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Affordances of Augmented Reality for Education:

Case study of MoleQL – Mobile Application for Learning Chemistry

Master's thesis

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Augmenteeritud reaalsuse positiivsed omadused hariduses: MoleQL-i näitel - mobiilirakendus keemia õppimiseks

Magistritöö

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

Effective and digitally proficient educational system is an integral part of the development of information society. Therefore, many countries are actively deploying information and communication technologies into their educational systems to achieve the goals of e-governance and develop the 21st-century skills in current generation of digital natives. However, the educational reforms are often done for sake of change and do not always consider all the aspects of the usage of digital solutions at schools.

Augmented reality is one of the exponential technologies that has high potential to impact how school materials are taught and learnt. Currently, the technology is only at early stages of development but it is evolving at a disruptively fast pace. This research is an attempt to explore the affordances of augmented reality for educational domain. The study presents the state of art, previous attempts to use augmented reality for the educational purposes and concentrates on the features of augmented reality that bring additional value to the education.

Research was done by collecting quantitative data from the surveys with educators and pupils and deriving qualitative data from the comprehensive teacher interviews which constituted to the core findings of this study. Quantitative data was analysed with the apparatus of descriptive statistics, while qualitative data was interpreted by the means of thematic analysis. Interview respondents were demonstrated with the prototype of the mobile application with augmented reality called MoleQL which allows to visualise basic chemical reactions on the screen of the mobile device by scanning and combining paper cards.

Study identified the main problems in modern educational system and gave the overview of how some of them can be addressed using augmented reality as a learning tool. Findings of the study indicated that augmented reality is considered to be an efficient and engaging way to present complex natural phenomena and can be especially useful for teaching sciences.

This thesis is written in English and is 49 pages long, including 5 chapters, 15 figures and 0 tables.

Annotatsioon

Efektiivne ja digitaalselt kompetentne haridussüsteem on informatsiooniühiskonna lahutamatu osa. Seetõttu rakendavad mitmed valitsused informatsiooni- ja kommunikatsioonitehnoloogiaid oma haridussüsteemis, et saavutada e-valitsuse eesmärgid ning arendada 21. sajandi oskuseid praeguses digitaalajastu generatsioonis. Paraku juhtub tihti, et haridusreformid on tehtud lihtsalt selleks, et neid teha, tihti ei arvestata kõiki digitaallahenduste aspekte, mida üritatakse koolides rakendada.

Augmenteeritud reaalsus on üks kasvavaid tehnoloogiaid, millel on kõrge potentsiaal mõjutada kuidas õppematerjal on koolides õpetatud ja õpitud. Hetkel on tehnoloogia oma arengu varajases staadiumis, kuid ülikiiresti arenev. See uurimustöö on katse uurida liitreaalsuse positiivseid kasutamisvõimalusi haridussüsteemis. Uurimus esitleb tehnoloogia hetkeseisu, katseid, kuidas augmenteeritud reaalsust on üritatud hariduses rakendada ning keskendub selle tehnoloogia võimalustele loomaks lisaväärtust hariduses.

Uurimustöö sai tehtud kogudes kvantitatiivseid andmeid küsitledes haridustöötajaid ja lapsi ning õpetajaid intervjueerides kogudes kvalitatiivseid andmeid, mis kinnitasid uuringu peamisi leide. Kvantitatiivseid andmeid analüüsiti kasutades kirjeldava statistika uurimise meetodeid, kvalitatiivsed andmeid on tõlgendatud kasutades temaatilist analüüsi. Intervjuu vastused on demonstreeritud liitreaalsusel põhinevad nutirakenduse prototüübil MoleQL, mis laseb kombineerides omavahel paberist kaarte ja neid mobiiltelefoniga skaneerides, visualiseerida keemilise reaktsioone.

Uurimus identifitseeris peamised moodsa haridussüsteemi probleemid ja andis ülevaate kuidas osadele nendest saab läheneda kasutades augmenteeritud reaalsust õppevahendina. Uurimustöö leiud viitavad, et liitreaalsust peetakse efektiivseks ja kaasahaaravaks viisiks keerukate loodusnähtuste esitlemiseks ja võib olla eriti kasulik loodusteaduste õpetamisel.

Lõputöö on kirjutatud Inglise keeles ning sisaldab teksti 49 leheküljel, 5 peatükki, 15 joonist, 0 tabelit.

List of abbreviations and terms

AR	Augmented reality
AV	Augmented Virtuality
EdTech	Educational technology
ICTs	Information Communication Technologies
MR	Mixed reality
STEM	Science, Technology, Engineering, and Mathematics
UI	User interface
VR	Virtual reality

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1 Introduction and motivation

In modern world, countries need to be digitally-savvy and the level of effectiveness and sophistication of public services often identifies the prosperity and competitiveness of the country on macroeconomic level. Education can be considered as a public service and the level of its development relies not only on the educational programmes but also on the usage of information and communication technologies (ICTs). The heavier the usage of ICTs, the more developed information society is. Therefore, deployment of the products of the technological advancement into educational systems is vital for fostering the 21st-century skills in current generation. One of such technologies is augmented reality.

Augmented reality (AR) has been a widely-discussed topic in the technological industry already for a few years. However, adoption of the technology that enables users to overlay virtual objects into reality is still an ongoing process. The situation has slightly changed in July 2016 when the world heard of Pokémon Go – location-based augmented reality application for collecting virtual characters in the real-world surroundings. This application acquired millions of users and spread the word about the technology but brought only little additional value besides entertainment. In fact, augmented reality can be used for numerous other purposes and spheres, like engineering, healthcare, education, military, retail, life events, etc. This *thesis' primary goal* is to research which effects and benefits the technology of augmented reality can have in the educational domain. Thesis' goal comes from the *problem* that current educational system spends substantial amounts of money every year but still lacks innovativeness and effective teaching methods.

As a bridge between virtual and real worlds, augmented reality offers many opportunities for studying which has been increasingly interesting for the educational researchers. However, empirical studies on the effects of augmented reality on teaching and learning had limitations in terms of evidence. This study is not aiming to resolve this limitation due to the restricted time frame and its main *research question* is *how augmented reality can be beneficial and valuable in* and the author will use the case study of MoleQL, a mobile application for learning chemistry, for demonstrating the mechanics of the technology.

The sub-questions that open up the main research question are the following:

- How augmented reality can address the problems that exist in the educational system?
- How educators perceive augmented reality and how they see its potential?
- How can augmented reality be incorporated into teaching and learning processes?

The *key objectives* which will help to answer the research question are:

- The first objective is to outline theoretical framework behind the technology of augmented reality, define its current state and application in the educational sphere.
- The second objective is to clarify the effects and features augmented reality offers for teaching and learning.
- The third objective is to conduct a series of interviews with practising teachers to identify the opportunities and challenges of AR in education following the methodology of the qualitative research. The interviewees will be done along with the demonstration of the mobile application MoleQL for the illustration of the affordances of AR.
- The fourth objective is to synthesise theoretical knowledge with practical outcomes from the interviews and identify the findings.
- The fifth and final objective is to define the limitations and practical recommendations for the integration of augmented reality solutions into the educational settings.

When the objectives have been covered, it is expected to achieve the set of recommendations for incorporation of AR applications as a tool used in the formal education. The main *artifact* in this study is a mobile application with AR for learning Chemistry.

The research follows the order of the defined objectives. The first chapter, *Literature review and theoretical concepts,* explores the theoretical framework of augmented reality, provides an overview of allowances of AR, such as visualisation of complex spatial relationships or abstract concepts, and gives the review of previous theoretical and empirical papers that addressed questions of how AR can be used for educational purposes and gives context of current state of art. Analysed resources not only include academic articles but also industry reports which helps to present the bigger picture and outline possible future development scenarios of the market.

The second part of the research concentrates of the methodology used for this master's thesis. Augmented reality is analysed with the help of conducting qualitative interviews with education practitioners. In this chapter, the author presents the broad description of research questions and main hypotheses for the research, introduces the case study of MoleQL and describes data collection, analysis and validity procedures.

The third chapter expands on MoleQL case study and describes features, user mechanics, benefits and competitive advantages of the mobile application. In this part, the author describes the main teacher interviews, surveys with pupils and teachers and testing outcomes. Then the results are validated.

The fourth and final chapter brings to the light the summary and findings, their implication and relation to the existing evidence and limitations of the research. Then opportunities of the future work are presented.

The *novelty* of this research is that it is one of the few researches that use visual augmented reality, most of them concentrate on location-based AR. Furthermore, it is the first study that uses MoleQL to prove its benefits for the point of view of teachers. It presents the opportunity to dive into the actual development of a start-up project that deals with augmented reality. The results will be used in the ongoing and development of MoleQL application, which brings practical value to the research.

2 Literature review and theoretical concepts

If we look at the classroom fifty years ago and nowadays, we will notice that not much has changed in the instructional style. If we compare the way assessment is done, it would be even harder to see the difference.

Teachers in some countries have received an opportunity to use LSD projectors, laptops and tablets. However, these resources are hardly backed up with the content of high quality that brings much additional value. Even more, the range of educational solutions is so wide and confusing that teachers simply don't have enough time to make a choice and, most importantly, deploy the selected product is the classroom.

In this chapter will introduce augmented reality as a term, define its taxonomy, give an overview of the market conditions and present the feature of augmented reality that make it a valuable tool for teaching and acquiring knowledge.

2.1 Definition and taxonomy of augmented reality

Term "augmented reality" (AR) has been defined diversely by different researchers of educational technology and computer science. One of the fundamental definitions appeared in the paper of Milgram, Takemura, Utsumi and Kishino [1] and divided into two approaches: broad and restricted. Broad approach refers to AR as "augmenting natural feedback to the operator with simulated cues." Restricted approach, in turn, focuses on technology aspect and defines AR as "a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world." [2, p. 283]

Azuma later presented a definition of AR based on its key characteristics as a system that fulfils the following three features:

- a combination of real and virtual worlds;
- real-time interaction;
- accurate 3D registration of virtual and real objects. [3]

Klopfer, by contrary, was against restricted approach and indicated that term augmented reality can be used for any technology that mixes real and virtual information in a meaningful way. However, today when augmented reality could be created and deployed by various technologies like desktops, tablet, mobile devices, head-mounted displays, it would make sense to use broad notion of augmented reality. [1]

To look at the taxonomy of augmented reality, it is important to describe the extent to which reality is augmented. Milgram offered for this purposes Reality-Virtuality continuum that ranges from real environment to virtual one. The graphical representation can be seen in figure 1.1 and it gives the understanding of mixed reality which is a situation where real and virtual world objects are presented together. [2]

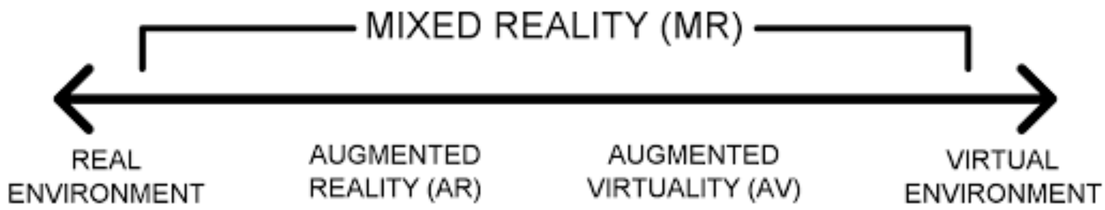

Figure 2.1 Reality-Virtuality continuum by Milgram et al.

Per the continuum, AR is a combination of real and virtual elements and includes more real than virtual ones. On the other hand, augmented virtuality (AV) is defined as a situation where virtual environment is enhanced by the elements of reality and includes more virtual information.

According to Klopher, AR and AV can be also distinguished by weight of augmentation. He offered two types of situations: lightly and heavily augmented reality. Lightly augmented reality is a situation in which user is highly depends on the real environment information. [1]

In order to understand the bigger picture and scope to which AR can potentially have effect, in the next section will be presented market research and available solutions for education.

2.2 Market and application of augmented reality application education

According to the forecasts in Markets and Markets Report, the global mobile AR and VR apps market will grow at the compound annual growth rate of 75.72% during the period 2016-2022. [4]

Looking closer into education, augmented reality, as one of the biggest trends in educational technology for 2017, has a potential to disrupt K-12 and higher education software markets. It could become a common tool for educators and revolutionise how students are taught. By the estimates of Goldman Sachs report, by 2025 AR/VR market has the potential to attract 15 million users and bring proximately $700 million [5] in revenue to the software companies. AR represents approximately 25% of overall market size but potentially could cut even bigger slice of the pie. Overall, education is not seen as the high revenue generating sector but can greatly grow general adoption. [6]

The biggest challenges that could prevent positive scenario are the number of people accustomed to technology, strapped budgets for education and new quality content creation. All of them could limit the uptake of the market.

Overall, AR is a powerful visualisation tool that provides students with an opportunity to learn by interacting with objects in three-dimensional environment. New Media Consortium/CoSN Horizon Report in 2016 estimates that adoption period will take from 2 to 3 years and its level will define the investment opportunities of the market. [7]

Unlike virtual reality, AR does not necessarily require special equipment like head-mounted displays (HMDs). As the processing power of smartphones is increasing every year, there are more and more devices that have capacity to be used for AR detection. For example, in 2016 Lenovo launched PHAB 2 Pro. It is the first smartphone ever to support Tango Project developed by Google. This technology allows depth tracking, basically, to ‘see the room’. [5]

Recently Asus introduced ZenFone AR which also supports this technology and the list is likely to expand making AR a common hardware capability. [8]

To look deeper into application of the technology in education, the author will give the examples of actual educational AR applications. Augmented reality apps in general and, specifically, those used in education, can be divided into 2 categories. First includes the ones that already have augmented content and user just needs to "activate" it by scanning the target. Second category are apps or platforms that have their own authoring tools which enables users to create their own AR content.

Aurasma falls into the second category. Founded in 2011, *Aurasma* is based in London and it is one the world's leading AR platforms. It is a drag-and-drop web studio where teachers, students or anyone else can create augmented reality experiences, so called, auras. Targets like images, objects or physical locations can be easily brought to life with interactive digital content as well as shared with others. [9]

Netherlands-based company called *Layar* was found in 2009 and offers mobile augmented reality browsers and interactive print tools. Educators mostly use *Layar* to augment posters on different topic or create geo layers. Pupils is Spain, aged 9-10 years, hand-crafted posters illustrating the functions of the human body systems. They used *Layar* creator to add digital assets they found online to physical posters and it helped them to understand the basics of biology. [10],

French company *Augment* provides an end-to-end solution for configuring, managing and viewing 3D content in augmented reality. It offers free licences for educators, students and academic institutions. Students who use *Augment* pursue careers in architecture, engineering, 3D animation and design, medical sciences, etc. The Department of Classics at the University of Reading, for example, used Augment and tools for 3D modelling to create a detailed historical tour in ancient Rome for the students to explore eternal city by themselves. It allows a far more dynamic engagement with the site during field trips rather than just looking through the lecture slides. [11]

Talking about apps which do not have tutoring tools in addition, *Anatomy 4D* gives the chance to explore the human anatomy in 4D. Student can study the entire body or look through the details of separate organ systems. There is also a spectacular model of human heart. It was developed by DAQRI which specialises in computer vision and AR hardware. Target images can be downloaded online or from the library that comes with the app. [12]

Latvian *Anatomy Next* is very beneficial for medical students as it contains incredibly accurate 3D anatomy models that can be visualised in AR and, what is important, are validated by the academics in medical field. Authors claim that models can be used to support the curriculum and enhance students' skills in spatial visualisation of anatomical relationships. This application can be used as initial step to prepare students and interns of medical specialisations to get more knowledge of surgical procedures. [13]

MoleQL which will be used for the case study is an AR solution for learning Chemistry. It is being developed in Estonia and helps students to overcome the hardness of studying science by visualising chemical elements and providing background information on their application in the environment. The target paper cards can be scanned separately or combined to form chemical reactions - like but safer and more cost-efficient for educational institutions. The solution has received much feedback form educators and students. [14]

Above-mentioned list of educational AR apps is far from complete but it gives an insight that augmented reality brings learning to life and makes it far more engaging than current system. The biggest challenge for educators might be the creation of 3D content in case they want to use completely new models as it requires quite complex skills and knowledge.

2.3 Features of augmented reality for education

Augmented reality is a technology used for games creation. Therefore, the author will analyse it from the point of view of game-based learning.

Studies show that game-based learning has been recognized as a helpful tool in enhancing learning by making it more fun and engaging. According to Prensky, games that combine educational objectives and subject materials may hold the potential to make the learning of academic subjects more centered on the learner, easier, more enjoyable, more interesting, and, thus, more effective. [15]

Instead of using traditional teaching approaches, the students can actively process the information and come up with a solution. Tasks completion in the game responds better to the needs of contemporary work environment where processing and analysis of information are crucial. [16]

It is important to foster education, acquision of new skills for future. In 2016 World Economic Forum presented the research where it recognised that there is a gap between the skills people learn and the skills they need an it is becoming even bigger. Traditional learning is no longer equipping students with the knowledge they need in their future careers. As a result, there was a set of 16 skills derived - students need them in the 21st century to be competitive, the summary is presented in Figure 2.2. [17]

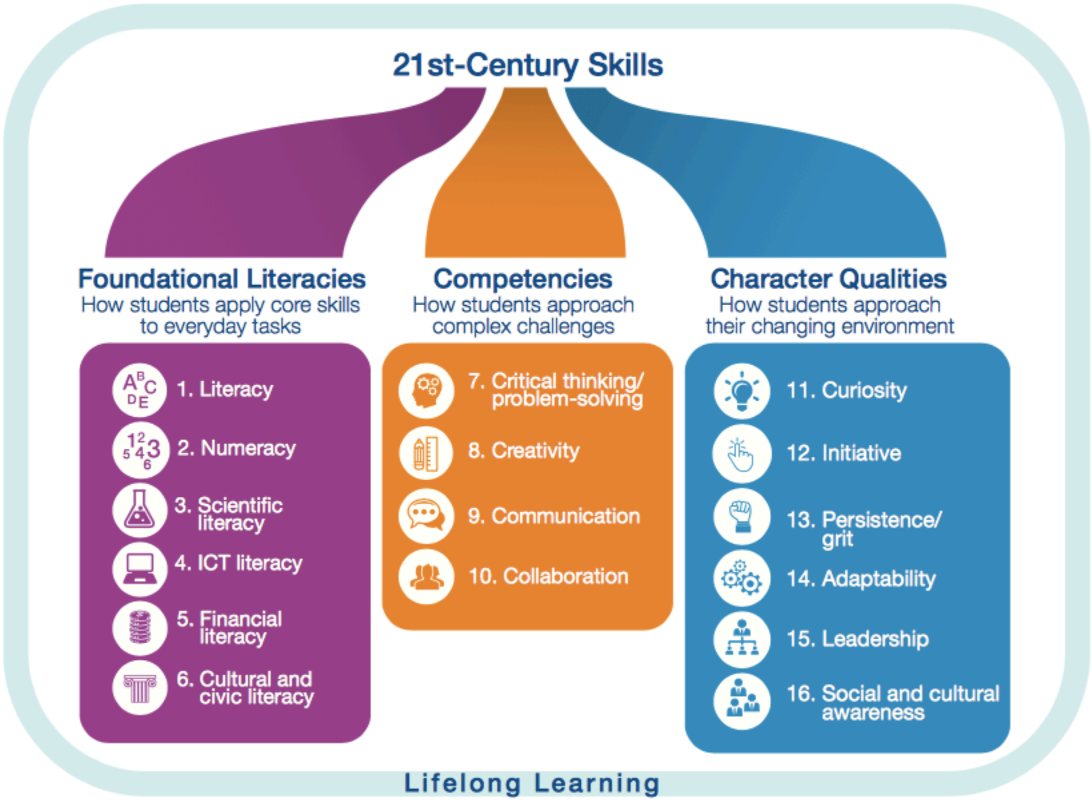

Figure 2.2 21st century skills *(source: World Economic forum, New vision for education report).*

One of the ways to foster this skill set is to incorporate play-based learning where augmented reality can play sufficient role.

To define the features and benefits of AR for education, the author will turn to the research conducted by Wu et al. [18] whose research outlined several affordances of AR for educational purposes:

- 3D virtual objects that learners can learn with 3D objects to observe and model physical phenomena.

To illustrate this, Kerawalla et al. presented an example of using 3D augmented reality for teaching astronomy. The study, which included AR projected on the whiteboard and traditional teaching session with physical 3D models, showed that that teachers realized the benefits of using 3D and acknowledged that AR can make inaccessible subject material available to students. The limitation of this study was absence of the proof that AR was significantly more beneficial than real-world 3D models. [19]

- AR can provide representation of otherwise invisible concepts and events or those that are hard to observe.

This quality is also present in MoleQL which will be presented in more details in the upcoming chapters.

- Real-life problems can be situated in the collaborative instructional scenarios.

The concept of situated learning is a theory that describes the process of learning as vey social, embedded in the lives of students. Mobile AR system could provide situated learning enhanced by computer simulations, games, models, and virtual objects in real environments. For example, in *Environmental Detectives* described by Klopfer pupils learnt outside the classroom by using handheld computers to make the investigations and gathered data for specific locations, analysed it and offered solutions. [1]

- AR could enhance learners' senses of presence, immediacy, and immersion.

Students could feel themselves present in place with others while being immersed into the game.

- Finally, AR can make the connection between learning in formal and informal settings.

For example, CONNECT project used AR to develop a virtual science thematic park. It had two modes: school mode (formal) and museum mode (informal). [20]

All in all, these are the basic affordances of AR and some of them will be presented in practical part of the research.

3 Research methodology and hypotheses

As mentioned before, this research has a strategy of case study. The following sub-chapters will present the research questions, hypotheses derived from the questions, describe why case study method has been selected, introduce the data collection procedures as well as methods of data analysis and validity.

3.1 Research questions, propositions and hypotheses for the research

In one of the previous chapters the main research question and its sub-questions have been introduced. In this section, the author will provide the detailed explanations why these exact questions were chosen.

The main research question is: *How augmented reality can be beneficial and valuable in classroom from teachers' point of view?*

Key goal of this research is to test whether augmented reality can be beneficial in educational sphere and define in which ways it can influence learning and teaching. According to Shanks, propositions are deduced logically and may be considered more specific versions of the research questions. They provide further details to the inquiry. Hypotheses are generated from the propositions. [21]

For formulating the research proposition, research questions are reworded in the form of *If…then* predictions and accompanied with the corresponding hypothesis.

Research question 1: How augmented reality can address the problems that exist in the educational system?

Research proposition 1: If problems in educational system exist, then augmented reality can a tool for addressing some of them.

Research hypothesis 1: Augmented reality can be a useful tool for addressing some of the teaching problems.

To be able to state that augmented reality can bring about change, it is vital to identify which problems exist in modern educational system. When problems are clear, it is possible to make imply the conclusions how they can be addressed with the help of technology and to what extent.

Research question 2: How educators perceive augmented reality and how they see its potential?

Research proposition 2: If teachers adopt the technology, then it has the potential to be valuable learning tool.

Research hypothesis 2: Augmented reality can be well perceived and adopted by the teachers.

As AR is quite poorly adapted by the society, this sub-question aimed to identify what is the attitude towards it teachers have. As a lot of teachers do not even know of the existence of this technology, first teachers were approached with the definition of AR a visual tool for explaining study material within condensed timeframe.

Research question 3: How can augmented reality be incorporated into teaching process?

Research proposition 3: If augmented reality is deployed into the classroom, then it can increase pupils' engagement and provide visual explanation for the complex topics.

Research hypothesis 3: Augmented reality in the classroom can used for explaining study materials more efficiently.

Education is traditional and resistant for change field. Therefore, this research had the aim of finding out how to approach the teachers to present the value of AR tools and encourage them to use educational games inside the classroom.

3.2 Case study method selection

Case study method has been selected to construct the research. As outlined by Yin, case study can be defined as "an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." [22, p. 13]

Synthesizing definition from different studies, the condition case study can be outlined. This research fits the definitions as it involves real-life context of the studied phenomena, uses multiple sources of information, the studied phenomenon does not have clear boundaries with context and there is a lack of experimental control present. This methodology allows to pursue the objective of not only increasing the knowledge about the topic but also bringing about change about it – in this case, discovering ways to improve education. [23]

According to Robson, there are three types of purposes for the research: exploratory, descriptive, explanatory, improving. Current study is exploratory – it is an attempt to explore the current state of augmented reality in educational context, searching new insights, generating ideas and hypotheses for the further studies and tests. [24] The design type allowed the research to be more flexible. It has quite high degree of realism and low level of controls.

3.3 Data collection procedures

Data for this study was collected through the surveys and interviews, that is a first-degree method. Surveys contributed to the collection of quantitative data and were an attempt to explore the topic to prepare the ground for more complex and rich in data interviews. Teachers survey involved the collection of data from 46 educators who mainly teach Chemistry of other sciences. For the pupils' survey 25 respondents were selected. Prior the survey they were demonstrated the prototype of MoleQL mobile application during Chemistry lesson at one of the schools in Estonia and were familiar with the technology. Pupil's survey has been done to check whether similar conclusions hold if getting the data from different kinds of respondents.

Interviews facilitated the study with qualitative data - the core source for the research. The use of qualitative case studies is a well-established approach in case study methodology. The form of interviews allowed to be in direct contact with the interviewees and collect rich content data in real time. Interviews involved 3 respondents – 2 teachers of Chemistry and teacher of Mathematics. As this study concentrates on the point of view of educators, no qualitative data has been collected from the pupils except for the real-time feedback during chemistry lesson.

Important to note, that both quantitative surveys were conducted in cooperation with the author's colleagues who also write the research on the topic augmented reality but focus on different angle of analysing AR in education.

3.4 Analysis procedures

After the data has been collected, quantitative data has been summarised into graphs and has been analysed using the apparatus of descriptive statistics It is used to describe the basic features of the data in a study. Is provide the simple summaries about the sample, for example, distribution, percentages, etc. and usually use graphs for visual representation. [25]

Quantitative data allowed to get basic understanding of the current state of art and to prepare questions for the interviews more thoroughly. Qualitative data has been transcribed, translated if the interview was not conducted in English, and analysed using categorisation and sorting. Analysis method used was thematic analysis which is common for qualitative data. It consisted of examination of data and recording pattern, or themes in it.

According to Braun, thematic analysis includes the following phases:

- familiarization with data;
- generating initial codes;
- searching for themes among codes;
- reviewing themes;
- defining and naming themes;
- producing the final report. [26]

All these phases were conducted during qualitative data analysis, the resulting themes were mapped using the freemium software - XMind tool for mind mapping. [27]

3.5 Validity procedures

The validity of current empirical research was ensured by the means of triangulation. It suggests taking multiple perspectives towards studied phenomenon and, therefore, providing a broader picture. [23]

Firstly, the study involved data source triangulation - data collection from different sources. Teachers and pupils accounted to the conclusions from different points of view.

Secondly, methodological triangulation has been involved. It means that different types of data, qualitative and quantitative, were collected and combined. As a result, qualitative data facilitated the research with broader and richer results, but lacked precision. This precision has been provided by the means of quantitative data collection and analysis.

Finally, the results of this study were peer-reviewed by other students who work on the usage of augmented reality in education.

4 Case study of MoleQL - mobile application for learning Chemistry

This chapter is the most important part of the research and presents a detailed description of the characteristics an augmented reality application used for the demonstration and gives an opportunity to see in detail what makes augmented reality such a promising technology for education and what does it have to do with traditional learning theories and practices. Chapter contains the detailed description and analysis of the conducted qualitative and quantitative researches.

4.1 Overview of MoleQL augmented reality application

Teaching and learning sciences is a complicated matter and has a high level of abstraction. Therefore, it is vitally important to ensure high effectiveness of usage of teaching resources and make the selection of additional tools as efficient as possible.

Chemistry requires the knowledge and understanding of complex specific vocabulary. It sounds and is written not as something kids have encountered before. Gaming approach can help to seamlessly develop this essential skill.

As Gee outlined, children develop vast vocabularies and language constructs while playing Pokémon (in this case, not even an AR game). There are so immersed into the gaming experience that after a while become the experts of this language and prepare themselves for action in the domains in which the specialist language is used. Kids construct new knowledge based on the experiences they have had before in order to understand new things a classical explanation for the constructivist learning theory. [28, p. 4]

The same principle can be applied to learning any of sciences and is pupil are base their knowledge with familiar analogies, the process of constructing knowledge is much more effective. MoleQL is being developed by Estonian company Subatomic OÜ with this thought in mind: the usage of augmented reality should help to bring familiar context into learning, both physical and cognitive.

The operation principles of MoleQL are simple. Firstly, the user needs to install the mobile application on a handheld device – a smartphone or a tablet. Secondly, to use the app, he/she should download and print out the paper cards each of which represents different chemical elements. When both points are done, user can scan the paper cards with the mobile device and the application will retrieve and render 3D animations of chemical substances floating above the card within user's natural environment. Besides, what brings large value, is the face the user can combine 2 or more cards together, add the condition like temperature and see how a certain chemical reaction occurs. In the following section the author will give the review of existing and planned feature of MoleQL.

4.2 Features and benefits of MoleQL

Augmented reality offers rich authentic experiences and serves as the foundation for creating memorable mental simulations that users can remember after using the application. As a combination of physical and virtual experiences, AR simulations are easy to recall and get accustomed with the concepts they demonstrate.

MoleQL aligns with above description and contains the following principles and this list is not exhaustive:

- *Memorability:* the users can easily recall the experience of using the application as it involves both usage of visual and physical memory as paper cards need to be physically put together in the right combination to run the reaction.

Hsu at al. recognised that visualization reduces students' cognitive load when they engage in tasks related to Science, Technology, Engineering, and Mathematics (STEM) as they use additional cognitive channels to process data. [29, p. 2]

- *High-quality content:* all materials that were used for the creation of educational content were thoroughly checked with the teaching practitioners.

Constant cycle of building, measuring and learning allows to create a qualitative product which takes into consideration user needs. This methodology is called Lean, it was originally suggested by Eric Ries and now it is widely used by start-up companies for building useful technological solutions. [30]

- *Gamification:* learning by playing and exploring is increasing pupil's engagement and captivating their attention.

AR is highly relevant technology for game creation, thus it provides support for learning based on the games along with discovery-assisted learning, as stated Cabero and Barroso. [31]

- *User-friendliness of user interface (UI)* – application offers straightforward user experience as it requires only to use camera roll.

This feature is still work in progress as the content grows are requires easy and logical systematisation. Therefore, additional parts of the user interface are being designed and tested.

Some of the features that are yet to be developed include:

- *Additional level of content* – the application will not only visualise chemical reactions but also provide the information on theory behind the processes being studied and the possible application of this knowledge in real life conditions.

- *Multi-platform support* – currently, the app supports only Android-based devices, iOS support will be added in the nearest plans.

- *Audio experience* – audio effects bring additional realism to the user experience and make it more familiar to the conditions of real life. It means that pupils can experiment with chemical substances like in a chemical lab where sound can be one of the signs of the successful reaction.

Overall, MoleQL is in theory a beneficial application, even though it is still a prototype. The results of exploratory testing with students are presented in the next section.

4.3 Testing MoleQL and the outcomes of quantitative surveys

As mentioned in the previous chapter, quantitative data has a supportive role for this master thesis. User testing and feedback is always richer with qualitative data. However, to support the methodology of the research and identify its direction, the author participated in a user testing and a follow-up questionnaire with the pupils.

Additionally, surveys were conducted with the number of teachers about the aspects of teaching sciences and the usage of educational games without demonstration of the app.

It is worth mentioning that it was not the first time MoleQL when has been demonstrated to the public. The team developing this mobile application has taken part in the number of hackathons, including Skype University Hackathon (the name at that point was 3Ducation), Mektory Start-up competition at Tallinn University of Technology, Startup Day Conference, Unconvention 2017 Innovation Forum, Cross Motion Conference and other. [32], [33], [34], [35]

Testing with pupils took place in one the schools at the Chemistry lesson of the 8th grade. Pupils were demonstrated with one reaction between Carbon and Oxygen.

The algorithm of steps during the demonstration followed these steps:

1. Scanning paper cards.
2. Combine 2 cards with the elements
3. Heating up the compound with specially assigned button as the reaction requires high temperature for Carbon to start burning. The representation of the same reaction can be seen on the Figure 4.1.

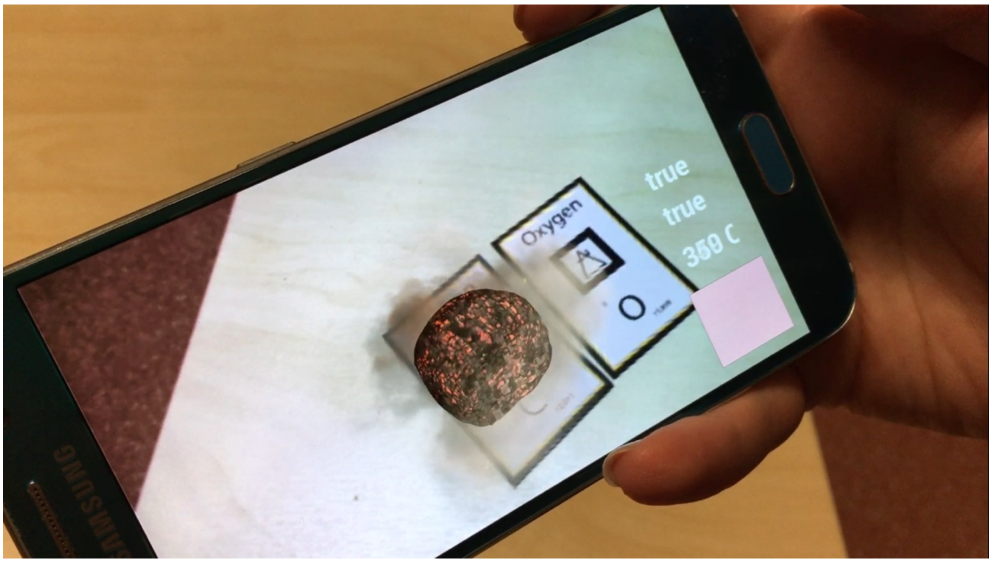

Figure 4.1 Sample demonstration of MoleQL in action.

The demo-video can also be viewed by scanning the QR code below.

Figure 4.2. Short demo-video with MoleQL.

Due to the limitations in equipment, testers used only 2 phones per whole classroom. Therefore, the class was divided into the groups of 2-4 people and application has been demonstrated to each group. This allowed to show the application only briefly but the general feedback was positive. One the pupils stated that it explained the process more efficiently than previously in the classroom without the usage of augmented reality or mobile devices.

After the testing pupils were offered to fill in the Google form with the questions related to the usage of educational games in the classroom, their motivation to study, the most challenging and appealing topic in Chemistry, etc. As a result, 25 responses were obtained.

Question about the usage of the educational games (Figure 4.3) showed that *48% of the respondents for not really use the educational games*. Another *48% use this kind of games sometimes* and *4% of the respondents reported frequent usage of educational games*. This can imply the following assumptions:

- Respondents who indicated that they do not use educational games might don't know how to define the educational game or do not consider these games as valuable in terms of additional knowledge.
- If 48% use educational games sometimes, then these games might lack the features to be more appealing and captivating.
- There is a small cohort of adopters that use educational games frequently and they should can influence the mass adopters. Especially, this is true for the emerging technologies as augmented reality.

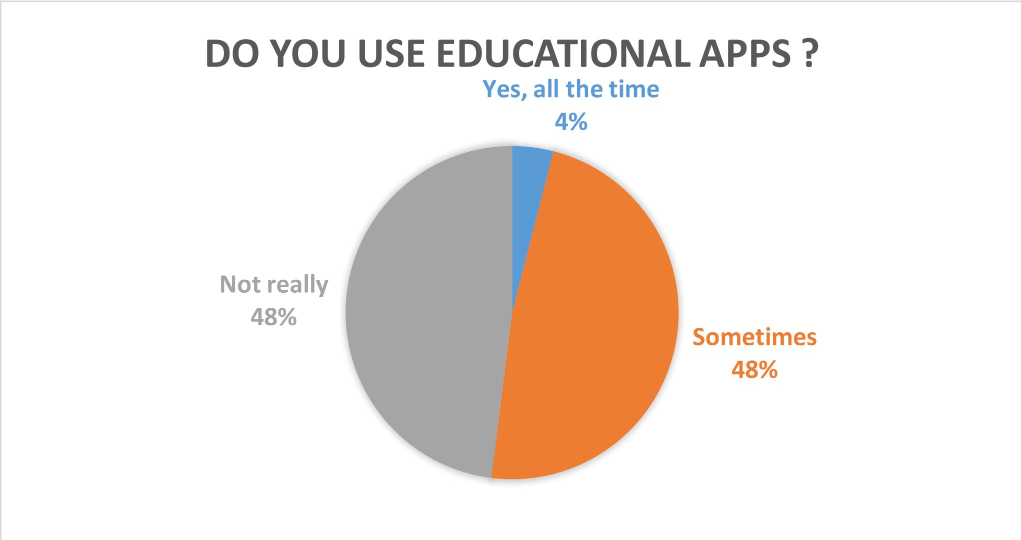

Figure 4.3 Survey for pupils: Do you use educational apps?

Part of the survey questioning about the usage of mobile phones in the classroom (Figure 4.4) exposed that *36% of pupils use the phone at most of the classes*, *40% use them sometimes* and *24% do not use mobile devices*. This result may be explained by the fact that not always student use their mobile devices for the educational purpose and may use them for private matters which is not encouraged during the classes.

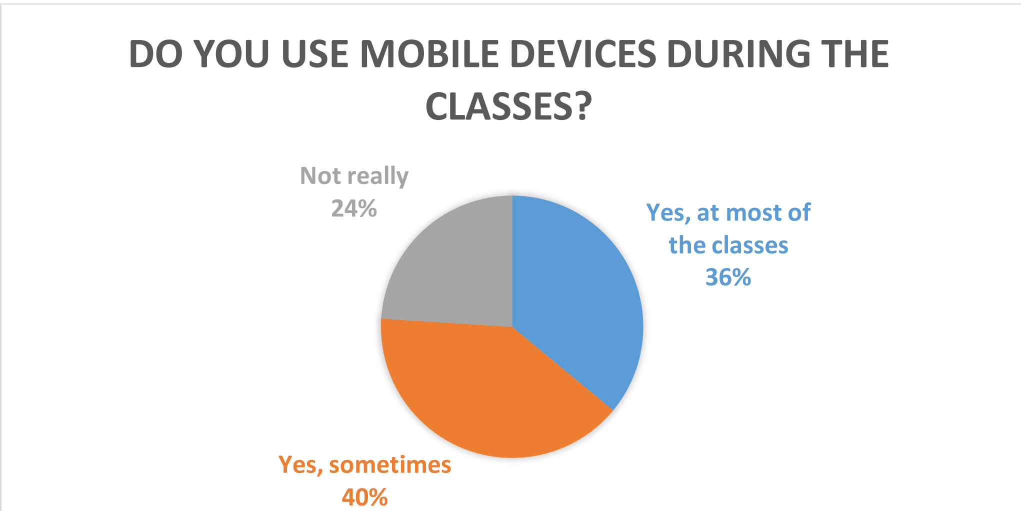

Figure 4.4 Survey for pupils: Do you use mobile devices during the classes?

Question "Would you like to use educational games in the classroom?" (Figure 4.5) revealed that *80% of the students would like to use educational games inside the classroom*. *12% of the respondents were hesitant* and concerned that games would distract them. Only *8% of pupils don't think it would be useful*. It means that there is a high motivation to extend the usage of educational games.

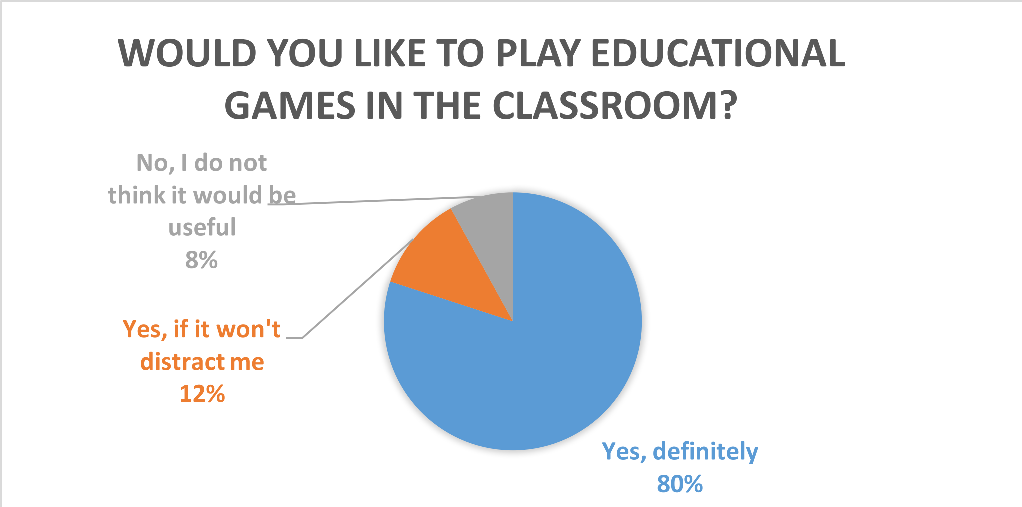

Figure 4.5 Survey for pupils: Would you like to play educational games in the classroom?

To ensure the data source triangulation and extend validity of the results, the author also contributed to another quantitative study - the *survey with 46 teachers* from Estonian schools. 85% of the respondents had more than 10 year of teaching experience.

Answering the question about the problems in educational system (see Figure 4.6), *39% of teachers indicated low interest of pupils to study*, 22% raised the issues of lack of study materials, 19% were concerned about lack financing, 11% put an emphasis on the face that programmes are not frequently updated. Finally, 9% of the issues where attributed to other factors, like lack of time to search for materials, staying up to date, etc. The results suggest that motivation of pupils and availability resources are the main constraints for effective teaching.

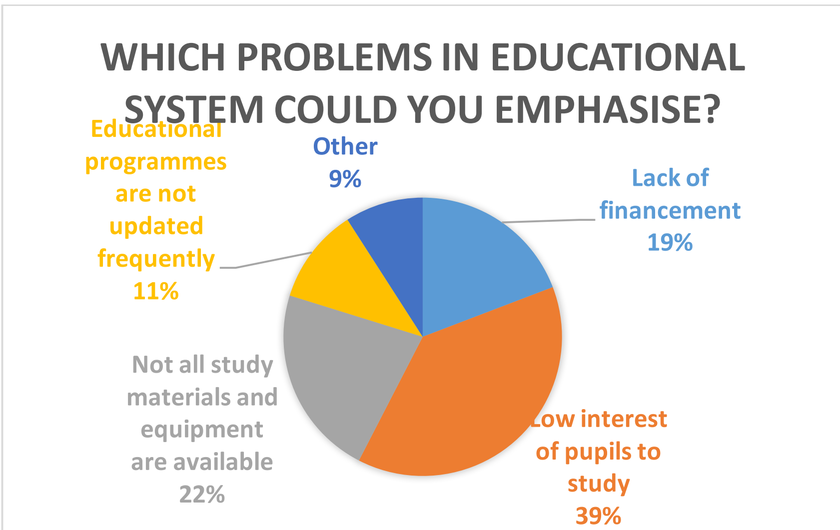

Figure 4.6 Survey for teachers: Which problems in educational system could you emphasize?

Question regarding the *usage of educational apps* (see Figure 4.7) revealed that *65% use them sometimes*, 31% frequently apply apps in the classroom, 4% do not really use them. The data suggests that there is a high potential and demand for the development of gamified educational solutions.

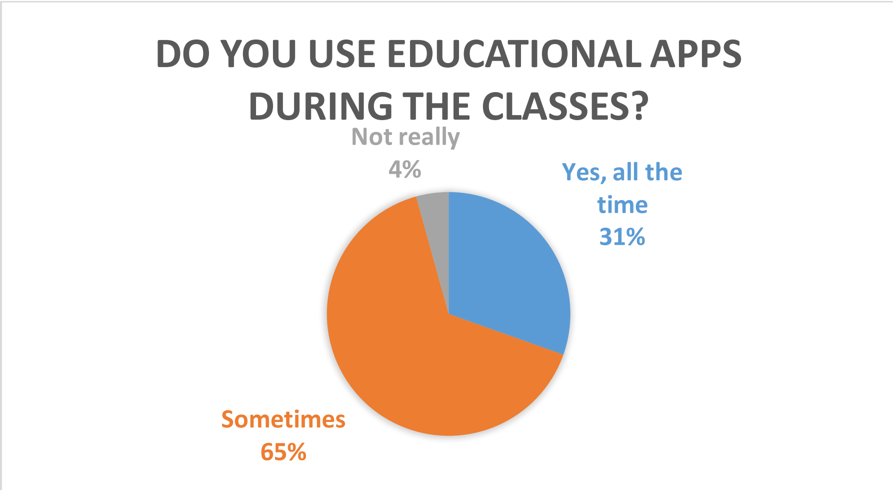

Figure 4.7 Survey for teachers: Do you use educational apps during the classes?

As visualisation is a core of the most kinds of augmented reality, teachers were also asked about their attitude to this concept (refer to Figure 4.8). 35% agreed that it is the best way for explanation, 61% partly agreed and the effect may rely on the approach. 4% do not consider visualisation efficient. Therefore, teachers mostly agreed on the effectiveness on visualisation.

Figure 4.8 Survey for teachers: Do you consider that visualisation helps kids to learn?

More specifically in relation to chemistry, the survey asked whether teacher would use an application which helps to visualise chemical elements and reactions – which describes MoleQL. Mentioning augmented reality has been omitted on purpose as technological term in the interview might be confusing.

Very positively, 94% answered that they would use such app during the lessons. The author may suggest that teachers would give MoleQL a try during the lessons as the question described its basic features.

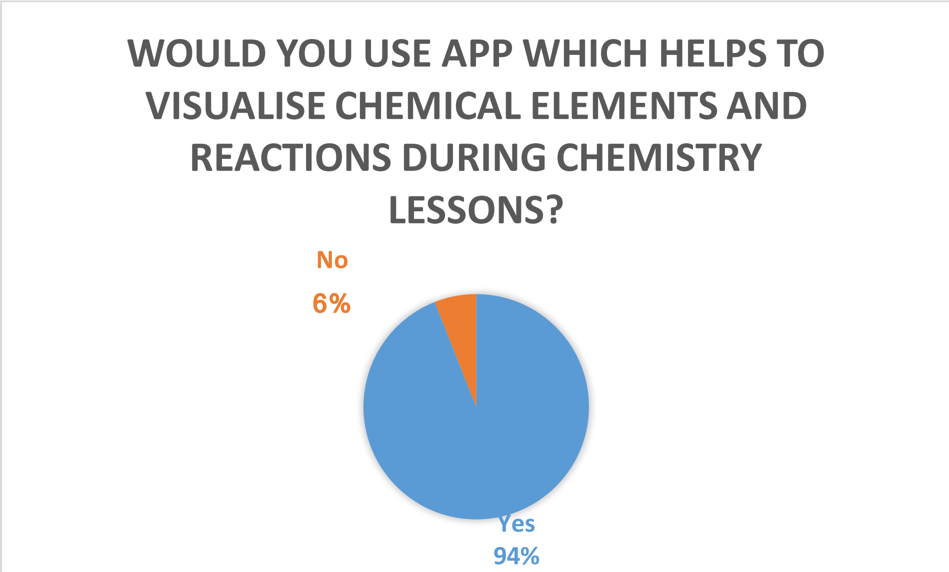

Figure 4.9 Survey for teachers: Would you use app which helps to visualise chemical elements and reactions during Chemistry lessons?

These findings indicate willingness to use educational games and the availability of the mobile devices that are needed for mobile augmented reality applications. The data must be interpreted with caution and further research is needed. To address the bias and get more conclusive results, the interviews with teachers were conducted and their result are presented in the next section.

4.6 Outcomes of the qualitative interviews with the teachers

Equipped with the quantitative data, the author also conducted qualitative interviews with the teachers. Their results largely contributed to the outcomes and opportunity to answer the research questions. In other words, they identified the most important finding of this research.

Interviews were prepared, conducted and analysed during the period from March till early May 2017. The number of respondents is 3 with an average interview duration of 35 minutes. The candidates were selected based on their experience in the profession of teacher, field of teaching and innovativeness. The interviewees were aware and consent that the interview outcomes will be used for this research.

Questions for the interviews can be found in Appendix 3. Not all of them were asked during each interview and variations occurred. This may not be a concern as the main purpose of the interviews was to identify the information supportive for the research and this allowed flexibility – variations were acceptable if the research questions were answered.

Based on the interviews, the author identified existing problems in the educational sphere. Themes of those can be viewed on Figure 4.10.

Identification of the problems in educational domain has been a part of the first research sub-question. The data derived from the interviews suggest that issue in education can be divided into three branches: curriculum-specific, organisation and resource specific, reputation-specific. Important to note that this classification is solely based on authors opinion and available empirical data and may not coincide with the opinion of other educational researchers.

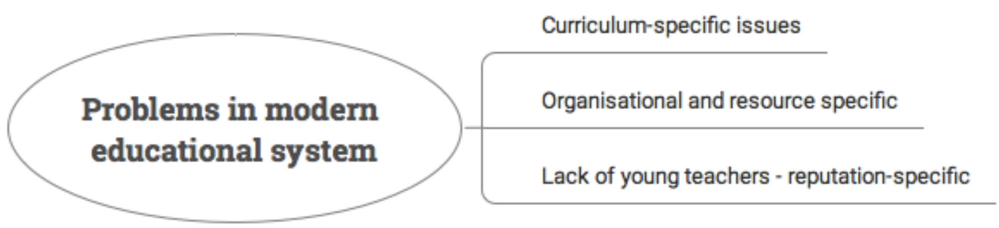

Figure 4.10 Themes from the interviews: problems in current educational system.

Curriculum-specific problems (for details refer to Figure 4.11) arise, firstly, due to the discrepancies in the study programmes. They may be unfocused so that pupils need to learn the whole range of subjects simultaneously and achieve only superficial knowledge. In this case, more in-depth approach to teaching is recommended. However, only in upper-secondary school when pupils are more less confident about their preferences and future choices.

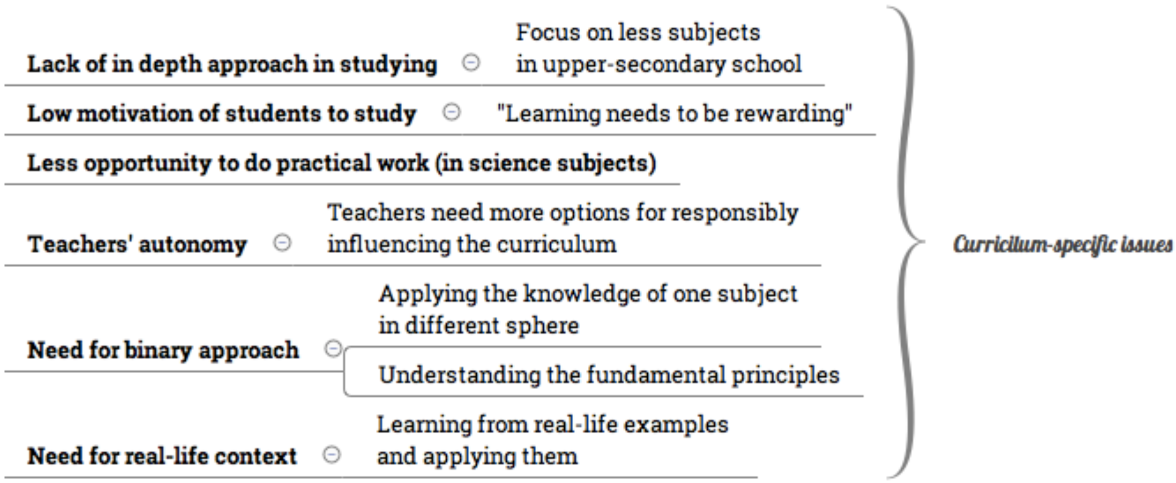

Figure 4.11 Curriculum specific issues

Lack of focus and need to be academically successful in different kinds of topic might lead to low motivation to study. Learning is now longer rewarding. Although one of the teacher argued that wide spectrum of knowledge and understanding of fundamental principles is needed as the competences obtained in one sphere might be handy and influence creative decision-making in another sphere.

The need for wide focus has been also supported by the opinion that so-called binary lessons maybe be applied. Binary lessons mean that, for example, knowledge of Mathematics is applied to the solution of the tasks in genetics during Biology lessons. More broadly, even programming can be taught without computers. In Finland, for instance, pupils are taught to think of programming more as tools to be explored and used across multiple subjects. In art class, they can learn about loops by knitting, which is, looking from another angle, is a stitches sequence that sometimes vary and sometimes stay the same. [36]

The conclusion is that study programmes should be balanced and to the extent take into consideration the needs and capabilities of individual students.

Issues concerning lack of time and resources (Figure 4.12) have been voiced during each interview. Due to the lack of time there is less time to be involved with the pupils and less time to find new resources. If teachers had more time, they could test new tools, including augmented reality-based. Besides, the programmes are forced to be shortened so that some of the topic are left out and some become more focused.

Lack of resources refers not only to the absence of some materials but also to the presence of unnecessary resources. Frequently, development programmes are centrally-administered and not always effective. Therefore, schools and teachers need more autonomy for the selection and acquisition of useful resources.

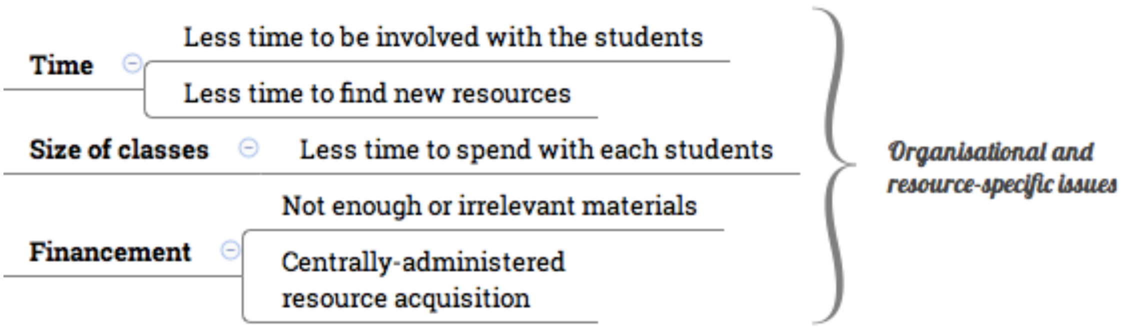

Figure 4.12 Organisational and resource-specific issues

The last section of issues concern the reputational factor of teacher's profession. It is extremely hard to attract young, academically proficient people as they simply have other options such as work in industries or research with the higher salary and better working conditions. Worth noting that young people have the peculiarity to try new approaches, tools, etc.

Next section of the interview was about the usage of ICTs in general and possible usage of AR. Figure 4.13 summarises the use cases of technological tool mentioned during interviews.

ICT tools are mainly used for three purposes: data analysis, visualisation and explanation. Excel and similar data analysis tool were frequently referred during the interviews. They allow not only to make calculations but also search for trends and outliers in data. Pupils frequently use it in sciences both during practical lesson and individual/group research home tasks.

Visualisation is highly valued quality offered by the technologies. It allows to present and describe abstract phenomena that are otherwise unseen or very hard to see. Furthermore, visualisation help to demonstrate complex systems. Augmented reality helps to deal with both tasks and offers highly visual and engaging addition to the theoretical material. AR tools can be used in the company with projector and interactive boards that are already quite common at schools.

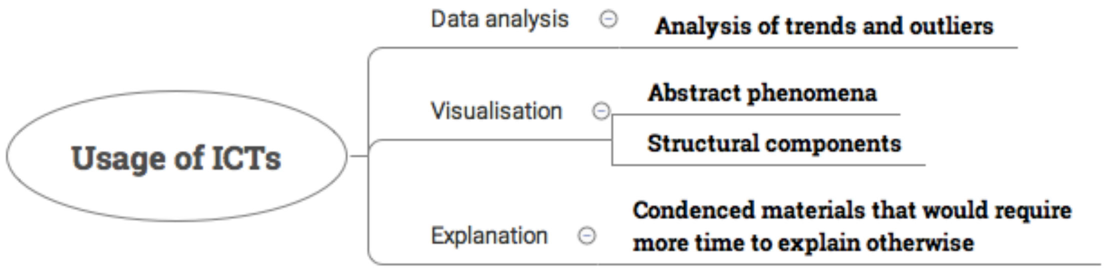

Figure 4.13. Themes from the interviews: usage of ICTs.

Demonstration of MoleQL prototype has led to the following conclusions:

- Augmented reality can be incorporated similarly as e.g. video with the experiment at Chemistry lessons.
- AR might be more useful and captivating for younger pupils.
- To make the decision to incorporate AR solution, teachers needed to see clear additional value as opposed to other tools.
- One of the colleagues of the interviewee used AR in the classroom. This was the first time the author faced such case in Estonia.
- Teachers tend to cooperate and exchange knowledge. The best way to deploy AR solution is to find early adopters.
- If there is any kind of materials that pupils want to play around with and at the same time notice some of the aspects to learn about, then obviously, it is a good idea to have them in class.
- Teachers are worried about lessons becoming too mechanical with the abundance of ICT, so it is vital to keep balance between traditional and innovative approaches.
- Educators expressed the opinion that if there is collaboration between desk mates, AR can be even more efficient.

Overall, augmented reality tools received quite good reaction from the educators. However, they would need more proof to use it in the classroom as a part of the curriculum. Augmented reality games still need to prove their educational component to be considered not only developmental but also educative.

4.7 Evaluation of validity of results

Since the start of the development, MoleQL has been demonstrated to thousands of people, either in person or from the pitching stage at public events. Much of feedback has been positive and user testing with a smaller sample of people – pupils as actual end users – mostly confirmed the obtained results. The outcomes of the surveys will be used in the development of MoleQL moving forward. However, these findings may be somewhat limited by the number and homogeneity of the samples and further tests are required to make more robust conclusions.

5 Conclusions and future work

This final chapter presents the summary of findings that derived after data collection and data analysis procedures, outlines the limitation and opportunities for future practical and academic work.

5.1 Summary of findings

Quantitative data for surveys displayed the following core findings:

- Pupils are willing to use educational applications and gems in the classroom and most teachers are willing to try them out or already doing this.
- Mobile devices can be handy in the classroom and certain percentage of pupils already use them but purposes are not clear.
- Teachers consider visualisation as powerful tool for explanation but its value largely depends on the approach.
- Lack of motivation in pupils and deficiency of material are the most voiced issues in education.
- Teachers are willing to try the app that visualises chemical elements and reactions. MoleQL can provide these affordances.

From the interviews' qualitative data, the author derived these conclusions:

- Lack of time and sufficient resources has been the most voiced problems during the interviews. For chemistry, it would be the time to find new resources and focus on students who need more attention. In terms of resources, practical work is not used enough due to lack of labs for practical workshops.
- Augmented reality can be incorporated similarly as videos with the experiment at Chemistry lessons.
- AR was mentioned to be more suitable for younger generations and explanation of fundamentals.

- Teachers needed to see clear additional value of augmented reality to strart using it in the class. Some already do use it.

All in all, qualitative data supports the findings from the quantitative surveys. Interviews allowed to look deeper into the results presented by the surveys.

Furthermore, the study answered to the certain degree all the main research question and its sub-questions.

Main research question:

How augmented reality can be beneficial and valuable in the classroom?

This research revealed the affordance of AR in classroom and explained on the example on MoleQL how it can be valuable for educational purposes.

Sub-questions of the research:

How augmented reality can address the problems that exist in the educational system?

Both quantitative and qualitative data derived from the respondents identified the number of issues in current educational system. Some of them, like lack of efficient materials can be addressed with the help of AR solutions. AR would help to explain the topics that require rich visual illustration or not always be replicated in practical surroundings, like practical work in Chemistry. Besides, AR potentially can deal with the motivational issues making learning fun, engaging and capturing attention. However, to find great AR apps, teachers would require time and opportunity to test them. Ideally, they should take part in the development of those solutions.

How educators perceive augmented reality and how they see its potential?

Research revealed that teachers generally express positive feedback about AR solutions. The challenging part is to convince them to be courageous to deploy. Besides, educators think of AR as a tool and need justification for its substantial educational value.

How can augmented reality be incorporated into teaching and learning processes?

The study showed that AR can be used in different ways to make learning more engaging. To incorporate it into formal education, developers need to offer the high-quality content and enough evidence on its effect. Generally, visualisation and ability to explain complex topic in short periods of time are the most valuable affordances of AR.

5.2 Implications of the results

The results of this study can be used for the incorporation of augmented reality solutions into formal and informal education. Besides, the results can be used for further theoretical enquires.

This study was one of the few which tested visual marker-based augmented reality solution. Location-based solutions are much better adopted and mentioned in the academic articles on the topic.

5.3 Challenges and limitations

The main challenge was this study was the fact that technology is not well adapted. Educational sphere is characterised by the high level of resistance to change.

It is common that teachers are inclined to use more traditional methods of instruction, as they worked for some time. But modern world is moving is developing so fast that skills learnt at school might be unnecessary in future. Teachers will more and more frequently find themselves in the situation when they need to prepare students for the professions that don’t even exist at the moment.

Methodologically, it was challenging to gather data from the different sources, transcribe in the case of interviews and analyse what is important and what should be left out.

Limitations may include the following:

- Data sample limitation;

- Prototype of AR app is only under development – therefore, the features cannot be demonstrated in the full spectrum;
- Testing was limited only to 1 class;
- No opportunity for longitudinal study due to limited time frame for thesis writing.
- This research didn't touch the point of view of parents and mostly concentrated on the formal education. Parents are kind of responsible of informal education and they might find AR useful too.

5.4 Future Work

Despite these promising results, question of the additional value of augmented reality remains. More comprehensive, differed and longitudinal user testing would allow to make the conclusions on user engagement and the effect from using augmented reality on the academic performance.

In the future, the team developing MoleQL will continue to improve the application based on the user needs and feedback.

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Appendix 1 – Questions from the survey with pupils

1. Age
2. Gender
3. In which grade are you?
4. Do you like studying?
5. Do you find Chemistry interesting?
6. What are the hardest topics for you during Chemistry classes?
7. What are the easiest topics for you during Chemistry classes?
8. Do your use educational apps?
9. How do you usually find out about new educational apps?
10. Do you use mobile devices during the classes?
11. Would you like to play educational games during the classes?

Appendix 2 – Questions from the survey with teachers

1. Age
2. Which subject(s) do you teach?
3. How long have you been working as a teacher?
4. Which problems in the educational system can you emphasise?
5. Do you use educational apps during the classes?
6. Do you agree that visualisation helps kids to learn?
7. Would you use app which helps to visualise study materials during Chemistry lessons?
8. What are the hardest topics for students to comprehend during the Chemistry classes?
9. What is your attitude towards the educational games?
10. Would you allow students to use educational games during the classes?

Appendix 3 – Questions for the interviews with the teachers

1. Name
2. School
3. Year of experience as a teacher
4. Subject(s) taught
5. Which problems do you see in current state of the educational system?
6. How do you think these problems can be addressed?
7. How do you keep your subject up to date and incorporate innovations?
8. Which materials do you have at your disposal?
9. Which additional materials do you use or willing to use inside the classroom?
10. What is the current procedure for adding new tools/materials on top of default curriculum, especially paid ones?
11. What are the biggest challenges in teaching Chemistry?
12. What are the most problematic areas?
13. How do you motive children to learn?
14. Which tools do you use for visualisation in Chemistry?
15. How do you manage to explain the most difficult topics?
16. How do you feel about working with computer/mobile phone with a class?
17. Why do you think e-learning is important nowadays?
18. Why do you think you should use e-learning in teaching?
19. Do you have any periodic goals for usage of ICTs and innovative digital solutions?
20. What is your attitude towards digital educational games?
21. How have you used educational mobile apps inside the classroom, if any?
22. How do you assess if children are learning with ICTs?
23. Are you aware of the technology of augmented reality?
24. Demonstration of MoleQL mobile application.
25. Would you such app at your classroom?
26. How this technology and app would be beneficial for your students?
27. Which challenges as a teacher it would help to solve / make easier?