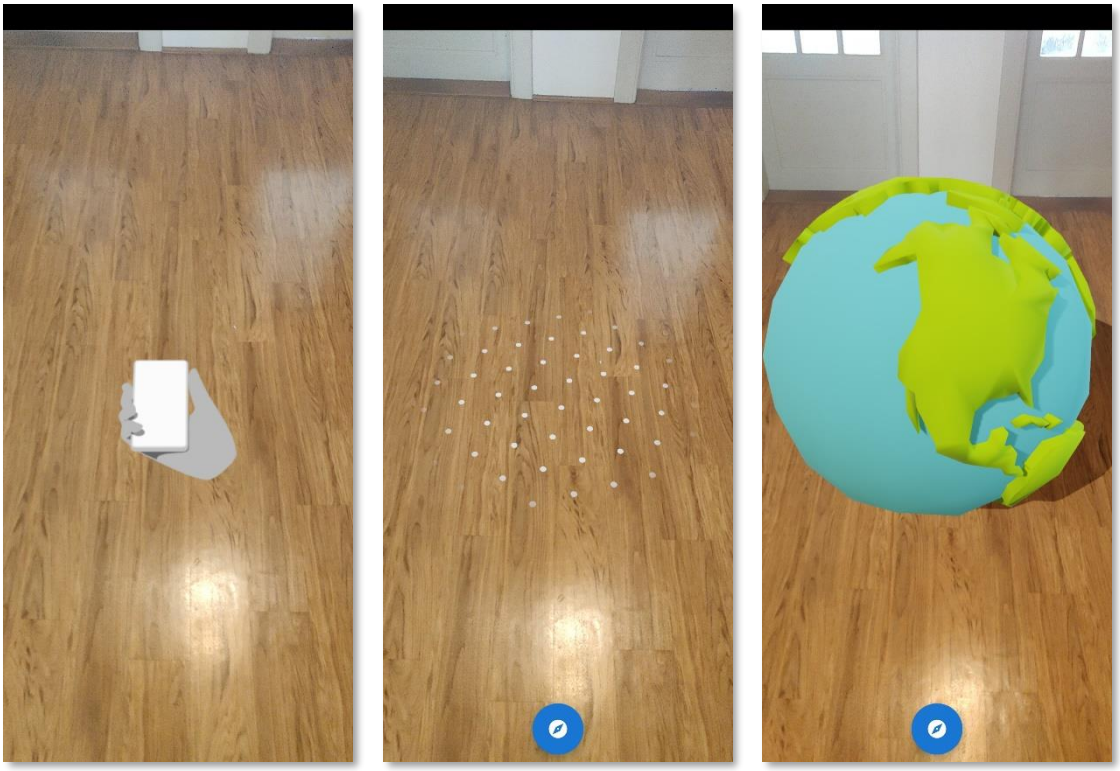

Figure 3 Print screens from the application Earth AR.

Application is very easy to use. There are no buttons or needless information of the display. At first, user has to do several circles with the mobile phone (a), after couple of moves some dots are displayed on the screen and blue button is uncovered (b). After pressing the button, the Earth is displayed instead those dots. When moving around the room it is possible to view the Earth from different angles.

demonstrate how to connect the real world with digital technologies and what will be available to almost everybody. After that, students could be keen on classes where it will be used.

3.2.2 LandscapAR

This is also an application that is designated for augmented reality. The main point here is to understand what contours on the map are and what can we imagine when we see them. When introducing the topic “What can be seen on the map” it could be really hard for some students to understand, what those lines (contours) on the map mean and how to imagine them in reality. They may understand, that it is a line that connects places on the map with the same altitude. But it is hard to understand when they see that the road from one point to another one is not going directly, but it is going around and is much longer. And exactly for such a situation, it is better to visualize it in 3D, where students will see the altitude of a particular area on the map and so it is not possible to go through mountains or valleys because of a steep slope. Unfortunately, it is not possible to see the

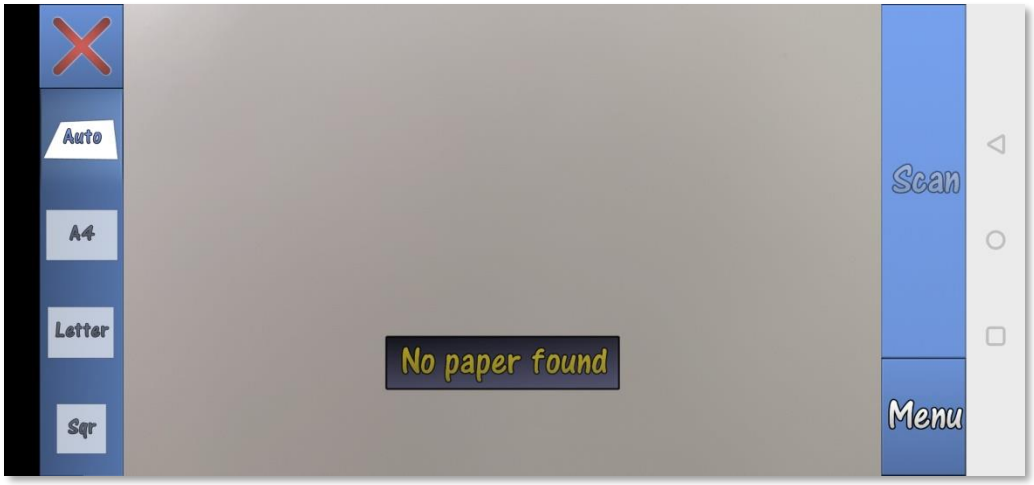

Figure 4 The menu of the application LandscapAR.

The main menu of the application is easy to orient in. On the left side a user can choose the type and size of the scanned paper (Auto, A4, …) and the button for the scan itself is on the right side. It is only active when the application recognizes selected paper form with drawn lines.

elevation on the map, and to draw it in detail for example on the board is also a bit challenging.

LandscapAR application could be a solution. It can visualize contours drawn on the paper and picture them in the 3D model on the mobile screen. Application is easy to use, at first user chooses the type of input (Fig. 4). The auto mode enables to see a 360 degrees experience – by moving the phone a user can see shapes from different angles. Or users can select the size/type of the paper. In this case, the 3D model is printed on the screen but is displayed from the top view. To use the application, students can draw several lines in various shapes (could be made-up shapes like letters, objects, the shape of the island, etc.) on the paper which represented contours (Fig. 5a). The application allows saving the image which as suggested by Defanti (2016) can bring new activities where students have to draw contours on the paper based on the saving shape.

Using the camera of the phone, the application will picture a 3D map of those lines on the mobile display, so students can immediately see the difference in the elevation (Fig. 5b). By moving the mobile phone around the picture, a student can observe the 3D model from various sides and see the difference in the altitude when lines are drawn closer to each other, or when they are sparsely outlined on the paper (Fig. 5c). It is then easier to imagine the terrain in the area. By looking at the screen, it could be easier to understand that when lines are closer to each other, the slope is steeper and the difference in the elevation will be higher. On the real map, this could mean cliffs or deep valleys. When

lines are further from each other, the elevation is similar in the area, which can represent for example lowland or a place, where the difference in the altitude is very small.

For this application, no headset is needed and it is possible to download this application on both types of phones with Android and iOS operating systems. Application is in the

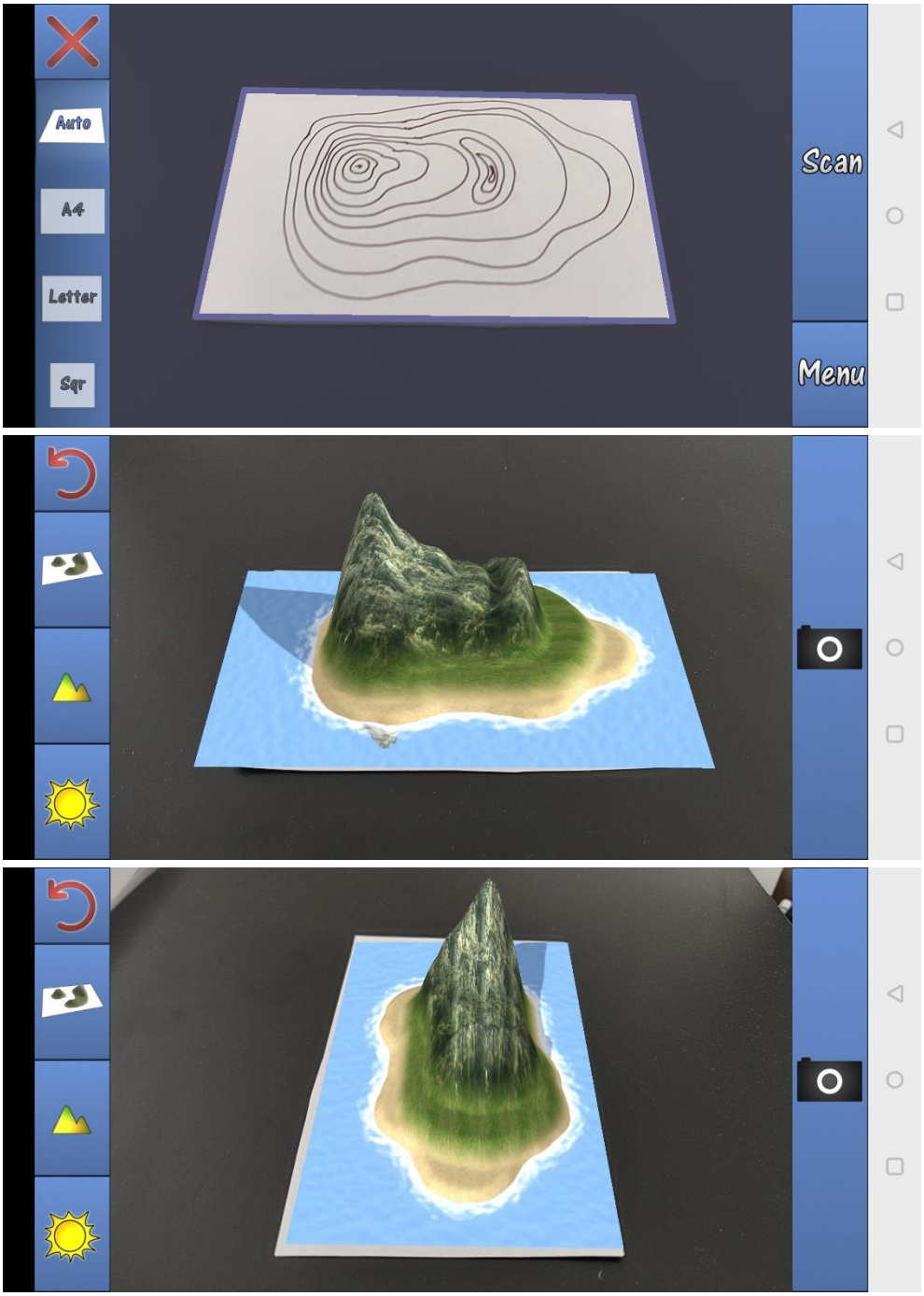

Figure 5 Print screens from the application LandscapAR

(a) Application identifies a paper where contours are drawn (in blue rectangle) and the button *Scan* is therefore active. The application is ready for scanning. (b) Application prints a 3D model of the drawn contours. A user can then use a mobile phone to turn around and to watch the picture from different sides (c).

English language, but similarly, to Earth AR, there are only a couple of buttons and no additional texts so again, this is not a big limitation. Teachers should prepare for using this during class. It is necessary to use white paper and the background should be definitely dark. In some cases, when the difference in the colour of paper and background was not that considerable, the application could not recognize the paper and did not picture the 3D model on the screen. Also, ideally, a black/dark pen should be used to draw contours on the paper.

3.2.3 Google expeditions

This application is the only one I used in my research that is designated for both virtual and augmented reality.

Google expeditions is an application that was created mainly for educational purposes. It provides many various expeditions in several areas like art, culture, science, environment, geography, and so on. Expeditions are divided into virtual and augmented reality, so even there if a user does not have a headset, it is possible to use this application. If a user wants to watch a particular expedition, it is necessary to download it directly to a mobile phone. After that, the internet connection is not needed. One of the biggest advantages of this application is that everything is for free and it is possible to download as many expeditions as a user wants. In Figure 6 we can see print screens directly from this application. The first picture shows us the ability to choose a particular expedition and the second one is one scene right from the particular expedition.

This application is used for a virtual trip all over the Earth. It is possible to visit many interesting destinations like cities, national parks, interesting buildings (exterior but also interior of such buildings), travel to space to see other planets or to go back in time to watch historical cities and so on. Each expedition is a compound of several scenes or images which are supplemented by additional information in a text or spoken words form. Images are mostly in 360° mode so a student can turn around with the headset on his head and the image is rotating. Information in the application is very interesting, it is not that long and provides some important facts about a particular scene/situation. Each expedition has also a quiz which is divided into three categories by level (beginner, intermediate and advanced).

The application could be used in two different modes. The first one is exploration mode, where each student can explore the application himself. Students will download

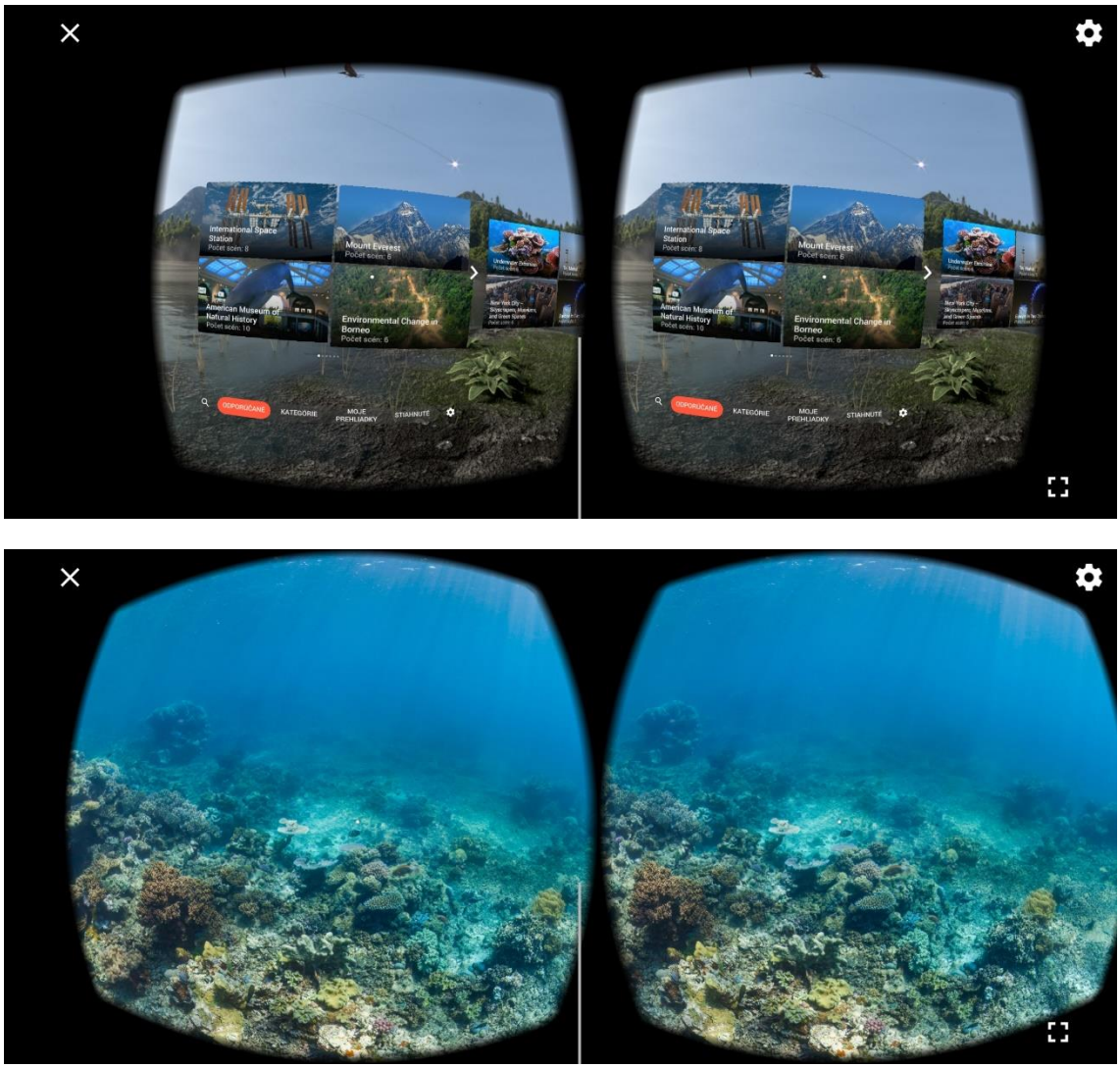

Figure 6 Print screens from the application Google Expeditions

This application provides many various expeditions from which a user or a teacher can choose. These pictures are shown already in Virtual reality mode, where special headset is needed to for better experience.

particular expeditions, and start and move around on their own. They can switch to a different scene anytime they want and they can read the information as they wish. Each student is an explorer on his own.

The second one is more interesting for schools. It is a guide mode, where the teacher will be the guide and students will follow the teacher's steps. The teacher prepares a particular expedition, students will join it and it can start. The teacher as a guild will choose a specific scene from the expedition and it will be automatically displayed on all students' mobile phones. Students then can move around and watch this scene. They have limited options – they cannot switch to another scene and they cannot see accompanying texts or quizzes. This is only available to the teacher who has other several functions

which he can use. If the teacher wants the students to look at a particular part of the scene (they are already predefined in the application with the explanation and short description), he can use a special pointer and all students will see an arrow that directs them which way they should turn to see this specific point. So, everybody is looking at the same part of the scene now. The teacher also sees small icons on the display – each icon represents one joined student, so he can directly see in which way students are looking at the moment and if they are focusing on a defined part of the scene. There is also an option to pause the expedition – now students cannot do anything in the application. This could be very helpful when the teacher wants to start a discussion or wants to ask something. And the last important thing is that the teacher is the only one who sees accompanying text and quiz questions with answers. This mode was mostly used in my research because I think this could have added value to the teaching process and it is similar to standard classes where the teacher is usually the one who guides students during the lesson.

The application itself has two big disadvantages. It is possible to set the language of the application to Czech, unfortunately, texts and quizzes provided for expeditions are only in English. This could be a big limitation for many schools, especially elementary schools, where students are not that good at the English language so far. On the other hand, this could be an ideal opportunity to learn some new English words not only from geography but in general. Another disadvantage of the guide mode is, that it is necessary to be joined to the same Wi-fi for the whole time of the expedition. This applies to both the teacher and the students. This could be for some schools problematic – a strong and stable wi-fi connection is an essential precondition.

Apart from these two disadvantages, Google expeditions still could find a strong place during the class, especially when introducing new topics not easy to understand or to imagine (for example Solar system), but also in regional geography, where students can travel to specific places like deserts, rain forests, savannah, etc. Since the application already provides additional information about scenes, it will be easier for the teacher to prepare. Also, it can help in the development of communication skills where students can describe particular scenes, can express their opinions, and also interpret the situation in the selected scene in the expedition.

Google expeditions and LandscapAR were also selected for teaching during Geography class by Defanti (2016).

3.3 Teaching preparation and students

The research itself was performed in an elementary school in Slovakia and together 29 students from three different classes participated. Unfortunately, four students could not participate during the whole process which is why I did not include them in this research. So, the final number was 25 students – 14 students from seventh grade, four from eighth, and seven from ninth grade. For each grade, the research took together almost four hours of net time. The research was conducted separated in each grade.

Students were not told in advance about using this technology during teaching, only the teacher knew about it. The main point was to find out at first if they already knew AR or VR, if so, where they heard about it and if they have any experience in using it. Another important part was to watch the initial reaction when introducing this new technology during the class. The first impression could be very valuable because the teacher can see how students react to something new, something extraordinary. A positive reaction can indicate that a similar response could be seen also with other non-common teaching methods. And this is a strong signal for the teacher who can involve new activities during the classes.

It was also important to assess, how hard it could be to describe everything to students and how much time the introduction take. The standard class lasts usually 45 minutes, and with no experience and underestimated preparation it could be a bit challenging to manage the introduction in only one lesson. Since the experience with AR or VR of students is not known in advance, it is hard to estimate the needed effort or the success itself. Virtual reality in teaching Geography is still something new and most schools do not have any experience with it, so this research could bring some estimation and insight on how to proceed.

There are also several significant aspects I had to take into account when starting with this technology in school. It is very important to discuss all of them in advance with the school or directly with the teacher.

If a teacher wants to be effective with this technology, it is necessary to have a sufficient number of both headsets and mobile phones. I had 13 headsets at my disposal (eleven VR boxes and two Google Cardboards) to provide to the school. Unfortunately, the school, where the research was done does not have any mobile devices which could

be used during the class. It was also impossible for me to bring several mobile phones and that is why it had to be agreed with the principal that students can use their own mobile phones during the lessons. Also, it was necessary to ensure, that everybody will bring a mobile phone to school. This could be crucial because it is something a teacher cannot influence and he has to rely on students and their responsibility. On the other hand, nowadays it will probably not be a problem since mobile phones are elements of our daily life. This, however, could spoil the preparation because students will be curious, to why suddenly mobile phones will be allowed in the school. If the teacher does not want to inform students about this new technology beforehand, communication is very important.

The best way for schools would be to have their own devices which can be used anytime a teacher needs for teaching. A school can buy the same mobile phones with the same hardware and software so everybody will have the same experience and quality. But then, this means additional money that a school has to spend. The bigger the classes, the more phones are needed and the higher the price for the purchase. And unfortunately, there are still many schools that do not want to spend money on such unexplored technology. In this case, the best and maybe the only solution is to allow students to use their phones during class.

Another thing to think about is the internet connection. Without the internet, it would be not possible to practice with AR and VR. However nowadays, many schools already have wi-fi available in the school, usually, it is password protected and only available for teachers and teaching purposes. Students are not allowed to use it and usually, they even do not have a password needed for the connection. This is reasonable because with the internet connection students could take advantage of it and use it even during a class which automatically leads to not paying attention to the lesson, interruption of the teacher, and bad behavior. The internet connection was a big challenge for me because the school did not allow to use wi-fi for students. That is why I had to arrange a special data SIM card for my mobile phone and to create a hotspot network[15]. This provided the internet for all students and also the ability to use Google experience in guide mode. Unfortunately, this phone was then used only for this purpose and was not used for the

[15] Intel corporation defines a hotspot as "a physical location where people can access the internet, typically using Wi-fi, via a wireless local area network (WLAN) with a router connected to an Internet service provider" (https://www.intel.com/content/www/us/en/tech-tips-and-tricks/what-is-a-hotspot.html). In case of mobile hotspot, using a mobile phone and data SIM card it is possible to create a Wi-fi network which can be used for people to join and have access to the internet.

AR/VR experience. For the guide mode, another mobile phone is needed because every device has to be connected to the same Wi-fi connection.

The last useful thing to consider could be a projector, which can mirror the screen of a mobile phone. When starting with this method in the teaching process, a teacher should explain to students how the application works, how to navigate in it, or what buttons to use for specific functions. The best way is to show it directly in the application. It is possible to use several options how to mirror a screen from a mobile phone into a notebook but the easiest way is to use a native function in the Windows system called Projecting to this PC. For this, a device that supports Miracast is needed[16].

For each grade, the same applications were used. Earth AR is an easy application to demonstrate, what can be done with mobile phones in the connection with specific software and to introduce augmented and later on virtual reality. The second application LandscapAR was used as a revision of the subject that was learned in previous grades (contour on the map, what does it mean, how can we imagine it, etc.). And Google Expeditions provides various scenes and expeditions which can be used practically in any class in elementary or secondary school.

The demonstration itself consists of several steps. At first, we discuss in class about virtual reality, I explained what it is, where can students get in touch with it, and also the benefits of using it. We also talked about the possibility to use it during the teaching process. We clarified the differences between virtual and augmented reality and also what other devices are needed. Till this moment, the whole discussion was only in an oral form and no mobile phones were used. The next step was very important – the presentation of the headset and how to use it. The headset itself has a size setting, which can be adjusted for everybody, and then there are two buttons on the top for adjusting the special lenses inside of the headset (only for VR box headsets, Google Cardboard does not have options for the adjustment). It is possible to move it forward/backward and to the left and right. This setting is crucial because if it is not correctly set students will not be seeing the display sharply and the experience will not be good. Also, the incorrect adjustment could lead to headaches, eyes pain, dizziness, or motion sickness.

[16] More information about this function could be find on this site https://support.microsoft.com/en-us/windows/screen-mirroring-and-projecting-to-your-pc-5af9f371-c704-1c7f-8f0d-fa607551d09c

Figure 7 Demonstration of VR in class

This figure shows the demonstration of the virtual reality in the class. Students were using headsets with their mobile phones inside. This demonstration is from the application Google Expedition in exploration mode, where students explore the particular scene which they or the teacher selected.

When introducing each application, I showed everybody how to use it. I take advantage of the projector and I was able to mirror the screen of my phone on the projecting screen so everybody in the class saw my display. That is why I was able to show all settings, buttons, and other important parts of the application. Then students started to join the hotspot. This took also several minutes because there were some technical problems. This step was crucial because without this they were not able to download the applications. Unfortunately, only at this point did I find out that mobile hotspot has one important limitation – only ten other devices could be connected at the same time. That was something I did not expect and the whole program was then a bit rearranged. Some students had to wait for the connection, meanwhile, others were already downloading applications. This unfortunately took a longer time than I calculated. But the main problem was for the application Google Expedition where, however, I had

together 13 headsets at disposal, only nine could be used at the same time (I, as a guide, also needed to be joined to the same hotspot, so only nine more mobile phones left to connect). That is why in the seventh grade some students were in couples and they switched with headsets (this was the case only for the Google Expedition application) when joining the guide's mode. Figure 7 shows what the demonstration looked like in the class.

While trying the applications, the whole time there was discussion in the class. Students asked many questions, some of them had problems and needed help, sometimes they had technical problems with the applications, with the settings of the headset a so on. Unfortunately, sometimes if several students needed help, I was not able to help them at the same time. That is why it is important to have one more teacher present in the class, especially when starting with this activity. On the other hand, I noticed that some problems students were able to solve by themselves or by discussing with others. In my opinion, since this was a completely new activity for them, they were very motivated to solve technical issues as soon as possible and to start using the applications. They probably did not want to wait for my help, because they saw that others are already enjoying augmented reality. This increase also their skill in problem-solving and communication qualifications or the willingness to help each other in case of any problem, particularly, if this is a new technology for them. During this activity, observation and continuous communication were crucial not only to check if everything is going well but also to notice if anybody had some health problems, which also appeared during the research.

In the end, after trying all of the applications, there was another discussion where we talked about student's experiences, what they liked about it, what on the other hand was surprising for them, how they like each application but also the possibility if they could imagine learning in school with this tool.

3.4 Data collection

For the data collection, I choose both quantitative and qualitative methods. Quantitative research consists of several questionnaires that students had to fill out. Together 5 various forms were used – one at the beginning of the whole research (before the introduction), one after the demonstration of each application, and one questionnaire at the end of the whole research.

The first questionary includes basic information about students and a couple of questions about their experience with virtual and augmented reality. Three different questionnaires were then prepared after the demonstration of each application. These were focused on each application itself – orientation in the application, controls, graphics, etc., and specific questions about whether the application itself helped students to better understand some topics (contours, the imagination of the Earth, the size of planets, and so on). And at the end of the whole process, there was another form, where students have to summarize their experience with AR and VR if they have any side effects or technical problems or the idea to use this technique during the teaching process.

Questionnaires were in written form. Various types of questions were used – open, single-answer or multi-answers questions, and questionnaires contained together 41 questions. The set of all questionnaires could be found in the Appendix of this thesis.

For quantitative research, interview and observation were used. The interview was realized at the end of the whole process and together 4 students were part of it. Before the interview, I asked students for their permission to record them. Only then the recording started. It took place in an empty class with only selected participants and took about 11 minutes. The interview consists of several questions about students' experiences and the main point of it was to get to know their opinion and explanation. Their answers were more complex and I was able to get more detailed information and better feedback from them than from questions in questionnaires.

The last activity on how to collect data was the observation of students during the activity. It was a continuous process and it was performed from the first moment. It was important to observe in the beginning how students react to a new technology, how are they able to learn how to use it, how they go through each of the applications (how hard it is for them to navigate or control the application), but also, if they experience any side effects. This could be a big issue and it is crucial for the teacher to immediately stop the activity when something like this will happen. If a student would continue it could have really bad consequences. If the class is too big it is better to have another teacher during the lesson to help students but also to observe if everything is going OK.

4 Empirical results

4.1 Basic results about the experience with AR or VR

In the previous chapters, I described the collection of the data and also the methodology which was used during the research. In this chapter, I will describe the results of the investigation.

As was mentioned before, several questionnaires were used to collect data and important information from students. When using new teaching methods during the class, it could be helpful to know, how women and men react to it and if they ever heard about it. The research took place in elementary school and questions from the first form summarize basic information about students and their experience with AR and VR.

Together, 27 students participated in the research. Table 1 reports the distribution of students. Most of them were boys and this goes for every class. We can notice that in the eighth grade only four students were in attendance. That is because of the Coronavirus disease 2019, where many students from this class had to stay at home because of positive tests.

Table 1 Basic information about the group

The table provides information about students who were part of the research. In each of the rows, a number for female and male students is provided. The last row and last columns show total numbers for students in a particular grade and particular sex respectively. The number total denotes the total number of students in each grade or the total number of all students.

	7th grade	8th grade	9th grade	Total
Female	4	1	4	9
Male	10	3	3	16
Total	14	4	7	25

This distribution of students is important in the connection of the next asked questions. In the beginning, I wanted to get to know if students heard about the terms AR or VR and if so, if they already experienced it somewhere. Also, I asked where or in which place it happened. Nowadays, there are several possibilities where people can read, see, or heard about it.

From Table 2 we can observe, that only one student never heard about augmented or virtual reality. Others have at least some information about it and almost half of the

students already have any experience in using it. This is not that surprising, because younger people are usually very interested in new things, especially in the field of technology, mobile phones, and digital tools. Another interesting outcome is that this one student was a boy. This could be a bit surprising because usually, boys are more interested in playing games on notebooks or mobile phones, watching television, or talking about technology than girls. But if we look at the experience, more boys have already tried this technology. So, however, all girls have heard about it, only three of them tested it. These days many stores with technology, mobile phones, or electronics are equipped with headsets and provide testing experiences for those who are interested. Many of them are video games or just videos. And that is most sought after by boys because usually, they like to play games and discuss everything around it.

There are also differences between individual classes. Nobody from the ninth class tested AR or VR in the past. This is significantly different from the situation in the seventh grade where the majority of students have already experienced it. This could be explained by the fact that AR and VR were not as widespread in a couple of last years as it is nowadays so older students did not have that many opportunities where to test them.

Table 2 Experience with augmented and virtual reality.

The table reports numbers of students who already have or have not heard about AR or VR and how many students have experience in using it. The table describes these numbers for the whole group of students and then for particular groups (girls and boys) and each grade respectively. The number in the rows indicates the sum of corresponded numbers in columns.

	Count	Girls	Boys	7th grade	8th grade	9th grade
Yes, I have already heard about it and tried it	11	3	8	9	2	0
Yes, I have already heard about it but never tried it	13	6	7	4	2	7
No, I have never heard about this term	1	0	1	1	0	0
Total	25	9	16	14	4	7

These results are similar to the results in the research performed in the US and UK[17]. They found out that more than 90% of all asked people already knew about virtual reality and 65% about augmented reality. But the difference is that they did not focus on students

[17] More information about this research could be find at the page https://blog.gwi.com/chart-of-the-week/augmented-virtual-reality/

at the elementary school but on the population between 16 and 64 years. In their research, Iftene and Trandabat (2018) found results that are again alike my outcomes. In their group of 12 students (between the ages of 9 to 16), only four of them did not have experience in testing this technology. The same results were found by Hussein and Natterdal (2015) in their research, where 11 of 25 students have tried VR in their life before the research. A bit different results acquired Yap (2016). In his research, he found that only four of 26 students had any experience with Google Cardboard. But he did not specifically ask for AR or VR but rather a specific application. That

In Table 3 we can find information, on where students met the concept of AR or VR. We can see that the most frequent answers are gaming and another place. As was mentioned before, gaming is very popular among young people and especially boys. They play various video games and they want to try new technology because it is very tempting to try something completely new out. It is probably the easiest way where to get in touch with this technology. In the discussion during the research, some of them mentioned that they already played some games using headsets and their mobile phones. Some companies focus on the development of virtual reality devices which are usually used for video games, like HTV Vive, or Playstation VR.

Table 3 Places where students meet with AR or VR

This table describes where students heard or test AR or VR. Numbers are shown for the whole group, and then for particular groups (girls and boys) and each grade respectively.

	Count	Girls	Boys	7th grade	8th grade	9th grade
School	3	1	2	2	1	0
Cinema	8	2	6	3	3	2
Gaming	11	2	9	5	2	4
Another place	12	7	5	4	2	6

Eight students answered the option cinema. When I asked them (after the first questionnaire) where they heard about it, they explained that in the cinema they used special glasses to watch movies. This could be a bit confusing. They mixed-up 3D movies with virtual or augmented reality. This explanation could be supported by the answers in the last question from the first form, where I asked for their definition of virtual reality. Some students answered that for them virtual reality means:

"It is a fake reality", *"It is an extension of possibilities, to be part of the action, funnier way to spend time"*, *"Something 3D, I had glasses on my head"*.

So, students thought that this 3D modelling which is pictured by the special glasses in the cinema is virtual reality. But after the explanation of what VR really is, they understood that it is not exactly what they saw in the cinema. But, on the other hand, there are also special cinemas (4D, 5D, or even 6D) where, indeed, the experience could be like augmented reality, because the scene from the projecting screen is going out into the space in front of the spectator.

The interesting point is also to look at the option school, where three students selected this. When I inquired what exactly they meant the explanation was easy – they saw me coming to the school with special headsets in the bags, and they started to talk about it. So, I do not take these answers as relevant to this research and I can summarize, that nobody from the group had any previous experience with AR or VR during school education in the past.

When students choose the option of another place, they usually meant TV and social networks (which was later on found out during the discussion). They explained that they saw many videos on YouTube where the concept of AR and VR were described. Students also read about it on Facebook or saw glasses/headsets on Instagram. Seven students out of 12, who select option D, did not have experience with VR, so they only saw it somewhere or heard about it.

The last question from the first block was to describe VR in a way, that students imagine it to be. However, some students already have experience with VR, it was not easy for them to describe it, which some students confirmed by the answers like *"I do not know"*. Besides this, students wrote several various descriptions, which could be divided into four categories:

- it is not real (*"It is a fake reality"*, *"It is a world which does not exist so far"*, *"It is only virtual, not real"*, *"It is a world that might exist once"*, *"It is not reals, it is a virtual reality, it is a made-up world"*, *"It is only an idea about reality"*, *It is only virtual, not real"*, *"A distorted place"*, *"Glasses which simulate reality"*),
- it is only a model of reality (*"It is a moulded environment, could be similar or completely different"*, *"It is a moulded reality"*, *"Reality, which we can observe using special glasses"*, *"Glasses which can create a new world"*),
- it is something supernatural (*"Supernatural things which I cannot see in reality"*, *"It is a world where supernatural things exist"*),

- or it is something connected to the games (*"A game that should resemble real life"*, *"A game in a real life"*, *"It is an extension of possibilities, to be part of the action, funnier way to spend time"*).

We can see their explanations are sometimes very different and answers are mixed between various classes, so it is not possible to say, that older students would understand virtual reality better, than younger ones. But we also cannot say, that students' answers were not right, because, all of them could in some way describe VR or AR a bit. In general, it is possible, to sum up, that for students, virtual reality means something unreal. It could be a game, the environment, or some kind of a model.

4.2 Results for the applications

After the first block of questions, we moved to specific applications. The first one was Earth AR. This application does not need special glasses or headsets, so that is why everybody in the class could try it at the same time. However, it is easy to use, the main point was to show students the possibilities of augmented reality. This application displays our planet in a 3D model directly in the room. This could be very helpful when studying the options for the representation of Earth or coastal and sea relief shapes. We can say, that this Earth projection on mobile is almost the same as the globe itself, but the image could be enlarged or lessened and it looks like the Earth is right in the class.

As can be seen in Figure 8, most students liked almost everything on this application but the most important is that this helped them to understand, how does the surface of the Earth look like. Students can go around so they can study the projection from all sides and this could be helpful for the teacher to describe important objects like oceans, continents, islands, etc. Unfortunately, the graphics of the application is not that excellent. Many smaller islands are missing, some shapes are not that clear and are blended together (for example it looks like the Baltic Sea is not connected with the North Sea by the strait, or some of the Great Lakes are missing). So, it is not good for detailed examination of all parts of the world. But this application was never meant to detailly described every single part of the world. This also noticed students where only 44% agreed that it is really good and this parameter of the application was evaluated as the worst one. More than half of the students had mixed feelings about the graphics quality. Later on, some of them

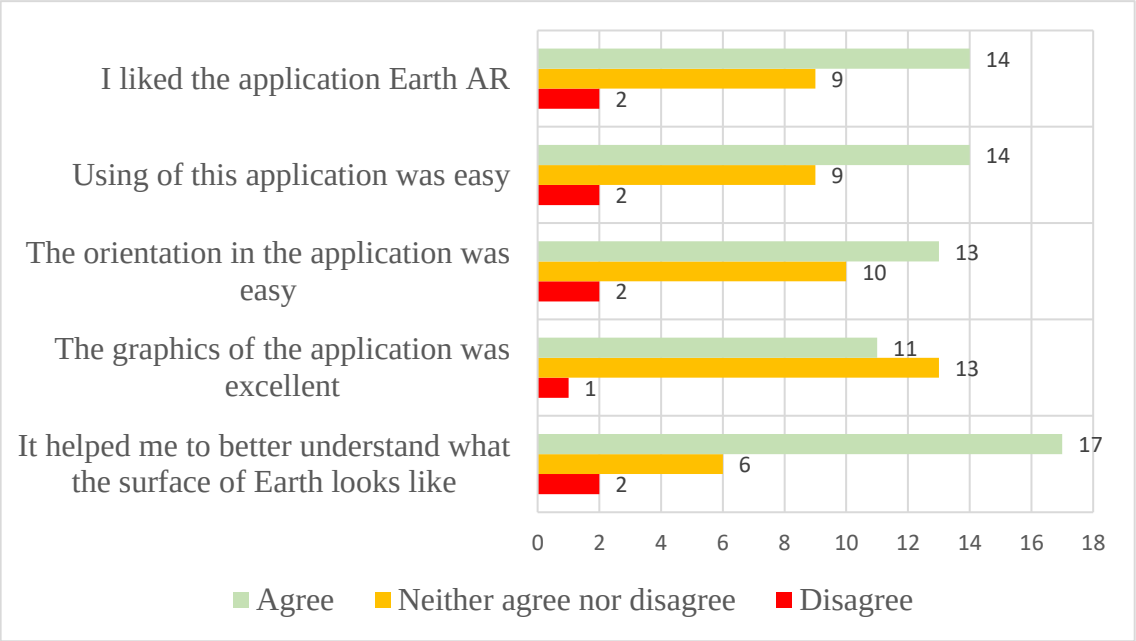

Figure 8 Evaluation of the application Earth AR.

The figure describes evaluation of particular selected attributes for the application Earth AR.

explained that this was really not that important for them. They mostly liked the possibility to see our planet directly in the class and focused more on the technology itself.

My description of the application from the previous chapter was also supported by answers in the second question, where almost 56% of students chose that the application was easy to use. This could be supported by students' answers in the last question in this block (What did you like about this application). Some answers were *"Everything"*, *"It was like in reality"*, *"It is easy to use"*, *"Probably everything"*.

On the other hand, unfortunately, some students had some technical issues when downloading and using this application which then affected their evaluation. In such a situation, I had to spend several minutes helping them download the app and also guide them with their phones to properly use the application.

This demonstration also showed another thing to think about – enough space in the class. This is an activity, where students are allowed and motivated to move around the class. But with a considerable number of students, it could be a bit crowded and students will get in the way of each other. Somebody will see Earth on their mobile phone, but suddenly some student could appear in the view. And since the application cannot filter the person out of the display, some interesting situations could happen (when a student is part of the Earth on the screen). This also happened in our situation but, luckily, students

took it as a fun part of the activity and they were making fun of each other. But then it is hard for them to focus on the Earth itself, and for the teacher, it is a bit challenging to calm the situation down.

If we move to a second application, we can see in Figure 9 similar results as for the first one, but in this case, the review was even more positive for all parameters. 20 students (80%) liked the application and only one explicitly did not like it. This application is more interactive than the first one. Now the application did what the student had drawn. This means that students could feel like they were part of the process itself and can affect the application. They are no more only passive spectators but an active part. So, the application now is not programmed to show only one thing (like planet Earth in the previous case), but to do what students want to see. This will give them better control of the environment and encourage them in trying it. This looks more like a game where they can play with drawing and be more creative and immediately see the result. Actually, students were more focused and motivated when trying this application, than when using Earth AR where they were nonactive watchers. This can improve their learning skills because they try to create something new and see the result. This is of course always better than pushing students to an activity that they do not like that much and are not motivated to learn and improve.

When I was watching students during this activity, they started to draw at first basic shapes like circles or curved lines, but later on, they made up their own shapes, like letters or even their names which application did not have any trouble picturing on the screen. This unfortunately leads to a long-needed time to test this augmented reality. Especially girls were very detailed in their drawing and it took them much longer time compared to boys. Another interesting observation was that everybody wanted to use this application in their own design. Students did not want to see a 3D model of a classmate's picture but most especially their own. This is also supported by the seventh question in this block, where 19 students (76%) agreed that they liked especially this situation where they can be creative and draw whatever shapes they liked.

Students also appreciated that the application is easy to use, however, there was one student who had a problem launching it. This student had to make a couple with another one, but they had only one mobile phone, so this so not very comfortable for them. Some

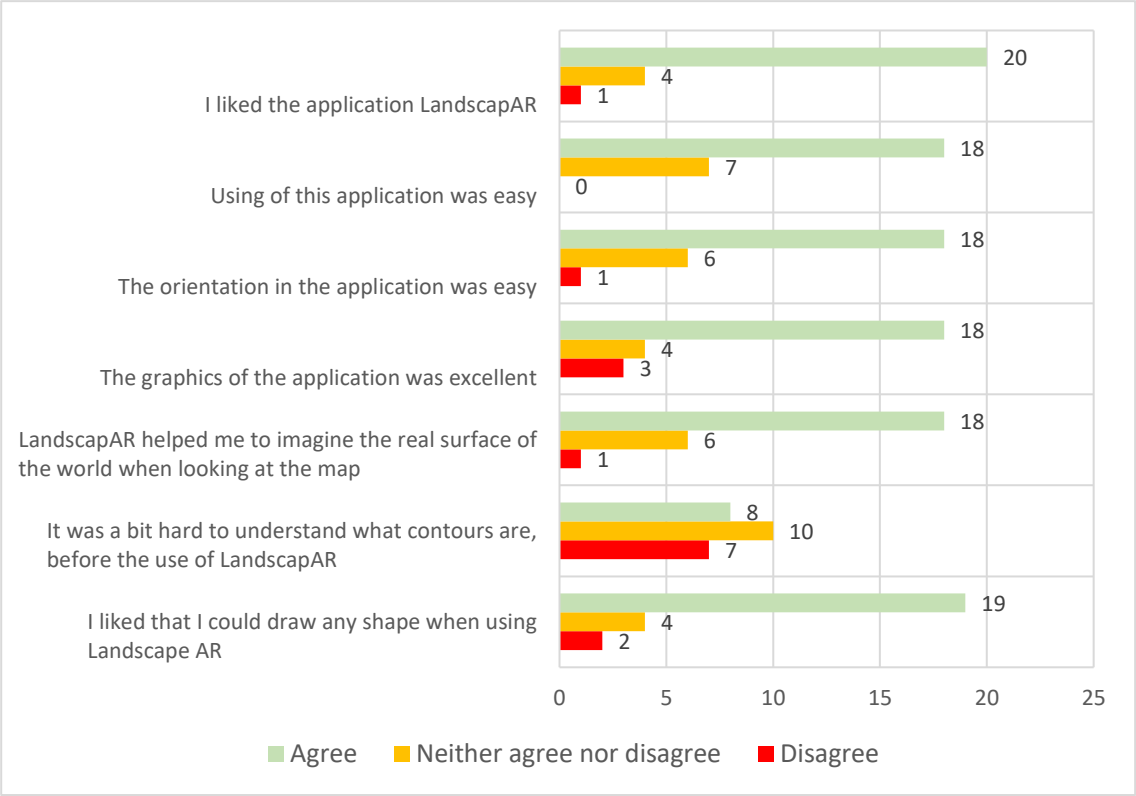

Figure 9 Evaluation of the application LandscapAR

The figure describes the evaluation of particular selected attributes for the application LandscapAR.

issues were also with the recognition of the paper by the application. Students had to try moving their phones around the paper so the phone was able to capture the paper.

When looking at other parameters like orientation in the application or the graphics, all have approximately the same results and are positively evaluated. Graphics in this application was again not that important because they did not describe any particular environment, but only the elevation itself. Students also confirmed this statement (in general for all applications) in the last interview, where two students explained:

"It was not entirely accurate to specific points but it was good."

"I do agree with Marek because we cannot see something like this in the book on the pictures and it is an advantage."

This means that a more significant fact for them was the ability to see specific moments/photos/situations in a 3D model even if the resolution or graphics details were not that good. In this application, this is probably OK, but there could be situations or topics where details could be a bit crucial and the application itself should describe it as best as possible, for example, a detailed map of a particular region.

When discussing with students in all classes before this application what do contours mean, where can we find them, or why they are drawn in some maps (in some cases the discussion started the other way around – what are these lines in the map?), some students were active and they were able to explain the purpose. Some of them were familiar with it but could not explain exactly why these lines are used in the map. After showing them, that a 2D model from a paper could be pictured on their mobiles in 3D, they better understood, that if someone wants to describe the segmentation of the terrain on the map, contours have to be used. Question six is the only one where only eight students confirmed that this application helped them with their imagination and visualization. This result is very positive because this means, that most students either did not agree with this statement or were hesitant in their answers which indicates that students remembered this quite well from previous classes. And this is very important feedback for the teachers because they could assume that students were already familiar with this topic and probably, understood it even without any special projection into the 3D world.

On the other hand, although 17 students in question six did not explicitly say that it was hard for them to understand the purpose of contours, this application definitely help them with the visualization, which could be supported also by the answers in question 5 where 18 students agreed that this application was helpful with the visualization.

During the interview at the end of the process, one student chose the best application this one. A student explained that LandscapAR was superb because it was able to visualize any shape drawn on the paper. *"On the application LandscapAR, I liked that we could draw what we want, and then we got the final island*[18]*. If I would like to have Mount Everest, I would just do contours on the paper and we could create it"*.

In the last question of this block, students were again asked what they explicitly liked about this application. Five students answered *"Everything"* but other responses are also interesting, and in my opinion very positive. There was only one negative feedback from a student, who had a problem installing the application (*"It did not work"*). Otherwise, we can see that also this application could find a place in teaching geography, however, only for one specific topic.

[18] The application pictures every shape as an island which is surrounded by the water.

"Almost everything", *"3D Graphics was the best"*, *"The topic itself"*, *"What I drew, this was pictured"*, *"I liked that the application showed us what we drew"*, *"The application is really good"*.

The last application we tried with students was Google Expeditions. This is the only application of my choice designed for virtual reality. However. it is possible to use it also for AR, in my research I focused on its use in VR.

In this section I tried to focus on several expeditions like travelling to our Solar system and comparing the sizes of planets, seeing various types of vegetation around the world where usually students cannot go (savannah or rain forest) or see changes in particular places around the world and the evolution of cities and housing development. The expeditions were chosen in consideration of the class and the expected knowledge students should have in particular classes. In this demonstration, I mostly focused on the guide mode, where I selected the expedition and particular scene and students were following me while using their headsets.

In Figure 10 we can see results from several questions that students were asked. It is possible to notice a similar pattern as for the previous two questionnaires. The overall rating is that 76% of students (19) liked this application and no one explicitly did not like it (this is the only application from the selection which has zero dislikes). This could be because students were equipped with headsets which was something unusual and for them new during the class. But this could be also because we did not use this application for AR, but for virtual reality. Now, they did not see the area in the class but they were completely moved to specific locations.

Another interesting result is that when asking about the orientation or the operation of this app, 22 students chose it was easy (again, the most among all three apps) and for 19, it was easy to use, whereas only one student disagreed with these two statements. This could be related to the selected mode, where students were only passive spectators and they did not have to control the application. In the previous two applications, it was expected from students to execute several steps (like drawing some lines on the paper, pushing some buttons) but now it was not necessary. They could concentrate on the content and did not think about buttons or settings. The only thing they had to do was to connect to the created tour, which took only two pushes. Later on, we also tried the exploration mode where pupils had freedom in particular expeditions. This required the

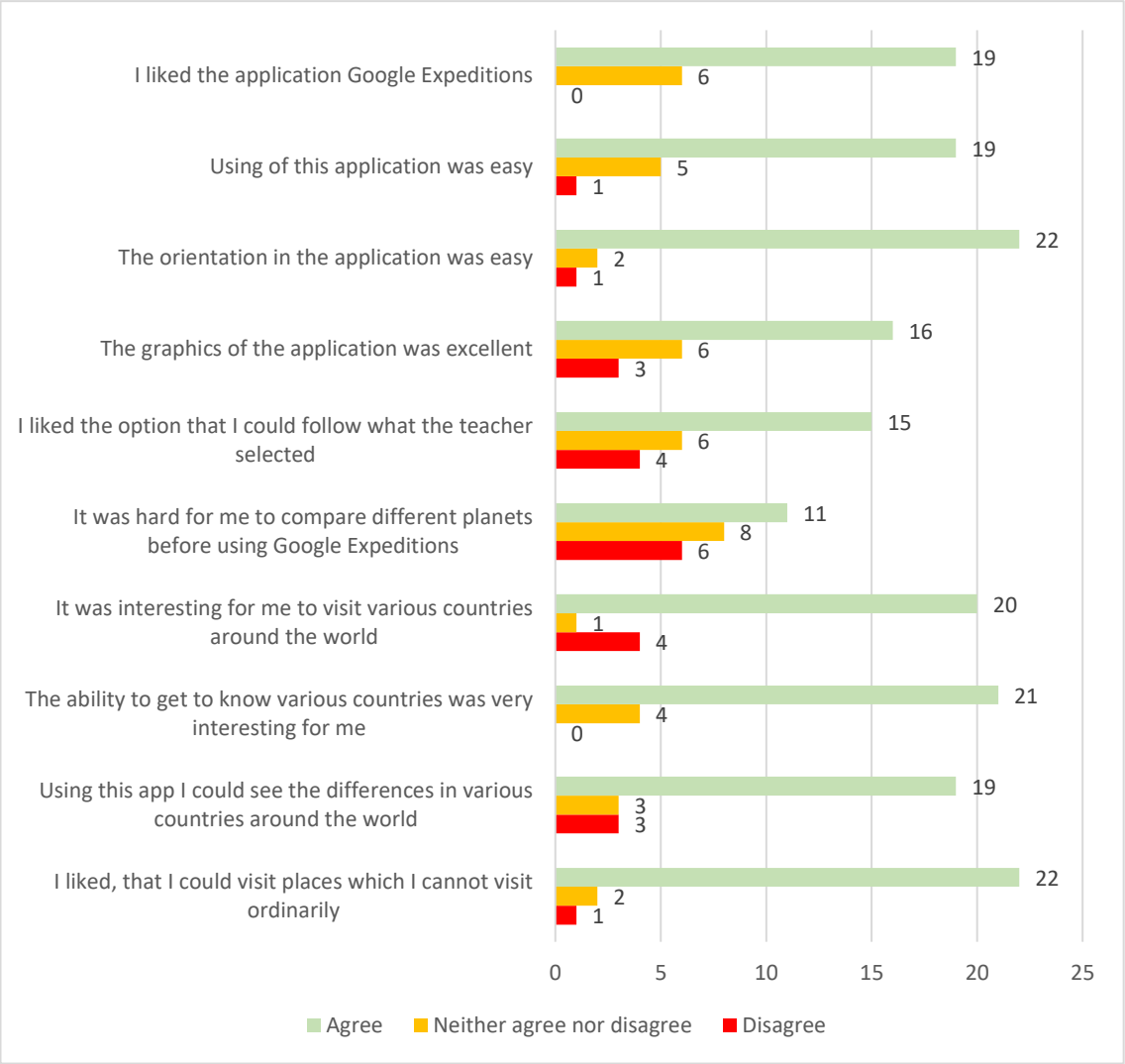

Figure 10 Evaluation of the application Google Expeditions

The figure describes evaluation of particular selected attributes for the application Google Expeditions.

control of the application, but apparently, this was also not a big issue. I observe this behaviour also when students knew exactly what to push, how to control the application, and they did not ask related technical questions. As Defanti (2016) and Yap (2016) explained, this application should mainly help teachers and is designed for education. And if it wants to be successful, it should be as easy as possible to use it. And according to students, this application is indeed quite simple.

Graphics in Google Expeditions was according to 16 pupils good, six students neither agree nor disagree and only three of them did not agree. This result is quite interesting because, unlike the previous two applications, photos and sceneries in Google Expeditions are mostly real and of high quality (except for several scenes which are artificially created) and it could be expected that users will appreciate this. The

application, however, has one small disadvantage namely it is not possible to zoom in or zoom out. So, we cannot look in detail at some particular photos, which could be argued if this was meant also by students, why they did not evaluate graphics higher. Unfortunately, even during the interview students did not specify the quality of graphics exactly for this app, they only explained that in general, it was good.

Question five is aimed to find out if students liked the selected guide mode in this application, where they followed what the teacher prepared. Only 15 students agreed with this statement and four were against it. We can look at these results in two ways. The first one is, as explained in the previous paragraph, that students probably liked that they were only observing what the teacher showed and prepared for them. They needed not to control the application or push some buttons to move to another picture. They did not think about it so they could completely focus on the scenery and the content of the particular expedition. But they did not have handling on the expedition and they depend on the teacher. Later, when I allowed them to use the exploration mode, the student was the one who selected a particular scene or who decides when to move to another photo. Now they were in control of the application. This freedom could be important for some students because usually they did not have something like that during the teaching and they appreciated it. One student supports this with his last answer – *"I could download, where I wanted to be"*. But, as can be seen from the results, more students liked this concept where they follow the teacher. In the interview at the end, one student explained, that it was good that the teacher could use a special pointer to bring all students to a particular place so students did not have to look at it by themselves.

If we move to the last four questions in Figure 10, we can see very positive feedback for all of them. These questions are oriented on the ability to visit and compare various places and countries around the world. This not only refers to cities but also to interesting places like underwater experiences, historical buildings, different types of vegetation, and so on. A student could compare how people are living in such places, how it varies to our cities, they could see fauna and flora around the world, or they could go to places where it is usually not possible to go like to explore seas and oceans, go to high mountains and peaks (for example base camps on the way to Mount Everest in the Himalayas), visit space and Solar system, or places which are very dangerous to visit, like Chernobyl nuclear power plant. All of this is very interesting to students because usually, they heard about such places, maybe see some pictures, but to experience it in 360° photos is much

more interactive and students feel like they are part of it. They can move around or switch to another photo (in exploration mode), they can turn around and see a particular place from several directions. It is a big difference from the static picture where it is not possible to see what is on the left or right. This is eventually a top-rated question, where 22 students (88%) really like this possibility (actually there was only one student who did not like this option).

This application was also selected as the best one form three students out of four in the last interview. They appreciated especially the possibility to see something, which could not be seen normally. They also saw the benefit that the details were much better than in the presentation or on the photos during the classic teaching class. This application provides many interesting expeditions and it is only up to the teacher, which to select and show to students.

In the end, after the demonstration of all three applications, there was the last questionnaire where students were asked to summarize this activity and express their opinion. Results can be found in Figure 11, and in Figure 12 particular questions about the whole process are available. In general, we can see that for 24 students using VR on mobile phones was interesting and only one pupil was not captivated. Similarly, 20 students consented that the whole teaching experience with VR was interesting, and a very positive fact is that no one disagreed with this (question 1 in Figure 12). Students also appreciated the graphics in the application. This is a bit surprising and in contrast to

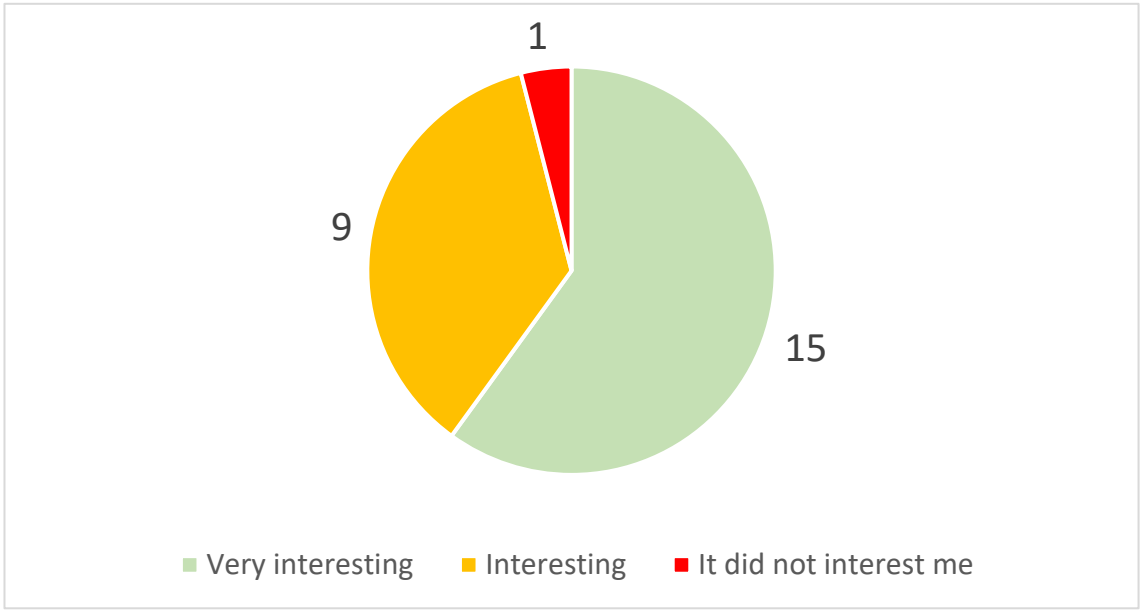

Figure 11 The overall evaluation of using VR on mobile phones.

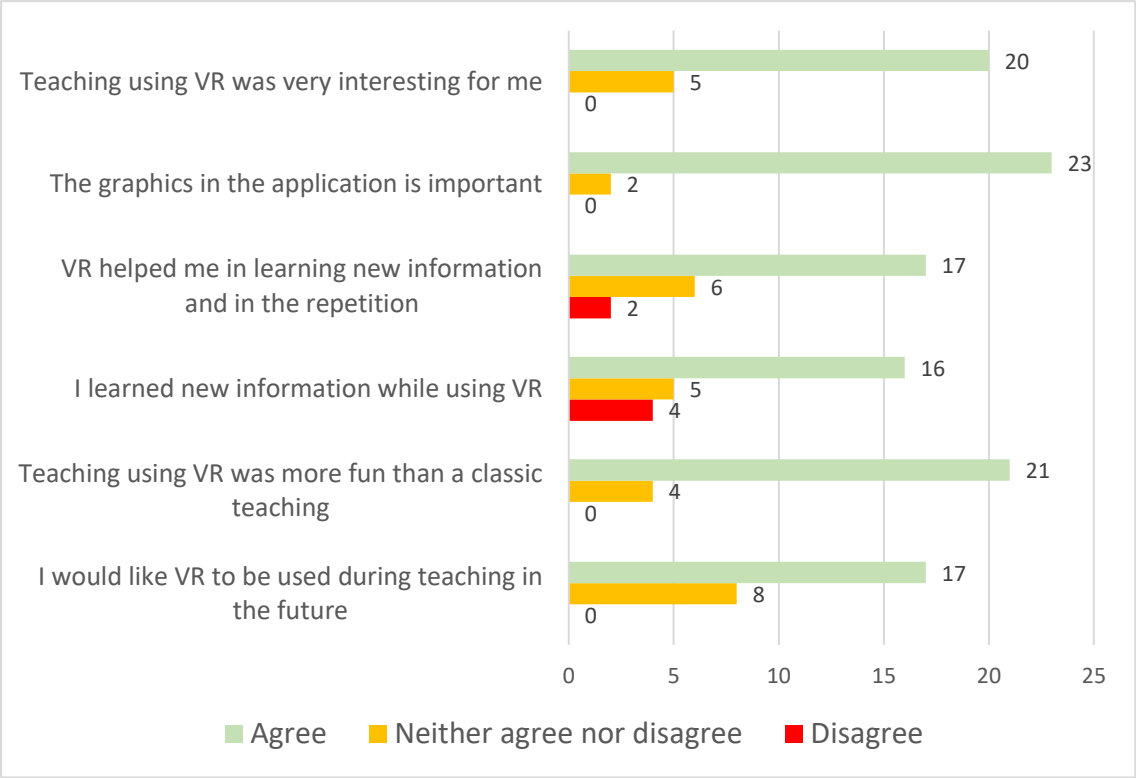

Figure 12 Evaluation of the use of VR in the teaching process.

the results from the interview and from previous questionnaires, where students usually did not rate graphics as a very important feature. This however could mean the general opinion. For some applications, graphics quality is not crucial (Earth AR, LandscapAR), because the main point is to describe some processes or to help with the visualization. But in other cases, students would probably prefer better resolutions so they can observe more details when visiting special locations.

Probably the most important are the last four questions in Figure 12 which concern the teaching process. The summary could be that for most students VR was helpful during learning, it brought new experiences and fun to the teaching process and students can imagine using this technology in the future during geography lessons. Since students can see much more things in VR applications, they would like to incorporate this technology also into the teaching process, but with some limitations. One student said:

"It is a big advantage because we can learn so much using VR, we can see many things which we cannot see in the book or presentations and I think this is a super advantage.

And another one added that:

"Using this for each lesson would stop entertaining everyone".

However, also here we can find some negative feedback, where for example four students chose that they did not learn anything new while trying this technology and for two students this did not help them in the learning process. And eight pupils were probably not sure if they like to use this in the future.

During the research, I was not able to discuss the results with all students so I do not have detailed information for particular questions. But there could be several reasons why some students answered like this. During the research, I noticed that some students were more active than others, and this activity was more interesting for such students. They were looking forward to trying something new, seeing something not typical, and experiencing a different type of lesson. This is however not true for everybody. Some students could prefer standard classes without new technology, something which they are familiar with. And in such a case, they probably did not want to be that active during the lesson so they did not focus on the provided information. This could be new for them so they focus more on the technology, not the content. And this would not help them to remember everything. Another thing could be students' results. Some students are more skilful and it is easier for them to learn something even without the consideration of which type of teaching tool is used. And for some, it is still a bit hard to remember everything even when they have special aids which support the learning process.

Another thing to look at is health issues. While using special headsets it is easy to get a bit dizzy or to have blurred vision or eyes pain after some time. Looking at the mobile screen is not very healthy for a longer period. And when somebody has a side effect during the lesson, this is not comfortable for the students. In such a situation, the student does not think about the lesson, new information, or content, but about the health issues and how to stop them. Also, for the teacher, this is a situation which he should immediately take into account and take care of such students. Therefore, the lesson is usually interrupted, teaching is stopped and this has an impact on the whole class and on the learning itself. And while using VR, such side effects are not that rare. We can see in Figure 13 that during my research students experienced some health issues, the most common was headache and eye pain (together nine students reported at least one side effect). One student even felt sick (this is also a student who stated that VR did not help while learning new things). In such cases, students immediately stopped with VR until they felt better. However, this is so exacting to observe, it is very important to think about

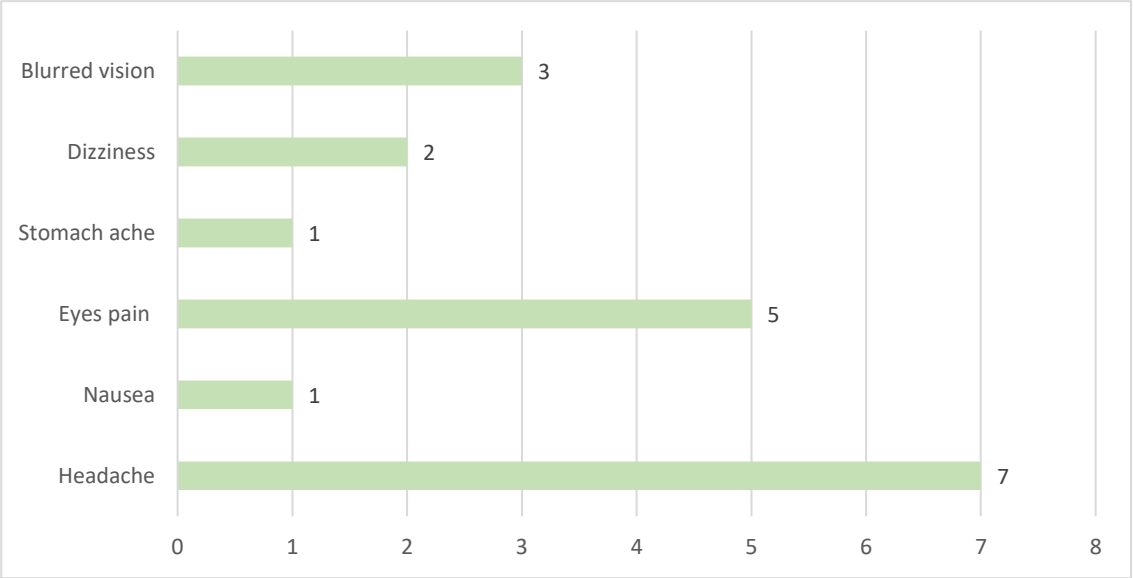

Figure 13 Side effects while using VR.

it in advance and be prepared for such a situation. The best way how to overtake it is to have at least one other teacher in the class or to wear a headset only for a couple of minutes and then put it down and continue with the class as usual. Also, talking to the students will help to better understand their feelings and it is easier to note when something is happening. Some health issues could be caused because of the graphics quality. The better resolution also precedes possible side effects, especially when using the headset. The longer is a student looking at a bad resolution application, the earlier he will experience headache or pain in the eyes. One student on the question, if they would prefer this technology to be used during the lessons said:

"I would support it, but not that often because half the class had a headache after that or they no longer wanted to so I would not give it that often."

The last reason for a negative rating could be the selection of applications. Earth AR and LandscapAR are specific apps to demonstrate only one topic. This topic could be easy for some students to understand so these applications actually would not help them to learn something new. Proper selection of applications is a bit challenging and time-consuming but has an important role in the process of preparation because wrong applications probably will not help students at all.

According to students, teaching with VR was more fun than classical teaching. Students were looking forward to it because it was something new. In the interview, all four students concurred with this statement. They mentioned, that during the lesson they

usually use books or presentations, and they are not able to see such details there as in VR. Also, the possibilities of VR are much greater than in books, where are only limited pictures and information.

When we look and the biggest pros of VR, we can see that 14 students chose a 3D representation of objects (Figure 14) and 10 students selected graphics, which are the biggest benefits according to the audience. This is closely connected to the overall rating of graphics in Figure 12. This outcome could be very valuable for teachers when selecting the applications. Nowadays, there are many applications suitable for geography teaching, but not all of them have really good quality. Also, from Figure 14 it looks like graphics is more important than a better understanding of geographical processes. According to 21 students, teaching with VR was more fun than classical teaching so they probably focused more on the content of a particular app and not explicitly on geographical connections. Teachers should also take this into account and prepare the teaching lesson as a combination of VR and others tools. The worst-liked feature was selected the control of the application. We can see that only one student liked it and 11 students did not like it (Figure 15). The language of the application is also important for 7 students. In some cases, it does not matter, which language is used because an application does not include many written texts. But for example, Google Expeditions is only provided in the English language and this could be a big con for some students.

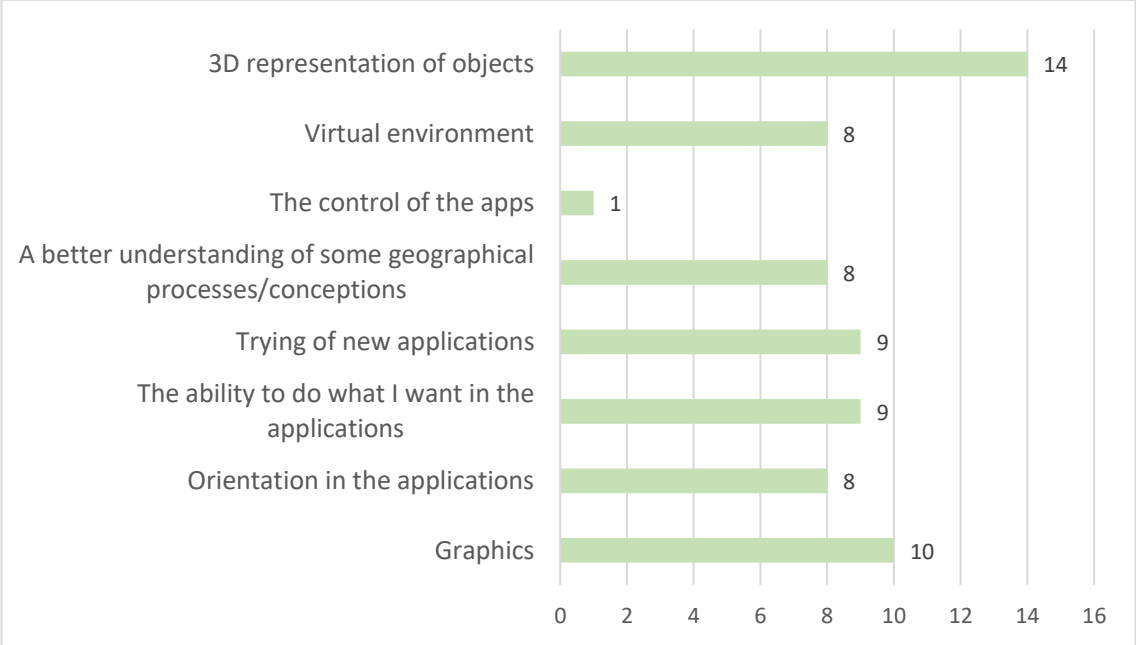

Figure 14 Things that students liked about VR.

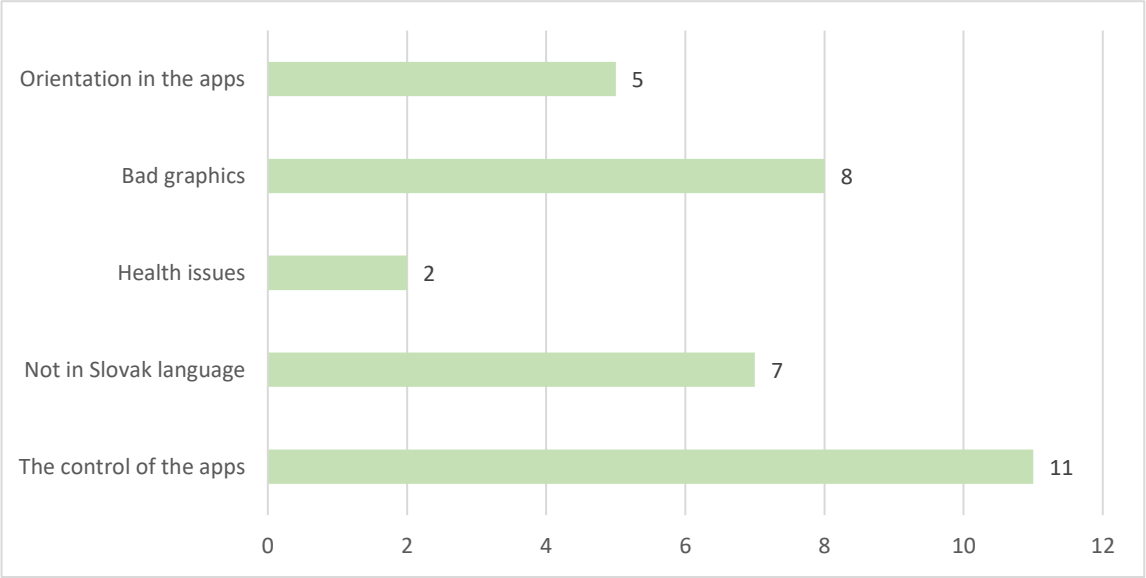

Figure 15 Biggest problems with VR.

5 Conclusion

In my thesis, I investigated the use of AR and VR during the geographic class. I focused on the students' reactions, the ability to prepare for such a lesson if this technology could help students in learning or during the repetition, and also if this helps in the improvement of the geographical competencies of students.

In general, I confirmed that using AR or VR during geography classes was very interesting for students and had a positive impact on them. Students liked the whole activity; the teaching was interesting and the lesson itself was more fun for them than the classical lesson. Students agreed that this technology provides more possibilities than books or presentations. This allows them to get to know and see more scenes than those printed in books. Also, pictures are usually at 360° so we can observe a particular place from various sides. This is unfortunately not possible when looking at pictures in the book. Since students found this very interesting, this technology could also awaken their interest in the study and attractiveness of geography. 17 students also like the idea to use this technology in the future during teaching. According to my results, I would say that this technology could be a big benefit to use during some specific lessons, exceptionally in regional geography.

VR and AR also helped some students in learning new information. This, however, depends on the selection of applications. Some applications are unfortunately oriented only on one area and will not help students in anything else. And if this particular area/topic is easy to understand, VR will not help students at all. For the application LandscapAR, only eight students reported that AR helped them in understanding what contours mean. Better results were for Google Expeditions, where 11 students better understand the differences between planets after one expedition using VR. The selection of applications is very important and crucial for this activity. Teachers should take into account the selected topics, and also information provided in the app. Some applications are designated for AR and some for VR. In my research, the best results were for the VR application Google Expeditions. Using special headsets during class was something new for students and they were really happy to try it. This can indicate, that applications for VR could have a better impact on students and could motivate them during the lesson. Another aspect that students selected as important was the graphics. This is connected to the quality of the content, health issues, and also to the selected technology. Mobile

phones have different screens, some are better than others and this has an impact on the overall experience. If the screen is not that good, students could experience blurred vision, a headache, or eye pain. Unfortunately, if the school does not have its own mobile phones, this issue could be a problem during this activity and various students will have a different experience. The best way would be to buy own devices with the same quality which I recommend.

If we want to motivate the students to learn something new, usually it is not good when we forced students to do something they do not like. But virtual reality could help. Especially some applications where students have control over the environment – they can do and see what they want. They are not dependent on the teacher but they are trying to find information or pictures which are interesting to them. They create their own experience which can help in remembering new things. Also, VR and AR helped them to understand connections and relations in geography which are hard to imagine. I confirmed findings by Shelton and Hedley (2002) and Kerawalla *et al.* (2006).

This technology also helped students in their communication and problem-solving. Unfortunately, many technical issues could be experienced during the process. But since mobile phones are very popular among students, they were motivated to try to solve the problem as soon as possible even without my help, sometimes with their classmates. They were also helpful when somebody else had an issue. When focusing on communication, students try to talk to each other, especially when trying LandscapAR. They presented the results to their classmates and this help them to interpret the 3D model of the picture. Also, Google Expeditions could help in their explanation, because they can describe the scene itself, where they have to think about how to express their thoughts.

When thinking about using this technology during class, teachers should take into account several things. It could be time-consuming to prepare everything and usually, it will not be possible to show everything during one class. The infrastructure is a crucial thing. The quality of the wi-fi network, the ability to join the internet or to have a hotspot, and related limitations could also have an impact on the prepared plan. Also, using phones during the lesson could be very tempting to use them for something else, like social networks, videos, etc. In such a case, students will focus more on the internet than on the lesson. The last important thing that could occur is health issues. It is very important to observe students if they do not experience any side effects and if so, the activity should

be immediately stopped. For students, this new technology could be a small shock and it is not good to use it for a long period. Also, if possible, it is better to have another teacher present in the class.

The main contribution of this thesis to the existing literature could be mostly by the rich summary of the history of AR and VR, especially in education and geography, and by the results of the research in elementary school. On the other hand, the limitations of this thesis I see in the relatively small number of students who participated in the research, where results could be a bit biased. Unfortunately, because of the Covid-19 situation, it was not possible to have more students participate. Another limitation could be the selection of only three applications. There are many applications oriented on various topics which could be used. This could be an interesting idea for future research to use more applications during a longer period. The last limitation of this research is no comparison between different classes in the same grade, where one class is learning using AR/VR and the second one is not using this technology. The differences in the learning process could be interesting and could also support, if this technology is a contribution to the teaching process or not.

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Appendix

Questionnaire before the demonstration

1. Name
2. I am
   a. Female
   b. Male
3. Fill in your grade
   …
4. Did you know the term Virtual and augmented reality before the demonstration?
   a. Yes, I have already heard about it and tried it
   b. Yes, I have already heard about it but never tried it
   c. No, I have never heard about this term
5. Where did you get in touch with VR/AR?
   a. School
   b. Cinema
   c. Gaming
   d. Another place
6. How would you describe VR and AR in your own words?
   …

Questionnaire after the demonstration

1. Name
2. How would you describe the use of VR/AR applications on the mobile phone?
   a. Very interesting b. Interesting c. It did not interest me
3. What did you like about VR/AR the most?

   a. 3D representation of objects b. Virtual environment

   c. The control of the apps

   d. A better understanding of some geographical processes/conceptions

   e. Trying new applications

   f. The ability to do what I want in the applications

   g. Orientation in the applications h. Graphics

4. Teaching using VR was very interesting for me
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
5. Graphics in the application is important
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
6. VR helped me in learning new information and in the repetition

a. Agree
b. Neither agree nor disagree
c. Disagree

7. I learned new information while using VR
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
8. The use of the applications caused me some side effects
   a. Blurred vision b. Dizziness c. Stomach ache
   d. Eyes pain e. Nausea f. Headache
9. The biggest issues while trying VR/AR applications were
   a. Orientation in the apps b. Bad graphics c. Health issues
   d. Not in Slovak language e. The control of the apps
10. Teaching using VR/AR was more fun than a classic teaching
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
11. I would like VR/AR to be used during a teaching in the future
    a. Agree
    b. Neither agree nor disagree
    c. Disagree

Questionnaire – Application Earth AR

1. I really like the application Earth AR
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
2. The application Earth AR was easy to use
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
3. The orientation in the application Earth AR was simple
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
4. The graphics in the application Earth AR was excellent
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
5. Application Earth AR helped me to better understand what the surface of Earth looks like
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
6. I liked the application Earth AR because of
   …

Questionnaire – Application LandscapAR

1. I really like the application LandscapAR
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
2. The application LandscapAR was easy to use
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
3. The orientation in the application LandscapAR was simple
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
4. The graphics in the application LandscapAR was excellent
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
5. LandscapAR helped me to imagine the real surface of the world when looking at the map
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
6. It was a bit hard to understand what contours are, before the use of LandscapAR
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
7. I liked that I could draw any shape when using LandscapAR
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
8. I liked the application LandscapAR because of
   …

Questionnaire – Application Google Expeditions

1. I really like the application Google expeditions
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
2. The application Google expeditions was easy to use
   a. Agree
   b. Neither agree nor disagree
   c. Disagree
3. The orientation in the application Google expeditions was simple
   a. Agree
   b. Neither agree nor disagree
   c. Disagree

4. The graphics in the application Google expeditions was excellent
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
5. I liked the option that I could follow what the teacher selected
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
6. It was hard for me to compare different planets before using Google Expeditions
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
7. It was interesting for me to visit various countries around the world
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
8. The ability to get to know various countries was very interesting for me
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
9. Using this app, I could see the differences in various countries around the world
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
10. I liked that I could visit places which I cannot visit ordinarily
    a. Agree
    b. Neither agree nor disagree
    c. Disagree
11. I liked the application Google expeditions because of
    …