BULGARIAN ACADEMY OF SCIENCES
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MODELS AND METHODS FOR THE APPLICATION OF VIRTUAL AND AUGMENTED REALITY IN EDUCATION

A B S T R A C T

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Introduction

We live in a time where digital technologies are constantly transforming the field of education. Their rapid development makes them more and more accessible and leads to their widespread entry into all stages of the educational process. This is also leading to rapid advances in educational technology, and institutions, educational experts and educators are looking for new ways to integrate digital solutions and improve the classroom experience. Augmented reality (AR) and virtual reality (VR), two technologies that allow mixing the real and digital worlds, and even blurring the lines between them, enable the creation of even more personalized and immersive visual experiences and offer the remarkable potential for innovation.

Findings made in this work indicate that there are not many comprehensive, standards-based environments suitable for implementation specifically designed for STEM learning. On the other hand, there are many ready-made and readily available AR/VR resources. Of key importance for their beneficial use is the educational approach used.

The present dissertation analyzes existing and proposes models for the use of AR/VR in education, together with methods for evaluating the effect of their application in the educational process and the combination of these ICT technologies with other teaching techniques and scenarios, as well as with the physical environment in the classroom.

Dissertation structure

The dissertation has four chapters.

In the **first chapter**, an analytical overview of modern directions and technologies in e-learning is made. It is motivated by the need to offer new models for the application of virtual training resources for certain target groups, as well as the need for specific methods, tools, examples of scenarios, and approaches allowing their effective application in the training process.

In the **second chapter**, the developed models for the application of augmented and virtual reality in various STEAM subjects with different educational goals and the possibilities of combining them with the project-based approach and a specially designed physical environment are presented.

The **third chapter** describes methods for evaluating the effect of the application of the developed models, taking into account the specifics of the taught subjects, as well as methods for combining AR/VR technologies with different teaching techniques and scenarios.

In the **fourth chapter**, an overview of the software environments for creating and the hardware means for using AR/VR educational materials is made. The updated and digitally adapted Bloom's Taxonomy and its implications for creating standards-based AR/VR educational resources are discussed. A SWOT analysis of the application of AR/VR technologies in education is prepared.

A summary of the obtained results is presented in the **Conclusion**. Directions for future research and development are identified. A list of scientific publications on the topic and noted citations are presented.

The dissertation contains 114 pages, 42 figures, 18 tables, and 121 bibliography sources.

Chapter 1 –Analysis of modern teaching models and methods

1.1 Modern trends and technologies in e-learning

In recent decades, learning has undergone major changes, from the standard classroom setting and teacher- and instructor-led learning to modern learning opportunities through gamification, artificial intelligence, and virtual reality. The development of information and communication technologies has led to the emergence of e-learning, i.e. education that is conducted, guided, and carried out with the help of electronic media.

Technology remains the leading keyword when talking about e-learning. Whether teaching children or adults, or developing corporate training courses, taking advantage of the expanded capabilities offered by new technologies is a must.

Regardless of the directions and trends in e-learning, it is based on two types of systems - a learning management system (Learning Management System - LMS) and a learning content management system (Learning Content Management System - LCMS).

Different types of training require different technologies and platforms for their implementation.

1.1.1 Microlearning

This is one of the preferred ways of learning because it allows the content to be broken down into smaller parts and makes it easier for the learner to absorb the information. Because in microlearning, the learning content consists of smaller modules, it is easier to complete them and the material to be absorbed on the fly.

1.1.2 Blended learning

Blended learning combines the strengths of both traditional and e-learning to offer the best for users. To make learning more effective, blended learning offers an educational program that combines face-to-face meetings and online lessons.

1.1.3 Gamification

One of the fastest growing areas of e-learning that uses game elements in non-game situations to improve user engagement during learning and subsequent evaluation.

It is believed that with the methods it uses, gamification can compensate for the shortcomings of other e-learning methods by engaging the attention and increasing the concentration of learners for a longer period.

1.1.4 Online mentoring programs

Online mentoring programs are gaining in popularity. Combining live meetings or live video links with e-learning, they are a great way to provide personalized experience and first-hand knowledge in a particular field.

1.1.5 Mobile learning

Mobile learning is a stage in the development of e-learning. The two types of training have similar characteristics. One of the things that differentiate mobile learning from e-learning is the use of mobile technologies – mobile devices and wireless communication technologies.

1.1.6 Standards for eLearning

Guidelines for designing and developing content, deploying it across platforms, and ensuring interoperability across devices can be found in the eLearning Standards, a set of general rules that apply to content, software creation, and management systems (LMS).

There are two main types of eLearning standards (Fig. 1.1). Course design standards address the various aspects of course design and development, and technical standards address the deployment of courses in LMSs or other types of portals.

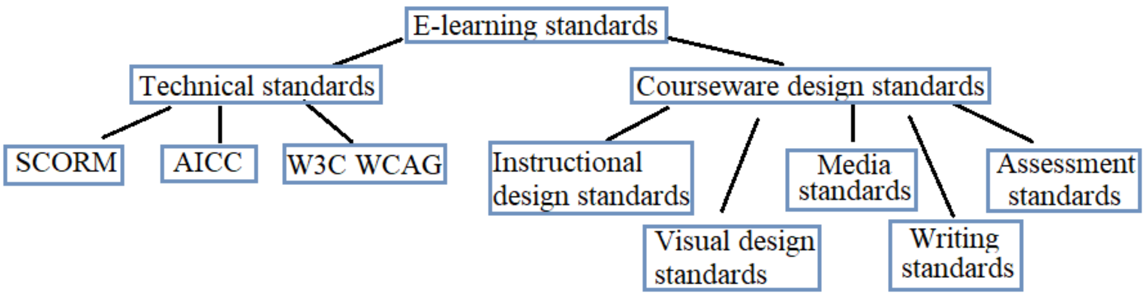

Figure 1.1 Standards for eLearning

1.1.7 Personalized training

The concept of personalized learning is not new to education. Personalized learning provides a unique, highly focused learning path for each student. Individual attention from the teacher is not possible in traditional education models with large numbers of students.

1.1.8 Adaptive Learning

One of the many possible approaches to personalized, highly focused learning for large numbers of learners is Adaptive Learning. It requires the use of various technological systems and tools. For the implementation of adaptive learning, knowledge and technologies from various fields are used - including computer science, artificial intelligence, psychometrics, education, psychology, etc.

1.2 Virtual, augmented and mixed reality

Virtual reality technology is based on computer graphics, simulation, human-computer interfaces and others. The use of virtual reality (VR) in education can be considered the natural evolution of computer-assisted or computer-based learning. The sense of immersion achieved through virtual 3D environments [Do, 2015] offers numerous advantages [Kersten, 2020].

Virtual reality is an artificial environment that is experienced through sensory stimuli (such as sights and sounds) provided by a computer, and in which human actions partially determine what happens in the environment, as defined by the Merriam-Webster Dictionary.

Unlike virtual reality, which creates a completely artificial environment, augmented reality (AR) uses the existing environment and overlays new information on it. Augmented reality is the integration of digital information with the user's environment in real time. AR is growing in popularity because it brings elements of the virtual world into the real world, thereby enhancing the things we see, hear and feel.

Of the several existing definitions of AR, the one provided by Paul Milgram (Department of Industrial Engineering, University of Toronto) and Fumio Kishino (Department of Electronics, Information Systems and Power Engineering, Osaka University) is the most frequently cited. Different types of reality are theoretically defined, which create a continuum that, starting from the real world, leads to a completely virtual world [Arena et al, 2022]. The following environments are distinguished in it (Fig. 1.3):

- Real Environment (RE): this is the environment in which we live and which is governed by the laws of physics;
- Augmented reality (AR): physical reality in which participants also see virtual elements;
- Augmented Virtuality (AV): virtual reality in which participants also see real elements;
- Virtual reality (VR): represents a synthetic world in which the participant is fully immersed.

Milgram and Kishino [Milgram et al, 1994] introduced the reality-virtuality continuum.

Another term is also in use – Extended Reality (XR). Augmented Reality (XR) is a term that combines augmented reality, virtual reality and mixed reality experiences, meaning that all technologically enhanced realities fall under the umbrella term XR. It's a relatively new technology that blurs the line between the real and digital worlds to create even more personalized and immersive visual experiences. This is done with the use of special headsets, glasses, joysticks and sensors, in order to improve the user's perceptions.

Based on this classification is also the classification of different types of technology.

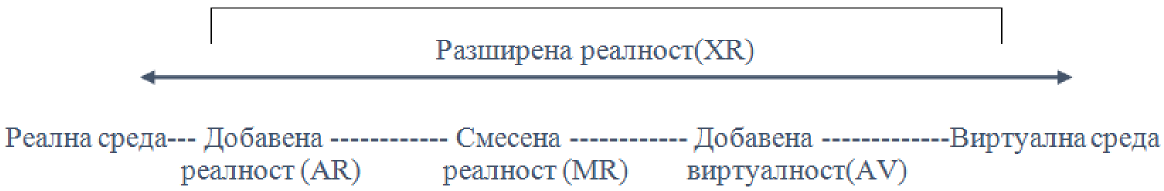

Figure 1.3 Reality-Virtuality Continuum (adapted from [Milgram et al, 1994], [Arena, 2022]).

AR can be implemented through different types of technologies, according to specific goals and applications:

- Marker Based AR
- AR without a marker (Markerless AR)
    - Location-based AR
    - Projection-based AR
    - Overlay AR
    - Contour AR.

Over time, it has become clear that there are very large opportunities for the application of AR/VR technologies in various fields dealing with diverse problems in the real world [Rebbani, 2021].

1.2.1 AR/VR - Virtual and Augmented Reality in Education

With the development of practical and affordable virtual reality and mixed reality, people now have the chance to experience an immersive learning experience both in classrooms [Cabero-Almenara, 2019] and informally in homes, libraries and community centers [Liu, 2017]. Many education technology companies are using virtual reality to bring lifelike experiences into the classroom while emphasizing the technology's ability to inspire and capture students' attention. It is noted that VR technologies encourage interaction and encourage active participation rather than passivity [Chandrasekera, 2018].

1.2.2 Goals and opportunities for using AR/VR in education

In the field of science, technology, engineering, and mathematics (STEM) education, fully interactive virtual laboratory simulations are designed to engage and stimulate students' natural curiosity as they learn [Nersesian, 2019].

The general conclusion of several studies is that augmented reality applications can improve the learning process, learning motivation and performance [Brij, 2021]. Despite the positive results, more research is needed, notes [Tzima, 2019].

1.2.3 Challenges and risks of using AR and VR in education

There are certain risks in using AR and VR in education. Experts are still trying to understand the impact of VR on children's learning. The disadvantages of using virtual reality are primarily related to cost, the time required to learn how to use the hardware and software, possible health and safety effects, and dealing with potential reluctance to use and integrate new technologies into a course or curriculum.

1.2.4 Fields of application of AR and VR in education

One of the things that can make AR technologies accessible is the application of the technology in different fields.

Augmented reality can be very suitable for simulations, especially in the field of STEM education [Diegmann, 2015]. As the computing power of computers has increased and their cost has decreased, the use of simulations has greatly increased. School laboratories and classrooms are beginning to be massively equipped with appropriate technological infrastructure. Especially in the field of STEM, access to quality laboratory equipment is difficult to provide en masse [Rienow, 2020], and simulations, in turn, allow students to experience processes and phenomena in a way that they would not normally be able to.

AR is growing in popularity because it brings elements of the virtual world into the real world, thereby enhancing the things we see, hear and feel.

1.2.5 Models for using AR/VR in education

Any type of information, including virtual information superimposed on a real environment, can be digitized, such as text, images, video, audio, web links, and three-dimensional (3D) models. This functionality is one of the main features allowing this technique to be applied to a wide range of human activities, education is the most important among them [Panciroli, 2017].

Augmented reality can be considered a didactic tool that contributes to transforming the ways of learning. It should provide the learner with a unique experience that is not easily replicated or possible in a traditional classroom [Geroimenko, 2020]. Therefore, the main goal of AR is to add more information that is more meaningful to real objects, thus improving students' understanding of the world they observe [Del Cerro Velázquez 2018].

One model for using augmented and virtual reality in blended learning is shown in Fig. 1.5.

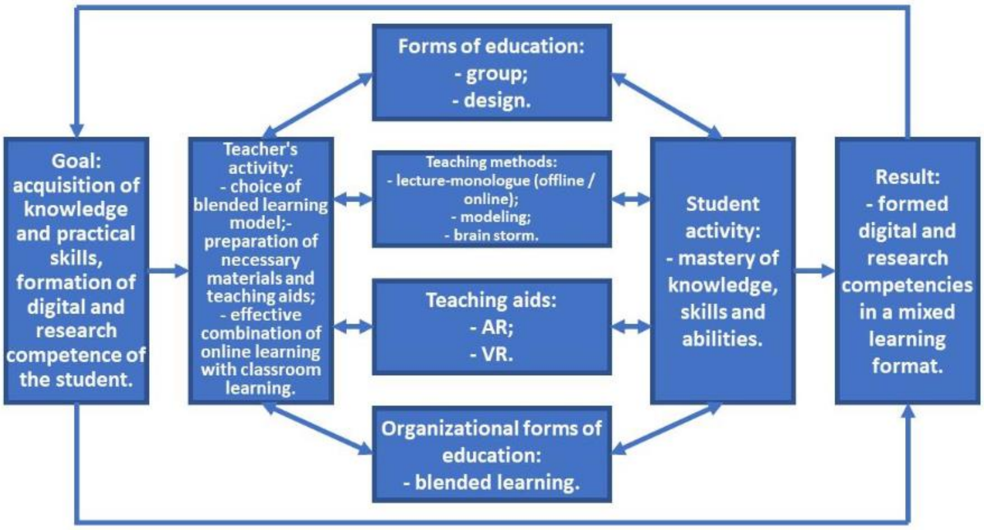

Figure 1.5 The model for using augmented and virtual reality in blended learning in secondary school [Kovalenko, 2021].

The taxonomy of the types of VR platforms used in education is closely related to the level of immersion and hardware requirements [Kamińska, 2019]. They are [Jumani, 2022]:

- Non-immersive VR systems
- Semi-immersive VR systems and platforms
- Fully immersive VR structures.

3D augmented reality technology can be used as a learning media with mobile phones or desktop computers. Augmented reality models vary as follows:

- 3D only
- 3D simulators
- 3D animation
- 3D video and multimedia,

with each model adapted to specific research objectives [Afandi, 2019].

An educational system using VR and AR in the work of [Osipova, 2019] means an ordered set of interconnected elements of electronic educational resources, forms and means for planning and conducting, monitoring, analyzing, and correcting the educational process aimed at improving the effectiveness of student learning (Fig. 1.8).

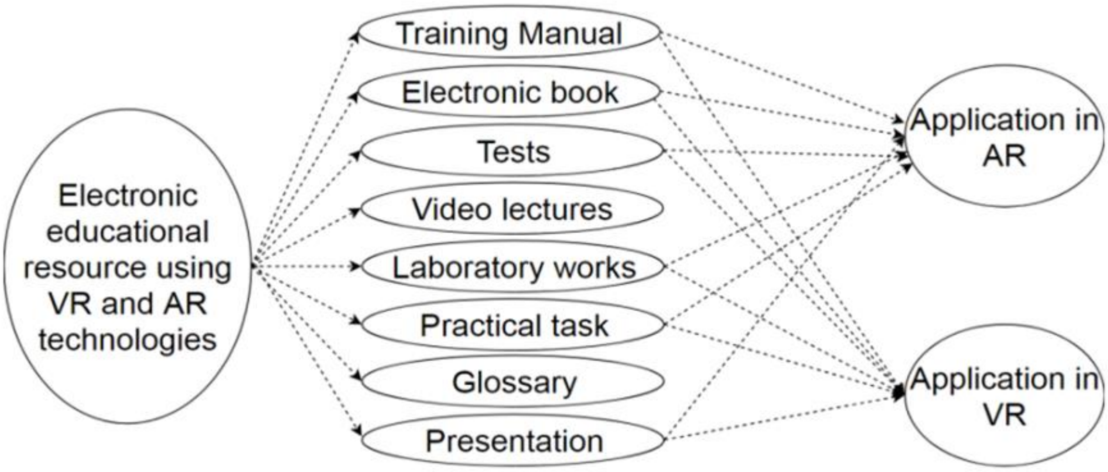

Figure 1.8 A model of a learning system using VR and AR [Osipova et al, 2019]).

1.3 Conclusions

As a result of the analytical review, the following conclusions can be drawn: Virtual (VR), augmented (AR) and mixed reality (MR) are modern tools that enable the renewal and upgrading of models and methods of teaching and knowledge acquisition. Combining AR/VR technologies in education enables a new approach to learning that usually complements traditionally used methods. There is a need to offer new ideas, tools, scenario examples and opportunities for virtual learning resources for specific target groups. Considering the advantages, disadvantages and functionalities of AR/VR technologies, it is important to determine when these technologies are appropriate and for what learning purposes, as well as for what teaching scenarios.

1.4 The objective and tasks of the dissertation

Based on the analysis of the state of the research, the aim of the dissertation is formulated:

To propose models and methods for using augmented and virtual reality in education.

For this purpose, the following tasks are defined:

1. To develop a model for the use of augmented and virtual reality in STEM education, taking into account the different educational goals and specifics of individual subjects
2. To propose a model for the combination of augmented and virtual reality with a physical learning environment.
3. To develop a model for combining augmented and virtual reality with project-based learning in a unified teaching scenario.

4. To propose methods for evaluating the effect of combining a learning environment mediated by augmented reality, implemented to improve the learning process and the understanding of learning material for certain learning goals.

Chapter 2 – Models for the application of augmented and virtual reality in education

The following definitions are used in this dissertation: •

“A theoretical model is a description or representation used to understand how a particular system or process works” [https://www.lexico.com/definition/theoretical_model]. A theoretical model is a framework that researchers create to structure a research process and plan how to approach a particular research question. The model allows us to determine the objectives of the study.

The term "Method" is defined as a certain systematic procedure for achieving or approaching something.

This chapter offers models for the application of augmented reality in the teaching of biology, mathematics and the arts. The specifics of each discipline are reflected in the offered models. In addition to the application of AR/VR tools in the teaching of specific subject areas, this dissertation proposes a model of combining augmented and virtual reality technologies with different teaching techniques, environments and scenarios. The aim is to investigate the impact of AR tools on students' learning outcomes.

2.1. AR/VR tools

One of the most successful examples of an AR system is zSpace®. In 2015, zSpace® Inc. introduced an all-in-one solution for education consisting of a virtual reality monitor and a PC (fig. 2.1). The system provides students with a realistic learning environment that is NGSS (Next Generation Science Standards) compliant.

Figure 2.1: zSpace® all-in-one solution

Zspace® consists of several training applications and simulations.

2.2 A Model for Application of AR/VR in STEM Education

The proposed model for using augmented reality is realized through the workflow (Fig. 2.2) of the same experiment for the 3 groups and the four taught topics.

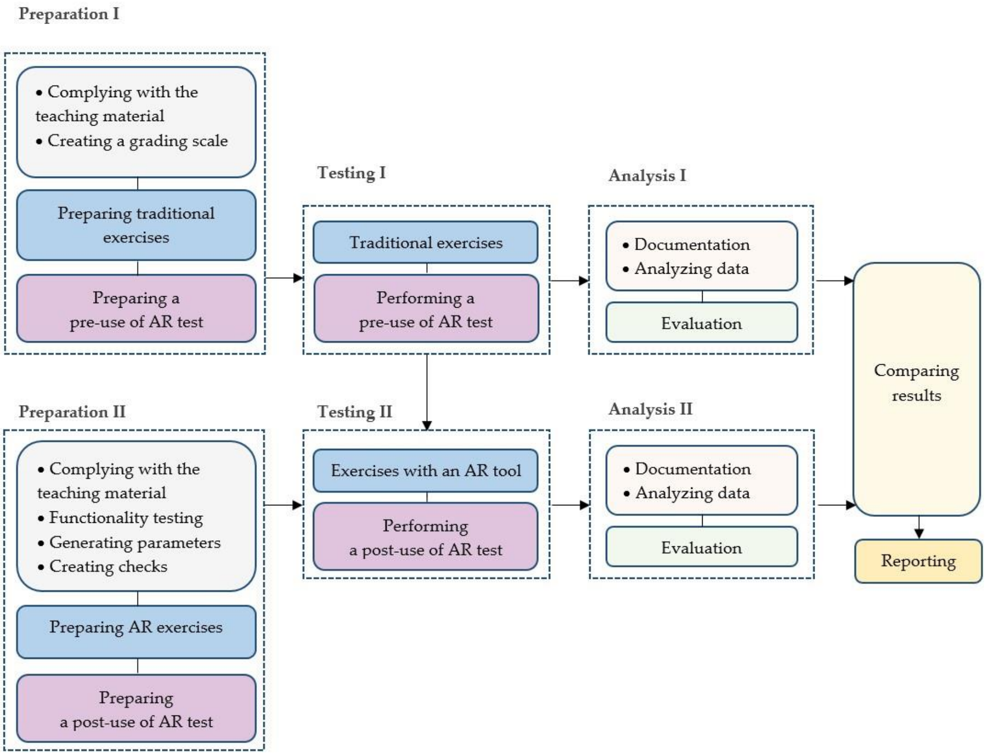

Figure 2.2 A model for using augmented reality in STEM education.

2.3 A model for the application of augmented and virtual reality in mathematics education

This part of the dissertation presents a study that aims to investigate the effect of using the Augmented Reality module of GeoGebra (an interactive application designed for learning mathematics and science) on the development of students' spatial mathematical skills through augmented reality.

2.3.1 GeoGebra Augmented Reality (AR) module.

GeoGebra is a well-known dynamic mathematical software for learning and teaching mathematics. GeoGebra 3D is a tool for the visualization of curves and surfaces in three-dimensional space, aimed at facilitating the understanding of abstract and applied geometric concepts [Trigueros, 2019]. The Augmented Reality (AR) application helps visualize mathematical figures and bodies generated by GeoGebra 3D by placing them on a user-selected surface. Tim Brzezinski [Brzezinski] provides many examples of AR modeling.

2.3.2 Application of AR GeoGebra.

Two ways to use the AR module are being explored:

- achieving a personalized student learning experience provided by GeoGebra's AR module through the GeoGebra 3D Calculator mobile application.
- a proposal for how teachers can teach and share a stereoscopic 3D experience with their students through the combination of zSpace (an all-in-one solution for AR education), GeoGebra and a dedicated zView camera.

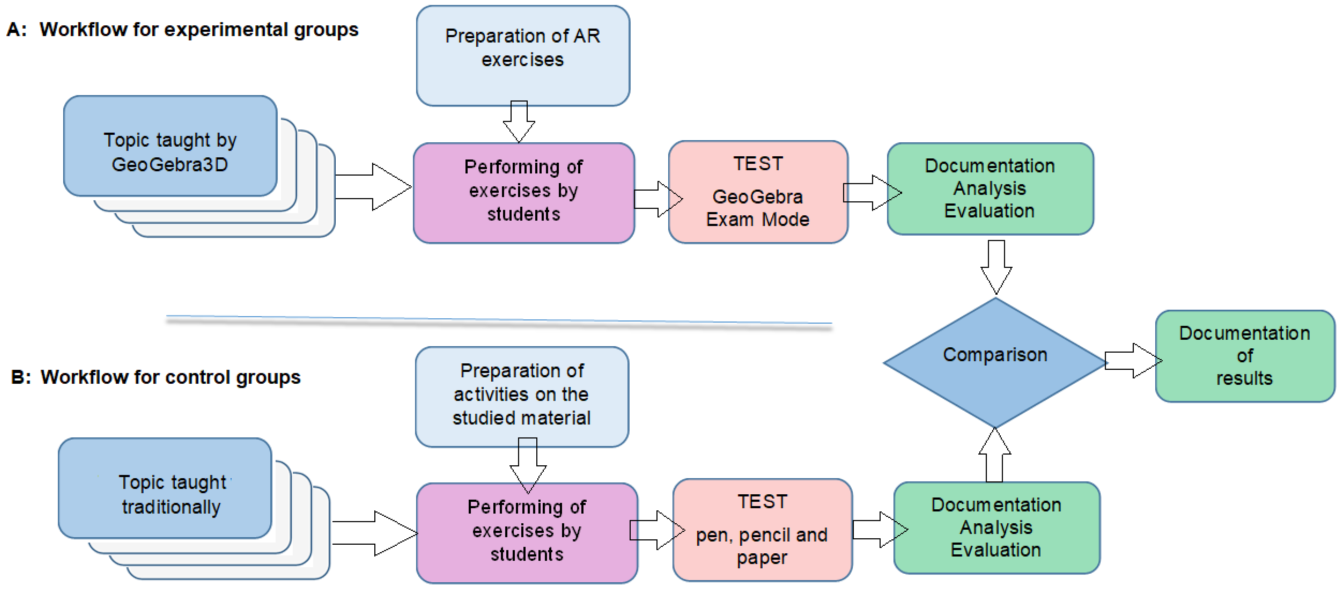

Figure 2.7. A general pattern for using the AR module

The experiment (Fig. 2.7) was validated with 76 participants, the results are shown in the next chapter.

2.4 A model for the application of augmented reality in arts education

Augmented reality is based on the concept of experience. The use of AR in education and its wider adoption can truly transform the learning experience.

The model proposed in this dissertation for the use of AR in teaching art classes contains 2 modules. One is to explore physical spaces and artwork in the classroom through the Google Arts & Culture AR application (Fig. 2.8). The other module allows students to create their own AR works by adding a virtual dimension to any artwork, including their own, through animations, video and music. The particular application that can be used is UniteAR. This model was developed (Fig. 2.9):

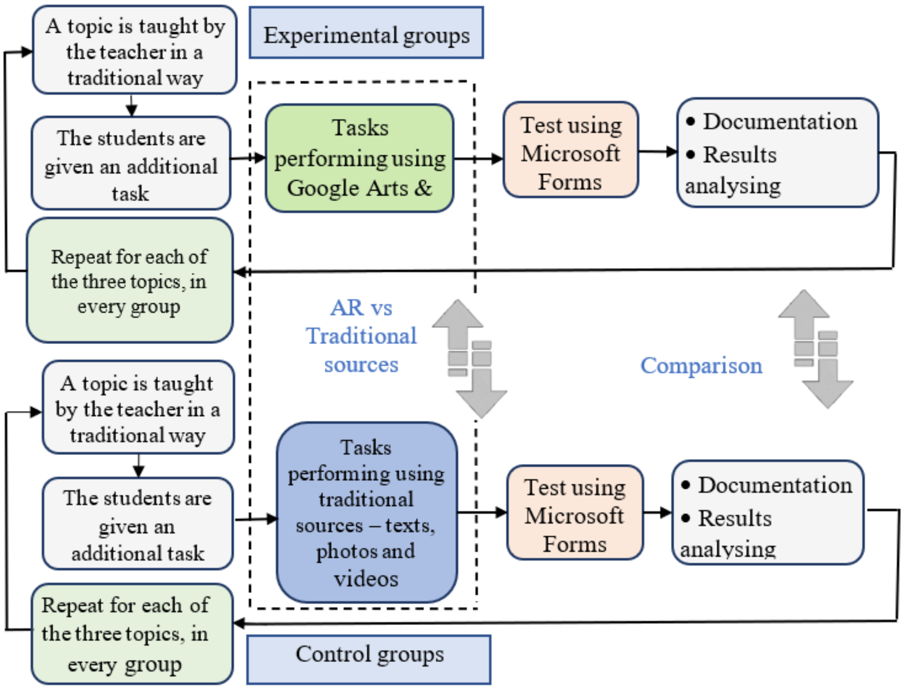

Figure 2.9. A Model of Application of Augmented Reality in Art Education

As various studies have shown, effective arts education, including arts integration across subject areas, promotes active, problem-based inquiry, data collection, evaluation, and communication.

2.5 Combination of project-based learning with AR/VR technologies

2.5.1 Project-based learning

Project-based learning (PBL) is a learning method in which students acquire knowledge and skills by working over an extended period of time to explore and respond to an authentic, engaging, and complex question, problem, or challenge [Savery, 2006]. In project-based learning, students work in groups to solve really challenging problems that are very often interdisciplinary.

One of the great advantages of PBL is that children learn by becoming "travellers" who travel the world of science, discovering a variety of topics from different subjects, rather than focusing only on a specific lesson being taught at the moment.

2.5.2 Combining PBL with VR and AR

In working to improve STEM education through project-based learning combined with virtual and augmented reality, we encounter the root “real” three times—*real problem, virtual reality, and augmented reality*. The real problem is born from the real environment, and virtual and augmented reality contribute to its solution. It is in this territory, where the three "realities" meet, that the apogee of effectiveness should be expected from combining PBL with VR and AR.

Starting from such assumptions and taking into account that the educational needs and ways of perceiving information of modern students have changed in the last few years, the present study aims to specifically reflect the relationship between the teaching approach of PBL, AR/ VR and STEM learning.

2.5.3 Model of usage of PBL and AR/VR

The model for combining PBL with AR/VR is hands-on. The target group is secondary school students studying in three different classes. Students from each class are divided into 4 groups, each of which consists of 6 students - 2 control groups and 2 experimental groups in each class. The students in each of the groups have the task of building a house in which energy is used in a sustainable way and using natural materials.

The project combines knowledge from biology, physics, mathematics, engineering sciences, crafts and applied techniques from the past and present, united around the idea of alternative sources of electricity, about the advantages and disadvantages of green energy.

During the work on the project, the students of the experimental group used AR and VR technologies to explore and compare different house structures and their properties, as well as to look at different cross-sections (Fig. 2.11). Students investigated different ways of air flow in different structures, the pros and cons of natural materials used to build sustainable houses (Fig. 2.12).

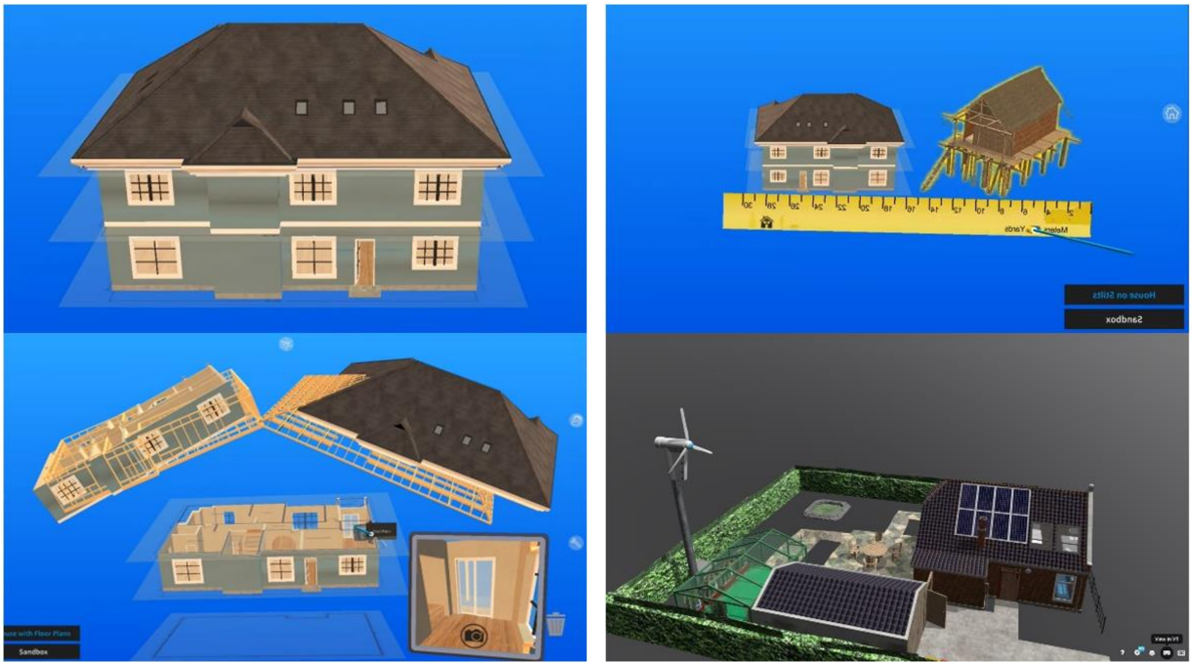

Figure 2.11 Exploring and viewing house structures using AR and VR.

Figure 2.12 A model of a sustainable home built by an experimental group of students.

The workflow model (Fig. 2.13) for the experimental groups is as follows:

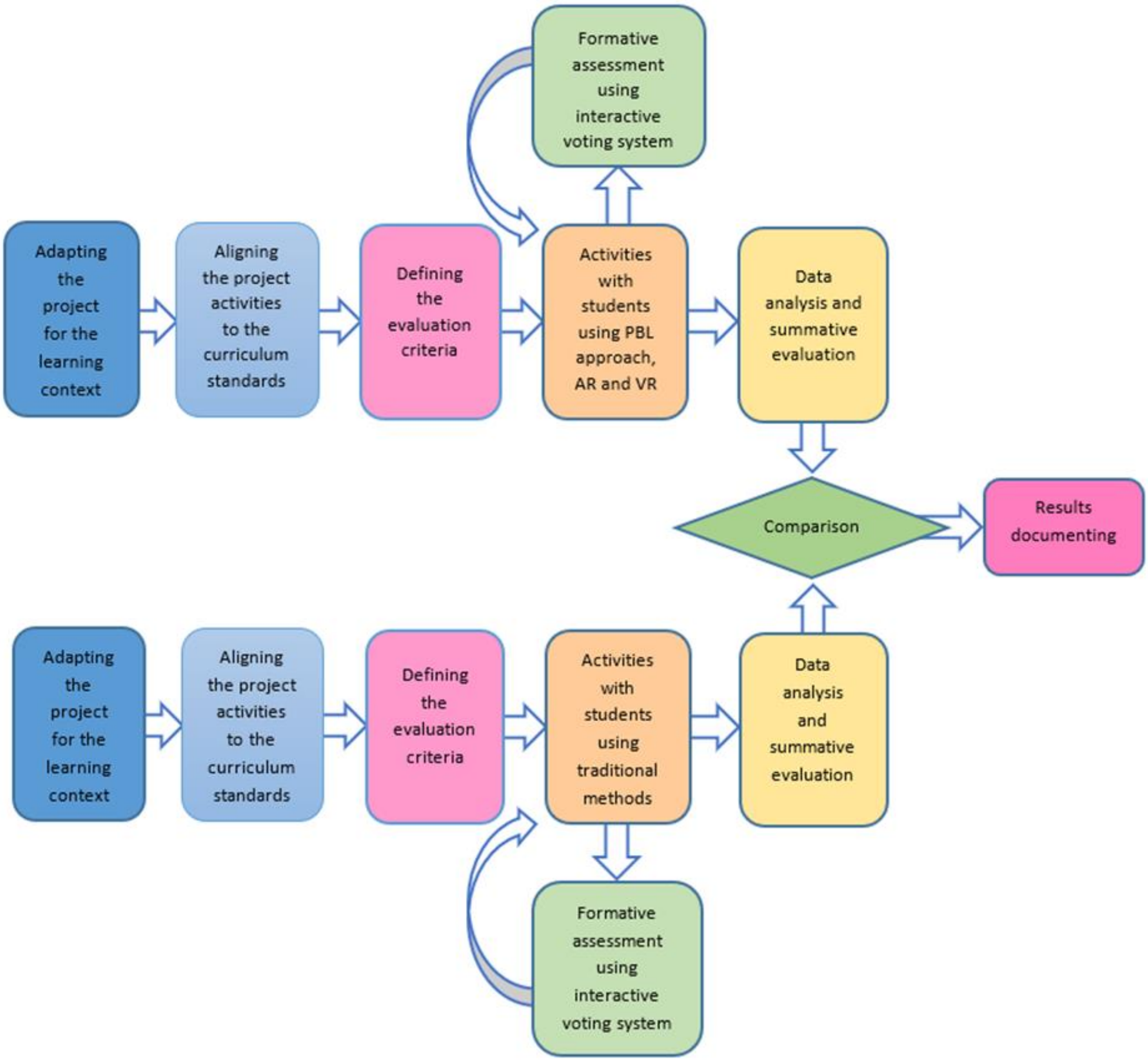

Figure 2.13 The workflow model

2.6 Combining AR with specific interior solutions to enrich STEM learning

The interior of the classroom should be conceptualized as a teaching tool that stimulates and supports the entire learning process, and helps establish rational and valuable educational tasks through the various expressive means of art and design.

The misconception that having the best technology in the classroom eliminates the need for beauty and cosiness is widespread. Augmented reality is considered sufficient to give students a sense of completeness both in their surroundings and in the learning process.

The model in which the five-member configuration teacher - student - content - decorative learning environment - added virtuality works will be examined in two classrooms built as a decorated learning environment.

Figure 2.14 The "Fifth Element" in motivation and success

To make this model as effective as possible, the following steps are required in the development of each lesson (Fig. 2.15):

Figure 2.15 The steps of the model

Figure 2.16 The classroom of Physics and Astronomy before (left) and after the conversion (right)

Figure 2.17 The classroom before (left) and after the conversion (right)

Figure 2.18 Biology and Health Education Cabinet

2.4 Conclusions

The developed models for the application of AR and VR technologies in various taught disciplines show that the use of augmented and virtual reality can be a very effective tool for personalizing the learning process and promoting inclusive and active learning.

As a result, the following conclusions were drawn:

1. A model for using virtual reality in biology education as part of STEM education is proposed. Experience shows that simulations are a promising way to improve student learning outcomes, especially in STEM subjects;
2. A model for the application of augmented and virtual reality in mathematics education is proposed
3. A model for teaching fine art with AR was developed, which contains two modules - one is for exploring geographically remote physical spaces and artistic works without leaving the classroom, the other is for creating your own artistic works by adding a virtual dimension to any work of art.
4. A methodology for combining project-based learning with the application of augmented and virtual reality tools is proposed.
5. A model for integrating the interaction between the physical environment and AR/VR technologies has been developed.

Chapter 3 Evaluating the Effect of AR/VR Application in Learning in Different Subject Areas

One possible approach to evaluating the effectiveness of a given simulation is to run benchmark tests.

Evaluating whether training objectives have been achieved, especially when a lot of investment has been made in equipment, is critical to the effective use of that equipment. This requires creating an evaluation strategy, collecting evaluation data, and making recommendations for further improvements.

The study evaluates the effect of working in a learning environment augmented with augmented reality and used to improve the learning process and deepen the understanding of the learning material.

3.1 Assessing the application of AR/VR in STEM education

Participants in the study were high school students, divided into three groups according to their fields of study - humanities, STEM and information technology (IT). These are 3 separate groups of students with specific interests who, at this stage of their studies, had to study the same study material in biology. Participants were required to study course material related to human anatomy during their compulsory biology classes. The number of participants in the groups was as follows: 28, 28 and 24.

The impact on students' progress was measured by tests comparing their results before and after using the AR applications. The AR system used was Zspace® (Figure 3.2).

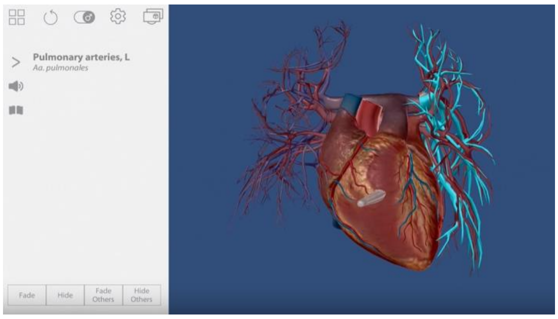

Figure 3.2. Screenshot of an augmented reality (AR) model of the heart and blood vessels

Pearson correlation was calculated:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \tag{1}$$

Where n—number of pairs of scores; $\sum xy$—sum of the products of paired scores; $\sum x$—sum of x scores; $\sum y$—sum of y scores; $\sum x^2$—sum of squared x scores; $\sum y^2$—sum of squared y scores. The two variables x and y are quantitative and continuous.

The histograms of the results of the 1st group of students are shown in figure 3.3.

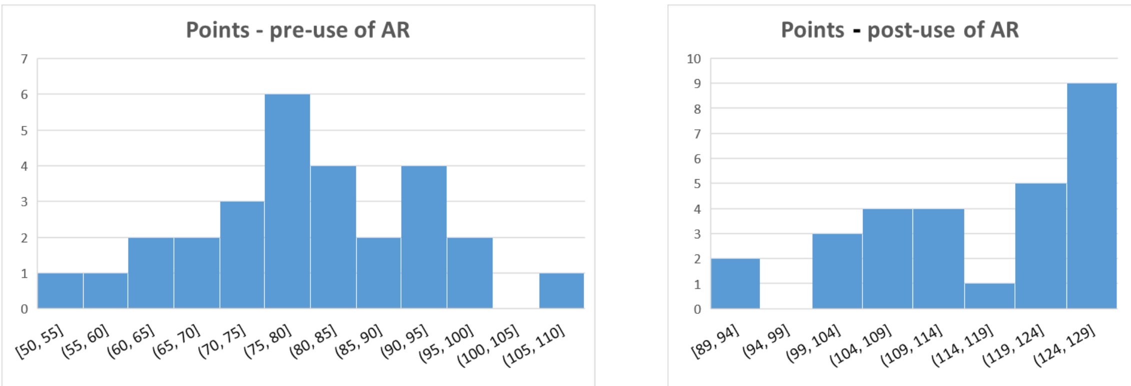

Figure 3.3. Histograms of student group 1 results.

It can be seen that in all three groups, the use of an AR system and environment resulted in a statistically significant difference in students' level of understanding of the learning material compared to traditional text-based and graphic-based learning tools.

3.2 Evaluating the effect of the developed models with GeoGebra's AR module

Two ways of using the AR module were explored:

- for a personalized learning experience provided by the AR module to students through the GeoGebra 3D Calculator mobile application.

- through the combination of zSpace (an all-in-one solution for AR education), GeoGebra and a dedicated zView camera.

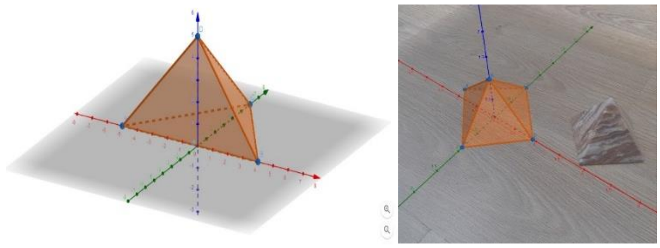

Figure 3.6. A preview of GeoGebra's AR module

In all 3 groups, there was an increase in the score in points. The average percentage increase is almost 30%.

3.3 Evaluating the effect of the application of augmented reality in education in the field of arts

This study presents results of the application of AR in the teaching of fine arts according to the curriculum for secondary schools in Bulgaria.

3.3.1 Exploring physical spaces and artwork in the classroom.

The first type of app that was explored in the study allows students to explore physical spaces and artwork while in the classroom.

The tasks that were set for the students related to researching ancient artefacts, a specific art gallery and researching a specific painting.

The app used to explore physical spaces and artwork while in the classroom was *Google Arts & Culture*.

3.3.2 Creation of own works

The second type of application that was studied allows students to create their own AR objects by adding a virtual dimension to any artwork, including self-created animations, videos, and music. The specific application that was tested is UniteAR [https://www.unitear.com/]. It is an augmented reality SaaS platform that allows users to create their own AR experiences in literally three clicks.

The following figures show some examples of student work done using an AR application in art classes ((Fig. 3.7), (Fig. 3.8).

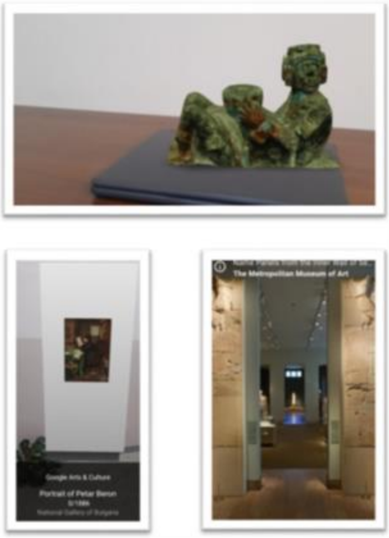

Figure 3.7 Student work done using an AR application in art classes

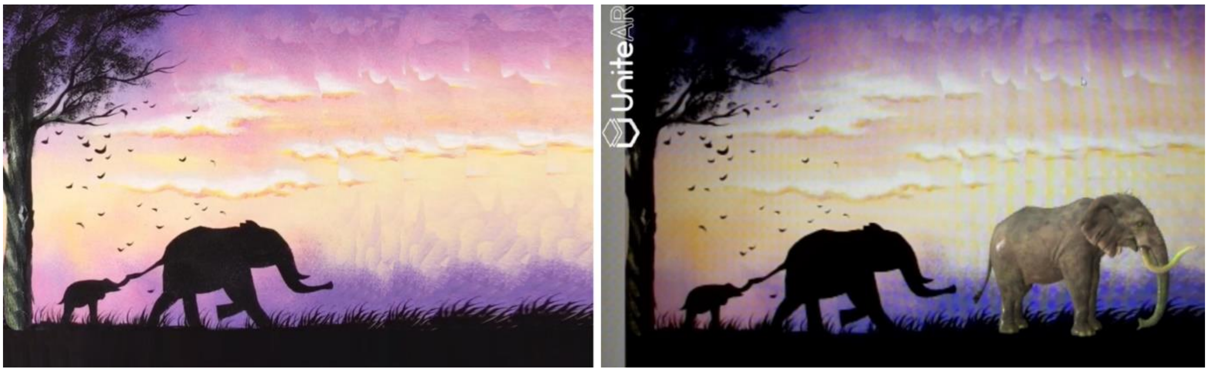

Figure 3.8 A 5th grade student's work with an AR application

Experience shows that a quality AR tool, providing a multidisciplinary approach, with customization options and with many visualization tools, can be very useful for students - to independently plan their work, draw conclusions and learn to express their opinions, by appreciating art-related subjects.

The second experiment showed that average student engagement increased by 27%.

3.4 Evaluating the effect of combining project-based learning with AR/VR

Experimental results have shown that integrating such a dynamic classroom approach as project-based learning with appropriate AR/VR applications can unlock and stimulate creativity, increase both student achievement and their motivation to learn.

An increase in points was observed in all 6 groups. The average percentage increase is 28%.

3.5 Conclusions

The aim of this research was to investigate the impact of different AR tools on student outcomes. The study showed a significant improvement in students' understanding of the research questions.

In line with other studies, AR/VR technology can not only facilitate teaching processes, but also make them more interesting and motivating. Based on the analysis of data on the effectiveness of learning through the use of AR, it can be confirmed that the integration of this technology into the learning process has a significant impact on student results.

The research showed that AR, especially when used in science education, allows students to explore, practice and interact with content without worrying about financial or ethical issues such as expensive supplies or animal injury. The technology provides many opportunities for experimentation, and in a safe environment. In general, virtual, augmented, and mixed augmented reality tools provide all of these capabilities.

The results achieved by students using the GeoGebra 3D Calculator mobile application are described, along with the personalized learning opportunities it provides and the learning challenges. The possibility of teaching through the augmented reality system zSpace in "3D Grapher" mode, with the 3D module of GeoGebra, was also explored.

Research has been conducted related to the use of augmented reality tools in arts education. The results show that the use of augmented reality can be a very effective tool for personalizing the learning process and promoting inclusive and active learning, and the engagement of learners is increased by 27% compared to that measured using traditional learning methods.

As a result, the following conclusions were drawn:

1. a methodology for evaluating the application and impact of tools for augmented and virtual reality in education in the subjects of biology, mathematics and fine arts is proposed.

2. a method for the combined use of PBL with augmented and virtual reality is proposed.

Chapter 4. Implementation of educational materials with the means of AR/VR

One of the big questions facing STEM educators is which application or simulation and experimentation environment to use for specific educational needs, and which development environment to use if they decide to create an educational resource themselves. .

Of key importance for the rapid development of these technologies and resources are the characteristics of AR and VR systems and the opportunities they provide to the user, namely:

VR: virtual world, immersive experience, sensory feedback and interactivity.

AR: the ability to combine digital and physical worlds, real-time interactions and accurate 3D identification of virtual and real objects.

4.1 VR tools for training implementation

Figure 4.1 Basic elements of VR

4.1.1 Hardware required to use VR

To use virtual reality, you need special glasses/helmets for virtual reality - VR headset/gear. VR helmets are devices that completely cover the user's eyes. They provide an immersive and captivating experience.

In the field of education, the most popular are helmets used with a mobile phone, as well as those known as "all-in-one" - autonomous helmets that contain everything needed to conduct a specific lesson and allow centralized control by the teacher.

4.2 AR means for the implementation of training

When we talk about augmented reality (AR), we have to keep in mind the two main types of AR technologies – tag-based and tag-free. The choice of technology determines the possibilities and limitations when working with the particular type of AR.

Figure 4.3 Basic elements of AR

4.2.1 Hardware required to use AR

The use of augmented reality is possible through various end devices.

The first group of AR devices includes smartphones and tablets capable of working with augmented reality.

The second group of AR devices are augmented reality helmets. They allow users to see what's in front of them, but they also overlay digital information.

The third group of AR devices includes systems consisting of several elements - computer system, screen, camera, glasses and various types of sensors. All this is combined with specially developed software, allowing the exploration and interactive interaction with complex 3D structures, as well as conducting various simulations and experiments. One such system on which some of the research in this work is based is zSpace® [zspace.com].

4.3 AR/VR Software Tools and Platforms

The many applications of AR require specific software and hardware. The software uses the coordinates of the real environment from cameras or other devices, and the goal is to transmit information about the position of the object in an XML file using ARML (Augmented Reality Markup Language).

With the increasing spread and success of AR applications in various fields, there is also a growing need to develop new approaches and technologies to ensure the quality of these applications [Tramontana, 2022].

4.3.1 Development environments for VR and AR applications

In recent years, numerous VR and AR application development environments have emerged. Among them, there are those designed for both beginners, advanced and professionals, and some of them are also web-based.

*Some of the most popular **VR** development environments are:*

1. Unity 3D
2. Unreal Engine 4
3. Blender
4. React 360

*Among the most used **AR** development environments are:*

1. Apple ARKit
2. Google ARCore
3. EasyAR
4. Vuforia

Identifying software suitable for use by such teachers is an important task.

The bottom line is that there are only a few tools for creating educational AR applications targeting the needs of teachers. They are:

1. Vuforia Studio

2. Blippar
3. AWE
4. AR Media Studio
5. Areeka

4.4 Bloom's Taxonomy Guidelines for Creating Interactive AR/VR Educational Applications

With the availability of many different options for the use of virtual and augmented reality, it is difficult for most teachers to choose the best technology and find its best application for the specific case.

An updated version of Bloom's Taxonomy [valamis.com, 2022] reflects the entry of new technologies and allows to clarify the learning objectives when applying AR/VR (Fig. 4.5)

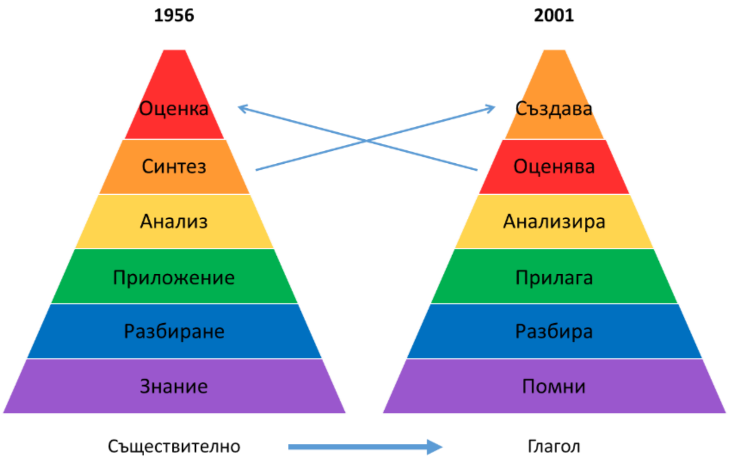

Figure 4.5 Development of Bloom's Taxonomy

4.5 SWOT analysis of the application of AR/VR technologies in education

The results show that the use of XR technology in primary and secondary education is multifaceted, can positively affect the learning outcomes of students, contributes to increasing motivation, engagement and interest [Galati 2019; Simon-Liedtke, 2022; Yin, 2022]. Reality simulation provides a stronger impact on learners than traditional materials; better practical upgrading of theoretical knowledge and economy of materials and safety.

4.6 Conclusions

This chapter summarizes the hands-on experience of the author of this thesis from conducting numerous experiments in a real environment with various AR/VR applications, which forms the conclusions that these applications need descriptions showing which resource, which tool and which activity on which level in Bloom's hierarchy could be used according to educational standards. This would greatly assist educators in making informed choices and providing effective and personalized learning.

Conclusion - Summary of the obtained results

The level of modern computing required to use AR/VR, together with the ubiquity of mobile devices and powerful desktop computing systems, provide new functionalities that can be used in teaching. In the dissertation, models and methods for applying augmented and virtual reality in education are studied in detail. Numerous real-world experiments have been conducted with various AR/VR tools, environments and teaching techniques to achieve a range of learning objectives.

A qualitative and quantitative analysis of the effect of using the proposed models using augmented and virtual reality was made. To achieve different learning goals in different teaching disciplines, as well as for different age groups of students, corresponding models were developed. Experiments conducted in a real learning environment have shown that simulations are a promising way to improve student learning outcomes, especially in STEM subjects. The evaluation of the level of achievement of learning objectives through the use of virtual and augmented reality, and with different approaches in teaching, was carried out with statistical methods.

In this dissertation, it is proposed that the application of AR/VR technologies in education be evaluated in three directions:

– use of AR/VR as additional technological means;

– combining AR/VR technologies with different teaching methods and scenarios;

– combining AR/VR technologies with physical surroundings/environment.

In view of the work carried out in the dissertation and the conclusions obtained in the course of the research and presented above, the following scientific and applied results can be formulated:

1. A model has been developed for using augmented reality in STEM education. The model allows for easy adaptation to the specifics of different STEM disciplines, encouraging creativity and teamwork.

2. A model has been developed for the use of augmented reality in mathematics education. The model allows the use of various augmented reality technologies, making it suitable for application both in the classroom and outside. Enables the use of different educational approaches.

3. A model for using augmented reality in art education is proposed. The model allows the use of both augmented and virtual reality. This makes it flexible and applicable to a very wide range of activities in art education. It enables the use of different educational approaches, encourages creativity, discovery and teamwork.

4. A model for combining project-based learning with augmented and virtual reality was developed. The model is practically oriented and allows the use of a multidisciplinary approach in working with students. Working on a real problem using both types of realities

creates a real sense of experience and successfully addresses an important but intractable problem such as student motivation.

5. Methods for evaluating the implementation of technological means for augmented and virtual reality for certain educational purposes are proposed.

Directions for future research

The main directions for future research on the topic of the dissertation include:

• Exploring the potential of AR/VR to enhance distance learning.

• Integration of AR/VR in the course "Technology Entrepreneurship".

• Integrating AR/VR into veterinary education.

• Exploring the potential of VR to improve students' communication, decision-making and teamwork skills.

• Creating methods and models for using holographic AR in education.

Publications on the subject of the dissertation

1. **Petrov, P.D.;** Atanasova, T.V. The Effect of Augmented Reality on Students' Learning Performance in Stem Education. *Information* 2020, 11, 209. **Scopus SJR 0.222, Q2** **https://doi.org/10.3390/info11040209**
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3. **Petrov, P.,** Atanasova, T., Kostadinov, G.. Enhancing Art education in school through augmented reality. 7th SWS International Scientific Conference on Social Sciences - ISCSS 2020, SGEM World Science (SWS) Society, Austria, 2020, ISBN:978-619-7603-15-6, ISSN: 2682-9959, DOI:10.5593/sws.iscss.v2020.7.2/s13.12, 99-106 (**e-library, Biblioteka WSB we Wrocławiu**)
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