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## **MASTER THESIS**

### **Educational content for children in augmented reality applications**

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## **Abstract**

Technology is an integral part of our lives and most of the time, without realizing it, it is an extension of human gestures and thinking. Internet of things is taking over almost every aspect of the daily routine of the modern man and the mobile phone has become the most important piece of technology in the current era.

Regardless of the age or occupation, using a touch screen or classic screen has become as natural as speaking, and many people are beginning to have difficulties using handwriting to the detriment of digital writing. It is only natural to think that in the near future we will witness the next step being reached, when we will no longer have to touch any screens, but voice commands will take full control.

Lying at the heart of education-related issues, this thesis aspires to deliver a support for adopting digitalization through the implementation of new media technologies in the education process.

Whether we are talking about primary or higher education, there is a big discrepancy between the way a class is conducted and the technology that is already available to students. The school runs in a classic way, which has proven its efficiency, but also its limitations over the years. The thesis will explore details about mentality, progress and the social component, aiming to answer the question whether the use of virtual and augmented reality in schools will affect socialization, but also if going to school will become irrelevant.

Starting from this idea, the first chapter will contain a theoretical research on the contribution of new technologies on the curriculum, outlining the most essential empirical findings on the mobile phone and augmented reality and how these can be used in the process of learning and understanding notions, in areas where this is possible and where it can have great relevance.

The next two chapters of the thesis will explore the main methods of creating augmented content and will aim to gain insight on the practical steps of the implementation process into a game engine.

Finally, the thesis will propose two practical augmented reality applications in order to explore the extent to which new media technologies can be introduced in the education system.

The thesis will evaluate the benefits and downturns of using technology in the formal education system, aiming to serve as a catalyst in the decision of adopting digitalization in the school curricula.

*“We need technology in every classroom and in every student and teacher’s hand, because it is the pen and paper of our time, and it is the lens through which we experience much of our world.” (David Warlick)*

**Keywords:** augmented reality, virtual reality, new media, education, digitalization, children, technology

## **1. Introduction**

The word digitalization is increasingly used nowadays, with the rapid acceleration of technology witnessed in the last few decades. In a broad sense, when we talk about digitalization we think of any action we do using a computer or a mobile phone, but also of systems and platforms that centralize and store in the same place data that can be accessed by anyone, anytime. To give some simple examples, we talk about digitalization when we are no longer obliged to wait in line to pay our bills, or when we make an appointment online. When it comes to the education system, we refer to the concept of digital to any course material and additional material that can be accessed in a non-traditional way, handwritten or printed, in the form of websites, presentations, audio or video material.<sup>1</sup> In Romania, there is a big paradox regarding digitalization in schools. Most recent studies show that our country is on 4<sup>th</sup> place in the world when it comes to Internet speed.<sup>2</sup> Despite this favorable context, 18% from the population aged between 16-74 years old have never used Internet, 57% use it daily and 64% of the people from the rural environment use Internet once per week.<sup>3</sup>

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<sup>1</sup> Luppigini, R., Hagi, A.K., *Education for a Digital World: Present Realities and Future Possibilities*, Apple Academic Press, 2012, p.72

<sup>2</sup> <https://www.speedtest.net/global-index>

<sup>3</sup> Florian B., Țoc S., *Policy note: Educația în timpul pandemiei. Răspunsuri la criza nesfârșită a sistemului educațional românesc*, Biblioteca Virtuala de Sociologie, 2020, p. 11

Normally, concepts such as virtual and augmented reality sound like a contradiction in terms, as reality cannot be both real and virtual at the same time (Elsaesser, 2014).<sup>4</sup> This happens because until recently, we could not access several realities simultaneously. We currently consider the picture we scan with the mobile phone in real life as one reality, and what is magnified above that picture as another reality.

A concrete and comparative indicator of the level of knowledge accumulated by students is represented by the PISA (Programme for International Student Assessment) tests<sup>5</sup>. The program aims at assessing students' capabilities on three important fields, reading, mathematics and science, and it is considered an indicator of the quality of a country's education system, and of the preparation for the labor market<sup>6</sup>. Students have to answer questions that aim to test their real knowledge, these questions being intended to make a correlation of theoretical notions studied in school with practical notions, that could help them overcome real-life challenges.

The latest results from 2018 place us on the 47<sup>th</sup> place out of 79 participant countries, our country achieving the worst results as compared to the previous nine years. 41% of the 15-year old Romanian students can be considered functionally illiterate citizens. The situation is even worse on the mathematics and science fields, where 46.5%, and 44% of the students did not achieve satisfactory scores, which may lead to the conclusion that they do not possess critical thinking, they cannot establish a cause-effect relation, and cannot draw a conclusion from a piece of information.<sup>7</sup> In fewer words, these teenagers do not have the ability to resolve simple problems that appear in real-life situations.

The main element that I chose to focus on in the education process is teaching notions through visualization, which in the end leads to a better understanding<sup>8</sup>. In fields such as mathematics, physics, chemistry, biology, we face abstract notions which are very difficult to be visualized.<sup>9</sup> The forces in physics, the cells in biology, the atoms in chemistry, the geometric

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<sup>4</sup> Elsaesser, T., *Pushing the contradictions of the digital: 'virtual reality' and 'interactive narrative' as oxymorons between narrative and gaming*, New Review of Film and Television Studies Journal, 2014, Vol. 12, p. 295

<sup>5</sup> Grek, S., *Governing by numbers: the PISA 'effect' in Europe*, Journal of Education Policy, Vol.24, 2009, pp.23-24

<sup>6</sup> OECD Publishing, *School Factors Related to Quality and Equity*, 2005, p.91

<sup>7</sup> <https://www.oecd.org/pisa/data/>

<sup>8</sup> Presmeg, N., *Research on Visualization in learning and teaching mathematics*, Handbook of Research on the Psychology of Mathematics Education, Sense Publishers, 2006, p.206

<sup>9</sup> Tuvi-Arad, I., Blonder, R., *Continuous symmetry and chemistry teachers: learning advanced chemistry content through novel visualization tools*, Chemistry Education Research and Practice Journal, 2010, p.48

bodies in mathematics are notions that are taught at a theoretical level and students take them as such, learning by heart notions that they only imagine, except for some limited laboratory experiments.

The main idea conveyed by researchers is that the technology should be seen as complementary to the classical curriculum.<sup>10</sup> Traditional elements such as working with a teacher, socializing between students, should not be replaced, and instead, they should be enhanced by adding more visual elements through technology<sup>11</sup>. Fourtane (2019) stated "By 2025, Generation Alpha will number 2 billion globally. It will be the wealthiest, most educated, and technologically literate in history."<sup>12</sup>

Almost every child of scholar age has a cell phone.<sup>13</sup> Unlike virtual reality where, for more complex applications we need a VR headset and a computer, which results in a financial investment, for augmented reality the required technology is already present, available and accessible to everyone. The same technology that we normally use dozens of times during a day, can and must be used for educational purposes without any additional financial effort. It is just a matter of requesting and creating educational content. In the classical paradigm, at the beginning of a class, students were often forced to turn off their mobile phones and even hand them over in order not to disturb. Through this thesis I support the idea that, when appropriate, students should be asked to switch on their mobile phones and open the application that helps them in the learning process.

The discussion must also target the difference between generations, a topic that is widely debated, but we cannot discuss about the use of technology without touching it. Starting from the researchers' point of view, I strongly believe that the biggest gap between two consecutive generations, in the history, is the one between our generation and our parents' generation.<sup>14</sup> Their generation is called Generation X, and most school teachers are still part of it. As a main characteristic, they are not very used to technology, because they did not have access to computers

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<sup>10</sup> Information Resources Management Association USA, *Virtual and Augmented Reality: Concepts, Methodologies, Tools and Applications*, IGI Global, 2008, p.208

<sup>11</sup> Seel, N., *Encyclopedia of the Sciences of Learning*, Springer, 2012, p.1444

<sup>12</sup> Fourtane S., *Augmented Reality: The Future of Education* from <https://interestingengineering.com/augmented-reality-the-future-of-education>, 2019

<sup>13</sup> Childwise Monitor Report 2020, <http://www.childwise.co.uk/>

<sup>14</sup> Catherman, J., *Guiding the Next Great Generation*, Revell Books, 2020, Chapter 3

or internet at the beginning of their career.<sup>15</sup> As a consequence, they have adapted their teaching style to an environment where the main teaching materials are the blackboard, books and pencils.

An example from abroad, as Kishor G. (2013) stated, is the Metropolitan State University of Denver, where the first online class was held 1996 and in 2013 there were around 8000 students enrolled in at least one online class<sup>16</sup>. On the same idea, Marathe S. (2018) created a SWOT analysis for online education in India (fig 2). The main elements in Strengths category are time and location that are independent, exposure to global standard of education. In Opportunities, he identified the enrollment of a more number of students in a session, in Weakness he talks about the absence of the teacher and a higher cost of education. Last, on Threats, he identified elements like security and authorization issues.<sup>17</sup>

Augmented reality is still a new technology even for very young people, who had access to technology since their birth. Under these conditions, a much greater and more sustained effort is needed to embrace such technology in a field where, for hundreds of years, almost nothing fundamental has changed<sup>18</sup>. Augmented reality "closes the gap" between the virtual and the real world because it directly interconnects the two worlds and the biggest advantage is that it does not disconnect the user from reality, thus allowing real interaction and socialization at the same time.

## **2. Interactive technologies used in education**

Interactive technology refers to the direct feedback received after pressing a button or executing a command. The most well-known interaction of this kind is the one with the computer and more recently with the mobile phone. When we refer to the education system, we can divide the discussion into three categories, the preschool, primary school system and higher education. Teachers play the most important role, and the use of new media methods in teaching must start

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<sup>15</sup> Vogels, E., *Millennials stand out for their technology use, but older generations also embrace digital life*, Pew Research Center, 2019, from <https://www.pewresearch.org/fact-tank/2019/09/09/us-generations-technology-use/>

<sup>16</sup> Kishore G., *Digitalization in higher education: Costs and benefits. Digitalization and Beyond*, Russell Square International College, 2013, p. 3

<sup>17</sup> Marathe S., *Digitalization in education sector*, International Journal of Trend in Scientific Research and Development, 2018, p. 54

<sup>18</sup> Monowar, M., *Rise of Augmented Reality: Current and Future Application Areas*, International Journal of Internet and Distributed Systems, 2013, pp.25-26

with them<sup>19</sup>. It is a matter of education, training and openness. Teachers use the computer for most of the administrative tasks, writing documents, internal communications or checking the email. In order to be able to transmit information to students using the new technologies, it is necessary for teachers to show an intense interest in this field. This objective could be challenging, especially in places where economic development is low, but can be achieved through innovation using the existing means and on-going training in order to keep up the pace with this continuously changing field.

4-5 year olds react very well to stimuli such as music and colors. This is supported by a study presented by Min (2005) where he shows that kindergarten classes are increasingly being accompanied by technology adapted to children's age.<sup>20</sup> Touch screens are the main form of interactive technology. They are used for playing stories, music, picturing colors or animals. The same study concludes that clicking on the screen in order to solve a puzzle or to discover a new notion it stimulates the children's ability to concentrate, but also increases their motivation to continuously explore. On the classical model, each notion is taught by the educator, and the children learn by repeating the information until they remember it by heart. Creating a visual environment through the technological means helps them learn to talk earlier by the need to respond to feedback received through a screen, especially where the response is auditory. Also, the use of a keyboard or buttons develops precision and skill, but also awareness of the cause-effect relationship, and the use of a joystick or a mouse adds precision to their actions.

At older ages, the use of interactive technologies in school increases. Starting with the fifth grade, the term laboratory (used for computer science, biology, geography etc.) is well known, and it refers to that place specially arranged for teaching a single subject using specific materials. Although the computer is used more often, it is used especially in computer labs for acquiring basic knowledge of the Internet or of document writing programs, but also for students studying programming languages. Interactive whiteboards have become very popular in schools, both in our country and abroad, many of them being obtained through European funds or state supported aids. According to a study, in 2005 half of the England teachers used at least once interactive

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<sup>19</sup> Kennewel, S., Tanner, H., Jones, S., Beauchamp, G., *Analysing the use of interactive technology to implement interactive teaching*, Journal of Computed Assisted Learning, Vol. 24, 2008, p.61

<sup>20</sup> Min, L., *An Exploratory Study of How Pre-Kindergarten Children Use the Interactive Multimedia Technology: Implications for Multimedia Software Design*, University of Texas at Austin, 1996, p. 6

whiteboards.<sup>21</sup> Such whiteboards allow students to create instantly visual presentations in front of their colleagues, by collecting information and manipulating images, audio or video sources in real time.

In higher education we can talk about other really interactive forms. Interactive technology becomes a norm in higher education institutions. First of all, using the computer becomes mandatory both personally and in class, due to an increased need of keeping up with the continuous flow of information, but also due to the presentations or projects that need to be prepared by students, which require gathering information from multiple online sources, as well as remote team collaboration. Depending on the specifics of the faculty, the technology becomes more specific, and in the case of institutions oriented towards science, we can even talk about the use of sensors, simulators, but also virtual reality.

Spence, Mckenzie (2014) talk about “student response systems”.<sup>22</sup> Their purpose is to allow students to respond and produce questions of the teaching material during a teaching session. These systems are designed to gather information from students with the help of a handheld device that is distributed to the students before the class begins. As we will see in the following chapters, such technologies are innovative, new-media, with hardware requirements that change regularly, and even globally they are used in a limited number of areas, and not too extensively.

## **2.1. Computer-based Virtual Reality simulations**

Since 1962, when Morton Heilig created Sensorama, a mechanical device which I will describe in more detail in the third chapter, virtual reality has evolved from the stage of niche-only technology, to a technology accessible to anyone and applicable in all fields. The word immersion is increasingly used when we discuss about common things, such as exhibitions, theater and film. We believe that we are immersed in a certain experience when all the senses merge for the same

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<sup>21</sup> Kennewell, S., Tanner, H., Jones, S., Beauchamp, G., *Analysing the use of interactive technology to implement interactive teaching*. Journal of Computer Assisted Learning, 2007, p. 62

<sup>22</sup> Spence, A., McKenzie, S., *Using interactive technology for lectures in higher education information technology*. IEEE International Conference on Teaching, Assessment and Learning for Engineering, 2014, p. 226

purpose. In a metaphorical sense, the act of listening to music in the headphones, or just simply looking at the sky can act as immersive experiences. An explanation would be that we are so overwhelmed by the experience that we often lose track of time, or we do not notice other events happening around us. By definition, immersion refers to the placement of a body in a liquid. Starting from this and extrapolating, for a complete immersion it is necessary to have a 360 degree environment, so that the simulation of another reality could be perfect. By comparison, when we watch a good movie on the TV, even if we can be immersed because of the acting, music, suspense, when we move our gaze from the screen, reality takes us out of that atmosphere, and the experience dissipates.

Virtual reality aims to simulate another reality in real time, parallel to the current reality. With the development of technology, people can experience real-life simulations such as normal or extreme sports, climbing, fishing and other games adapted to such an environment through headsets such as Oculus or HTC. A virtual reality simulation is actually a game, as it contains game mechanics and is created mainly in software dedicated to creating games, so when we refer to virtual reality, we think first of games and entertainment. This entertainment industry occupies the main place in the percentage of virtual reality experiences. Over time, the need for simulation has become part of the education and training process. Many domains benefit from such simulations, making it easier for users to experiment in an environment identical to reality, the main advantage being the fact that mistakes or errors have no consequences. The classic types of simulators, such as flight and medical procedures simulators, or the simulation of weightlessness in water, have evolved and now happen in virtual reality.

Since 1994, as shown by Psotka (1995), in one of the space missions to repair the Hubble Telescope, NASA used VR technology to train over 100 flight operators and engineers for what they we're supposed to do for supporting and helping the astronauts.<sup>23</sup>

The feedback received after the tests was better than expected, more than half of those who answered the questionnaires being pleasantly impressed by the use of this technology for learning. Wikens D. (1992) made a research on virtual reality and education. He identified some benefits

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<sup>23</sup> Psotka, J., *Immersive training systems: Virtual reality and education and training*. Instructional Science, 1995, p. 424

that are implied using this technology: motivational value, transfer of the learning environment, different perspective and a “natural” interface.<sup>24</sup>

A recent example of virtual reality learning is Labster<sup>25</sup>, a platform created by Michael Bodekaer and Mads Bonde that allows students to simulate a multitude of tests, scientific experiments, medical surgeries etc., through gamified experiences. The controlled environment is the right choice for these activities, as students can perform experiments that may be unsafe, have the opportunity to explore freely and make mistakes. Students can see fully equipped laboratories and surgery rooms, and can conduct experiments that are impossible to achieve in reality at this time, which prepares them for their future careers.

Another novelty from Labster is the involvement of game designers in building the simulations, which has put a much greater emphasis on the visual side. This has made the VR experience more pleasant and less stressful, for example students being able to make complex medical procedures while seeing and hearing the waves of the sea.

One study using Labster at Stanford University and Technical University of Denmark divided 160 students into two groups, half working only in classical laboratories and the other half in virtual laboratories.<sup>26</sup> The results of the study showed a 76% increase in learning efficiency for students who studied only with a virtual laboratory. The most interesting part of this study showed that when using the classical teaching methods, combined with virtual methods of learning, the teachers’ efficiency increased by 101%.

## **2.2. Mobile applications**

Each individual’s learning methods differ greatly depending on many factors. Felder and Silverman (1988) divide the types of learning into three categories: visual, verbal and kinesthetic.<sup>27</sup> Conklin (2005) analyzes the Bloom’s taxonomy which divides the learning process into 2 main

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<sup>24</sup> Wickens, C., *Virtual reality and education*. IEEE International Conference on Systems, Man, and Cybernetics, 1992, p. 843

<sup>25</sup> <https://www.labster.com/>

<sup>26</sup> <https://www.youtube.com/watch?v=iF5-aDJO6U&t=363s>

<sup>27</sup> Felder, M., Silverman, K., *Learning and Teaching Styles In Engineering Education*. Engineering Education, 1988, p. 676

categories: the cognitive dimension and the knowledge dimension.<sup>28</sup> The cognitive dimension is further divided into six other levels: memory, understanding, applicability, analysis, evaluation and creation, while the dimension of knowledge is divided into practical, conceptual, procedural and metacognitive knowledge. Harrison, Flood and Juce (2013) found in their research on mobile applications that usability is usually measured in terms of three attributes; effectiveness, efficiency and satisfaction. As a result of their study, they introduced another model named PACMAD (People At the Centre of Mobile Application Development) which brings together significant attributes from different usability models in order to create a more comprehensive model.<sup>29</sup> Dongsong and Boonlit (2005) make a classification of business mobile applications and found that most of these applications are daily news alert services, classified mobile advertising, restaurant and entertainment listings, wireless Web portals and mobile commerce (e-commerce) applications.<sup>30</sup>

Almost any subject and any form of teaching includes in its methodology a form of technology, from videos, online courses, to word documents or Powerpoint presentations. Since primary school, teachers hold their courses accompanied by presentations, and students, in addition to the handwritten assignments, have more and more homework that needs to be prepared using the computer. Since 2008, when Appstore was born (the place where Iphone applications can be downloaded was launched), but also since Android Market became Google Play for Android devices, the world has undergone a huge transformation. Mobile applications cover a wide range of fields, interests, information, games, entertainment, and if since the Internet was invented any information was at a click-distance away, now, with mobile phones and applications, everything is not a click away, but permanently with us in our pocket and even updates in real time.

Pea and Maldonado (2006) identified several key elements as advantages of mobile devices: portability, small screen, increased power, instant start-up, multiple communication

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<sup>28</sup> Conklin, J., *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Educational Horizons, 2005, p. 155

<sup>29</sup> Harrison, R., Flood, D., Duce, D., *Usability of mobile applications: literature review and rationale for a new usability model*. Journal of Interaction Science, 2013, p. 1

<sup>30</sup> Dongsong, Z., Boonlit, A., *Challenges, Methodologies, and Issues in the Usability Testing of Mobile Applications*. International Journal of Human-Computer Interaction, 2005, p. 293

networks, multitude of applications, data synchronization between devices and various types of inputs.<sup>31</sup>

It has already become a habit for young children, even from the age of 2, to be placed in front of a phone or tablet to watch cartoons, parents often using this as a pretext for having free time. The kids' interaction with such touchscreen devices is a very natural action, similar to the way they play with a toy. The multitude of methods of use, such as touching, swiping, pinching, shaking, tilting, speaking into the microphone, using the camera for interaction, all offer a complete and complex learning experience for children, even without the help of an adult.<sup>32</sup> A content analysis in the 'Education Section' of Apple's app store, conducted by Shuler in 2009, showed that half of the top 100 applications on the AppStore were used for the preschool or primary system. For the Android system, Avtar showed in 2014 that educative applications were in the first four accesses and in 3rd place in the best-selling applications.

The content of mobile applications for children is very diverse. There are many websites and advertisements that promote educational content, but there is no international standard for developers to follow when creating content for children. Thus, Guernsey and Levine (2015) invented the 3 C rule. They refer to Content, if the application is age-appropriate, Contextual, if the application is interactive and helps the child to learn by playing, and Child, what is stimulated inside the child after interacting with the application.<sup>33</sup> Although there are many applications with educational content, to my knowledge there are no such applications to be integrated and used directly in the school curriculum, as a requirement. This happens for various reasons, such as accessibility or openness, reasons that I will further discuss about in the following chapters of this thesis. Most of the applications are used by parents to compensate for certain lack of knowledge or to make the learning process easier. The most used applications are play and learn type, such as puzzles, quizzes, activities for learning the colors or shapes, practical guides, but also the ones for learning math, performing experiments, spelling exercises and grammar etc.

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<sup>31</sup> Pea, D., Maldonado, H., *WILD for learning: Interacting through new computing devices anytime, anywhere*. The Cambridge Handbook of the Learning Sciences, 2006, p. 855

<sup>32</sup> Papadakis, S., Kaligiannakis, M., *Mobile educational applications for children: what educators and parents need to know*. International Journal of Mobile Learning and Organisation, Vol.11, 2017, p.3

<sup>33</sup> Guernsey, L., Levine, M., *Tap, click, read: Growing readers in a world of screens*, Wiley, 2015, p. 53

### **3. Augmented reality**

#### **3.1. History**

Augmented reality is the technology that allows a virtual world to overlap with the real world. The main concept that represents the basis for the emergence and development of this type of technology was the need for immersion. If we think of theatrical art, theaters are a place where the viewer is immersed in a play. Through lights, sound, interpretation, lack of disturbing external stimuli and creation of an atmosphere, the spectator is immersed into another world for the duration of the play. When it comes to cinema, even if technology is evolving, cinemas are still the best way to fully experience the act of watching a movie. When technology is used on a broader level, in this case, the fact that we can watch a movie directly on the phone or personal computer, facilitates our accessibility, but limits the immersion.

Museums, art galleries, exhibitions are the best examples through which any type of art being exhibited tries, through the exhibition environment, to induce the viewer the desire to stay and visit for as long as possible, by the transformation of the space, so that wherever the spectator looks or walks, his mind is bombarded visually and aurally with information.

Augmented reality differs from virtual reality mainly because, in the latter, the viewer is introduced to another world, independent of the real one. In this case, state-of-the-art technology will soon allow the creation of an infinite world, with total freedom, the creation of avatars, similar to the world depicted in Steven Spielberg's Ready Player One film from 2017. In the case of augmented reality, all movies gave us clues about the future of this technology and some of its uses. Thus, in Star Trek, Terminator, Iron Man, Predator, Total Recall, They Live, the camera attached to head-mounted displays, or the camera implanted directly in the eyes superimposed images and information directly over reality, helping the characters with complex calculations or gathering clues or pieces of information.

As previously mentioned, among the first prototypes of digital immersion is the Sensorama created by Heilig in 1962. That was a device that introduced the viewer on an imaginary journey on a motorcycle in New York. It had a stereoscopic display, fans, odor emitters, stereo sound system and a moving chair. Augmented reality devices can be divided into two major categories: mounted on the head or portable, and using optical or video see-through. Ivan Sutherland is the

inventor of the first head-mounted display. He is also the creator of the Skecthpad software and is nicknamed the father of computer graphics. The optical see-through head-mounted display system invented by Sutherland was later used by US military pilots to view images from camcorders on helicopters. The name augmented reality comes from David Mizell and Thomas Caudell who used a head-mounted display at Boeing to overlay computer diagrams on the real-time production process. Paul Milgram and David Drascic discuss, in 1996, about the continuum virtuality. The scheme of Paul Milgram (fig.1)<sup>34</sup> has as a starting point the real environment, continues with augmented reality, augmented virtuality and reaches the virtual environment.<sup>35</sup>

An important point in the evolution of augmented reality was the launch of the ARQuake game. The original game, a first person shooter, appeared in 1996 and was played on a desktop system, with mouse and keyboard and involved walking in a virtual environment in which the user shoots monsters. The augmented reality version was created by Bruce Thomas, after which the company that created the original game exposed the source code and superimposed the game in real location, where the user wore an HMD and was able to see monsters in real space that he could shoot.

Coming closer to the present times, 2005 marked the beginning of augmented reality for smartphones, with the game ARTennis, a two-user game developed for Nokia phones. In 2008, BMW became the first company to use augmented reality for commercial purposes, using technology to add content to certain advertising materials. The year 2016 is again an important year because it brings back into discussion, but also in the attention of the general public the importance and the possibilities of augmented reality with the launch of the Pokemon Go game. This game used the phones' GPS and cameras to superimpose the Pokemon creatures in the real world. Users had to find certain locations using the GPS coordinates, and only when reaching their destination, they could capture those Pokemons. The game enjoyed immense popularity, sparking multiple controversies, some of them caused by the places where people went to find the pokemon,

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<sup>34</sup> [https://www.researchgate.net/figure/Simplified-representation-of-a-RV-Continuum\\_fig1\\_228537162](https://www.researchgate.net/figure/Simplified-representation-of-a-RV-Continuum_fig1_228537162)

<sup>35</sup> Drascic, D., Milgram, P., *Perceptual Issues in Augmented Reality*, Stereoscopic displays and virtual reality systems, 1996, p. 124

such as cemeteries. The game also had a positive impact, being considered a huge multiplayer and socializing game and a means for leaving the house and doing physical exercise.<sup>36</sup>

In an earlier section, we divided the types of augmented reality devices into two categories, but on top of these we can add spatial or external augmented reality. It is important to analyze the main differences between the various types of augmented reality. Optical see-through works by placing semi-transparent glasses in front of the eyes, which allow the user to see the reality, but they also reflect the digital content transmitted by the headset. Video see-through requires the user to see reality through a video camera that broadcasts in real time and that overlaps the virtual graphic elements over reality. In this case, what we see through the display depends not only on the graphics and the way they overlap, but also on the performance of the device's camera, screen refresh time etc.

In the case of a head-mounted display that uses video see-through, the technology allows an almost perfect synchronization between the virtual objects superimposed over the real world. As disadvantages, it requires the user to wear a camera and involves a real-time processing of the camera signal and a more unnatural perception of the environment. On the other hand, head-mounted displays that use optical see-through involve a mirror that reflects virtual objects on the display. This offers a more natural perception of the real environment, but the virtual objects are not so precisely superimposed over the real environment. Moreover, handheld devices that use see-through video have the advantage of being portable, equipped with a lot of sensors, very widespread, but the small screen can be a disadvantage in some cases. Another technology or type of AR I would like to bring into discussion is the spatial or external augmentation. This can use video see-through and optical see-through, without supporting mobile systems yet, but can also use direct augmentation, which means that virtual 3D objects are superimposed directly over the real environment, depending on the tracking system, face, body, eyes, forms etc.

The various types of devices that use augmented reality also use multiple types of inputs. When we talk about input, we refer to the way the system receives data, information and acts accordingly based on the gathered data. These inputs largely depend on the type of intended

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<sup>36</sup> Paavilainen, J., Korhonen, H., Alha, K., Stenros, J., Koskinen, E., Mayra, F., *The Pokémon GO Experience: A Location-Based Augmented Reality Mobile Game Goes Mainstream*, Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 2017, p. 2493

applicability, but also on the hardware capabilities of the device on which they run. Thus, in the case of handheld systems, the user can use the touchscreen to interact with what is augmented.

There can be multiple types of interaction, such as single touch, multiple touch, swiping, pinching etc. In the case of handheld devices, but especially head-mounted ones, there is direct interaction with the virtual world, certain objects, text, arrows, or any other object placed virtually acting as a trigger, once touched by the user. These objects fall into the category of virtual buttons that we will further discuss about in a later chapter. The phone's sensors are often used as inputs, the application responding when it detects movements of the gyroscope, magnetometer, global positioning system etc. Another type of interaction is gaze-input, without external or internal stimuli. In this case, the direction in which the gaze is oriented, or the direction of the phone in the case of handheld devices, can influence or send a signal for interaction. An example is represented by the Google SkyMap application, where the user points the phone to the sky in the direction of a planet or star, and the application offers information about the celestial objects. To continue with, there are other types of inputs, such as voice commands, gloves or wireless bracelets for interaction.

Tracking is one of the most important aspects of augmented reality that contributes decisively to the quality of the AR experience. Again, the type of tracking depends mainly on the purpose of the application, but also on the hardware possibilities. The most used type of tracking is the use of fiducial markers. These are represented by any object that is placed in the device's field of view that is being recognized by the application, and as a consequence, the application accurately places the 3D content on it. These markers provide information about the size of the environment or positioning information, but can also be a simple recognizable pre-recorded image. Image-based is the most used tracking system. Almost any 2d image can be uploaded to the system, and the application overlays virtual content over it once the image is recognized. An application can recognize one or multiple images simultaneously. In addition to a 2d image, other shapes can be used as markers, such as cylindrical shapes, squares, 3d objects. Another type of tracking system is the markerless one. Here, we are talking about several types. Area tracking, when the application first scans a room, turns it into 3d data and uses this data to position virtual elements over that space. Also in this category, there is ground plane tracking, in other words the application recognizes a straight surface, a terrain, on which the 3d content overlaps.

With the development of technology, but especially mobile phones, a new generation of augmented reality systems are developing. Google glass appeared in 2013, a technology that involved a pair of glasses similar to the regular eyeglasses, which projects on the lenses information, applications, can take photos, but also record a movie. It used a touch-based system on the side, but also a system for voice commands. At the same time, Microsoft launched a lightweight system, HoloLens, using the same type of glasses with similar functionalities. In 2018, Facebook announced that it will launch its own smartglasses in the coming years, glasses that will replace mobile phones in the future, acting as a holographic system that will display the content we now see on the phone, directly on the lenses. As the battle grows stronger and the devices become smaller and more portable, there are companies like Mojo Vision's that are developing augmented reality contact lenses. Although it is still a prototype, it could be the future of these technologies, as this technology would be both wireless and invisible.

### **3.2. General usage**

The concept of augmenting existed even before the launch of the technology we use today. In any field, augmentation was seen as an equivalent of the concept of improvement. We can talk about this concept when we refer to any product that is created on a large scale, where each generation that follows is augmented with a new technology. Thus, that product becomes better, more accessible, more targeted, more adapted to the requirements of the public. A good comparison can be made with the human beings. Most of the human augmentation, from a physical point of view, was achieved over time, through natural adaptation to climate, geography, landmark events etc.

There is a large array of literature works and science fiction movies that depict the human augmentation: the ability to run faster, to jump higher, to see better, to live longer etc., through various chips, processors, implanted computers. In real life, medical implants are an important form of augmentation. When someone loses a percentage of their hearing, it is already a common practice to be "improved" with a hearing aid. The main difference between man and products is that while for products, it is easier to simply replace them by a newer generation, for humans we

can only perform upgrades. The main engine that drives the evolution of technology is the modern man's need to accelerate any intermediate process that mediates access to the final product.

If we think of a museum, the visiting experience has been augmented for a long time with informative inscriptions about the premises, but especially about the exhibits displayed. With the development of technology, audio guides have emerged as a form of augmented auditory reality. These devices appeared due to people's need to contain a large amount of information in a way that is as compressed and ergonomic as possible. To further demonstrate this idea, we can think of the pop-up book. The content of children's books evolved from simple stories to drawing books and to audio stories. Taking into account the continuous and accelerated evolution of children's needs and desires, people created the pop-up books, which contain pages that can be folded, modified, or unfolded to form almost any 3d image of the information depicted in the story.

The augmented reality we refer to in this thesis has a wide applicability in a multitude of fields, but it has certainly not yet reached its full potential in any of them. In medicine, augmented reality can be used as a method of visualization, but also of training. Important research has been done to incorporate augmented reality with medical imaging. As a real-time viewer, Carmigniani, Furht, Anisetti, Ceravolo, Damiani, Ivkovic (2010) showed that the scientists introduced a system of seeing virtual anatomy through human skin.<sup>37</sup> In the same visualisation idea, the same research has been done on an augmented reality system for scanning the patients' wrists to diagnose arthritis. Another application could be checking the patients' medical background, which implies that the patient has implemented a tracking or identification system. In laparoscopic surgery Fuchs, Livingston, Raskar, Colucci, Keller, State, Meyer (1998) have shown progress that has been made with augmented reality. The AR system can display real-time 3D images to properly guide the incision.<sup>38</sup>

Augmented reality has begun to be more and more present in the museum environment. We can talk here about more types of applicability, such as guiding, detailing or superimposing other types of media on something real. Like audio guides, any image, sign, graphic element in a

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<sup>37</sup> Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M.. *Augmented reality technologies, systems and applications*, Multimedia Tools and Applications, 2010, p. 365

<sup>38</sup> Fuchs, H., Livingston, M., Raskar, R., Colucci, D., Keller, K., State, A., Meyer, A.. *Augmented reality visualization for laparoscopic surgery*. Lecture Notes in Computer Science, 1998, p. 935

museum can be scanned, allowing the visitors to find out in real time where they are located or details about the area to visit, to use interactive map for navigating virtually through the whole museum etc. The applicability on artworks, painting, sculpture etc. is very diverse and we can divide it into two categories. Such works can be scanned, allowing the user to find out new information about the work or the author, to view a video in which the author even speaks etc. A more complex use is represented by the superimposition of another augmented artwork, the original one that everyone sees representing in fact only a portion of what the author wanted to transmit initially, viewers being able to discover the missing part with the help of technology. A last use, in the same idea, can represent a type of museum in which the work is visible only with the help of augmented reality, the graphics coming to life on the walls of the gallery and the user being able to interact with this newly created dimension. Also on the cultural side, Huang, Liu, Wang (2009) shows us that augmented reality can be used to reconstruct ancient sites, ruins or to inform users about the history of the place or elements that they can no longer observe.<sup>39</sup>

Shopping can be transformed with this technology. Spatial augmented reality systems, without HMD or mobile device, already exist in the form of mirrors that use the camera to overlap the image of the viewer with other images. Thus, people can try on dresses or shoes by positioning themselves in front of such a mirror, that will overlap on top a variety of clothing that can be changed based on colour, size or other viewer's wishes. Recently IKEA introduced an augmented reality application through which the user chooses a product, generally furniture or decorations, then by scanning the room where they want to place it, the product overlaps in real time over the real room. Thus, the time spent for travelling repeatedly to the store, making choices, projecting the design and placing the order decreases dramatically.

The advertising industry benefits greatly from augmented reality. In 2008, the MINI car making company has run a campaign on their website, which required users to scan in front of a webcam their magazine. Once scanned, on top of a picture depicting a car, the augmenting reality application added a 3D version of the car being advertised. The potential for this industry is huge. A newspaper or magazine has a limited amount of space to store as much information and images

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<sup>39</sup> Huang, Y., Liu, Y., Wang, Y., *AR-View: and Augmented Reality Device for Digital Reconstruction of Yangmingyuan*, IEEE International Symposium on Mixed and Augmented Reality, 2009, p. 4

in a format as compact as possible. With augmented reality, people can scan part of a page and the user gets access to additional information, such as the trailer of a movie being advertised, can unlock paid content etc.

Games have a large share in the percentage of augmented reality usage. As previously mentioned, the popularization of technology at the mass level was realized through the pioneer ARQuake and later Pokemon Go. Playing a game with AR opens up new possibilities for players, who no longer have to sit still in front of a computer, but the gamified environment appears wherever the players are physically located. Games can also be multiplayer, each player leading a character that can interact with the characters led by other players. A very good use for augmented reality can be board games, where the big tables and instruction cards can be scanned with the mobile phone. This leads to much greater interactivity, but also opens up new possibilities for different types of content.

The automotive industry already uses this technology, offering new possibilities for the workers in this field. HMD devices, such as Hololens, are widely used in this field for adding information about parts, components etc. over real objects. Microsoft Hololens is a self-contained system running a special version of Windows 10 that generates and projects stereographic images onto the lenses of a headset. So, it contains a computer, speakers, sensor, buttons, camera and a vent. Noor A. (2016).<sup>40</sup> The financial gain is the main motivation in this industry, carmakers being aware that increased efficiency leads to higher earnings. The training and preparation time is quite long, especially in the technical departments. Thus, augmented reality devices help to simplify processes and do not prevent the physical maneuvering of an instrument because these devices use optical see-through. When looking at a component, the worker sees clear information about it, such as how to use or process it, the temperature, maneuvering techniques etc. All these lead to efficiency by decreasing the learning time, but also by eliminating the errors caused by an incorrect use. It is worth mentioning here that, in recent years, there is an increasing number of debates around job losses and the replacement of human workforce by robots, especially on production lines. This will certainly happen, because a robot has an efficiency of almost 100% with an unlimited effort capacity, while humans will be oriented professionally towards the type of work

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<sup>40</sup> Noor, A., *The Hololens Revolution*. Mechanical Engineering, 2016, p. 33

that involves their intellectual abilities and soft skills. Interestingly, although AR technology is state-of-the-art, its purpose, from our observations, is not to replace the man, but to improve human senses, accuracy and knowledge.

In the education system, augmented reality technology is used at low capacity. Although we will discuss in more depth about its applicability in education, it is worth mentioning some important aspects. In their research, Bower, Howe, McCredie, Robinson, Grover (2010) found that Augmented Reality systems can support and enhance a variety of pedagogical approaches, like constructivist learning, situated learning, game-based learning, enquiry-based learning.<sup>41</sup> Hsin, Lee, Chang, Liang (2012) discuss about the new skills that can be promoted in augmented reality environments. They emphasize things like the sense of authenticity, increase of motivation that can lead to more accurate knowledge on specific topics.<sup>42</sup> There are mobile applications that help children acquire skills such as drawing, reading, solving puzzles, visualizing elements of mathematics or other sciences. These applications utilize marker tracking or plane detection. An example of an application that took a basic concept from AR and developed it further is Mondly<sup>43</sup>. It is an application that teaches users foreign languages through speech recognition and has an augmented reality section, in addition to virtual reality. It uses a virtual assistant that provides directions and guides the user. The application also overlays 3d models, such as animals or objects, users learning these terms in different languages. Not many people know, but the application is developed in Romania and has received several awards, such as the 2016 application of the year by Facebook, Best New App in 2017 by the AppStore, and Google Play Editor's Choice.

### **3.3. Designing for children**

In the following sections of this thesis I will describe the means I used to reach the final ideas, create the design and develop the applications. A large part of the entire creative process is the identification and adaptation to the target audience. In this case, I knew from the beginning

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<sup>41</sup> Bower, M., Howe, C., McCredie, N., Robinson, A., Grover, D., *Augmented Reality in education – cases, places and potentials*. Educational Media International, 2014, p. 6

<sup>42</sup> Hsin, K., Lee, S., Chang, H., Liang, J., *Current status, opportunities and challenges of augmented reality in education*. Computers&education, 2013, p. 43

<sup>43</sup> <https://www.mondly.com/>

that the first application will be addressed to eighth grade students, aged approximately 14-15 years, and the second application to children starting with the age of 7 and ideally until 14 years old, but without an upper limit imposed.

In general, the design process of any augmented reality application is very similar to that of a game, with all the related processes. Any application is, after all, a game. What differentiates them is the content and the way the user interacts and relates to that content. Thus, the game designer is like a director, who has the overview, thinks about every rule and interaction and who collaborates with the programming and art departments for the final product. In order for a gamified application to target children, it must take into account some basic aspects, such as the design of auxiliary materials, images, cover, trailer, adaptation of content, rules, game mode, and the purpose and mode of reward. The details I refer to below are not necessarily mandatory rules to follow for a good design for children, but types of methods for creating such applications. Hourcade (2007) talked about Jean Piaget work on child development and on how children learn. He focuses on how children construct knowledge through a process he called adaptation, on the role of maturation, experience, social aspects, and emotional aspects and on the concept of the developmental stages of children.<sup>44</sup>

Most of the time, the term ‘children’ is followed by the term ‘educational’. The two terms are usually placed side by side, often just because they sound good and attract parents more than children. But clearly, the application is more likely to be bought or downloaded if it has a clear educational component: helping the child to learn, read, draw, count etc. Thus, the description of an application, but also the representative image that accompanies it can make the difference between downloading that application or not. Speaking of augmented reality, most applications use markers for tracking, so they require another material for working properly. This marker is a physical one, an image that the user must print, or be able to display on another display. It is a rather complicated process because it takes time until the user prints the image, or if displayed on a tablet, its surface can be too reflective and the quality of the tracking can be low. The other option uses for tracking a space where it identifies a floor on which the content is placed, such as

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<sup>44</sup> Hourcade, J., *Interaction Design and Children*, Foundations and Trends in Human–Computer Interaction, 2007, p. 282

dinosaurs, animals, objects etc. The third option is to buy a physical product, which is accompanied by a download link for the application. Thus, the user actually buys two products, which can increase the buying experience satisfaction, as this combines children's desire to press buttons with the parents' preference for having a physical product, a book that can be read traditionally, without technology. All these details, some having a more technical nature, are part of the preparation process and in fact this step has a much more important role. If the process of downloading, installing the application, gathering the marker is long and difficult, especially when it comes to children, they can immediately give up buying the product. This decision process is similar to the one used by large companies when deciding the game launch platform, Xbox, Playstation, Virtual reality, personal computer etc.

When it comes to content, we refer to all the elements that are displayed on the screen once the “open” button is pressed. All these elements need to be adapted entirely to children and to a specific age category. The most important part of an augmented reality application for children is the visual part. Current generations are addicted to the visual part from the earliest years of life, due to the technology they were exposed to. Television, internet, mobile phones, street ads, posters, everything is communicated mainly visually. We use gestures, we communicate through symbols in a fast way and adapted to the current times. Our parents' generations, but to a limited extent also our generation, rely mainly on words. The word, equivalent to information, could come from a parent or teacher and could only be contradicted by official sources of information, such as books.

This whole paradigm is one way of approaching the learning process, in a much more systematic and difficult manner, always seeking external approval. Nowadays, the process is the opposite, young generations preferring the “learning by doing” approach, accumulating knowledge through exploration, through tutorials and by understanding information, not by memorizing it. The content creator for children must take into account these very big differences in the process of creating an application, but also take into account some basic elements that will not change, regardless of the differences between generations, elements that I further explain in the next chapters.

The user interface elements represent the connection between the child and the application. Massod, Thigambaram (2015) refer to Guilford's Structure of the Intellect framework. They use this method to evaluate user-interface design of applications once the data collection is completed.

The Guilford's framework consists of operations (cognition, memory, divergent production, convergent production, evaluation), contents (visual, auditory, symbolic, semantic, behavioral), and products (units, classes, relations, systems, transformations, and implications) independent dimensions.<sup>45</sup>

The design of the user-interface elements must be visually pleasing and adapted to children through simple and clean animations. The color scheme is important to be consistent throughout the game, to make clear correlations between colors and their meaning in the game. From an early age, colors play a very important role. They are a language that transcends cultural barriers – a child in America will identify the red colour just like a child in Africa, but could associate it differently. Colors are correlated to many other forms of learning in kindergarten, such as songs, or learning math by games. The children are taught with vivid, strong colors, especially from cartoons, with very saturated tones. In augmented reality, as in any game, the color scheme should be clear and uniform throughout the experience, allowing the child to make correlations between buttons, elements and various functionalities, similar to the legend of a map. For example, blue is used for buttons with interactivity, red for text without interactivity etc.

The way a child interacts with the application, in other words the input used is perhaps more important than the content itself. A cumbersome experience or buttons that are not always properly pressed can ruin the experience for anyone, but especially for children, which can determine them to abandon the game. Children have the patience to sit for hours pressing a button continuously to shoot a target in any type of game, but they can just as well instantly abandon an application if they press a button and it does not respond immediately to the command. The most used inputs for children are touch screen, which allows actions such as swiping, scaling, pinching etc., but also device movement or rotation, voice commands, webcam etc. In augmented reality, interactions are used at a lesser extent – generally when scanning an image, users view an animation or a static, predefined piece of information. When the application contains buttons, these can be placed on the User Interface or as an object in the 3d space, next to the others. The choice

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<sup>45</sup> Masood, M., Thigambaram, M., *The Usability of Mobile Applications for Pre-schoolers*. Procedia - Social and Behavioral Sciences, 2015, p. 1820

of the inputs must normally take into account the purpose of the application and the ease of reaching the final outcome.

Another interaction type can be represented by the selected tracking method. As previously mentioned, two important aspects are the content and the quality of the tracking. For markers, the image must be ideally placed on an opaque, dull surface, with good lighting conditions in the room, preferably using natural light. Because children like stories and some of these can turn into complex educational experiences, on the market there are already books with augmented reality, where each scanned page depicts different animations or narratives. The other type of tracking, markerless, where the application detects a floor, has the advantage that it does not depend on an image, but generally it cannot support a complex storyline. An issue that occurs in the case of augmented reality, is the children's habitus of using the phone – the phone can be turned off or put down, and users can return to it anytime. In the case of Augment reality, if a child drops the phone and returns to it later, it is possible that the tracking will be lost and the application will need to be restarted.

The actual content of the application is in accordance with the theme and the conveyed message, in the case of narrative and educational content, but we can clearly state that the content is mainly dictated by the age segment. The main method of improvement and adaptation is experimenting and studying the way children play. The main questions that a children's game designer must answer to are how much time a child spends on a certain game mechanics, what are the stimuli to which he answers best (visual, auditory) and how easily he understands the type of game and interaction with the proposed input. An important issue that arises is finding the right balance between the amount of explanations provided upfront and how much information should be discovered by the user.<sup>46</sup>

The result is a ratio between the two that is best established only by allowing real experimentation of the application done by children. The explanations and the guidelines to the game mechanics are done through text that can act as a button, but a frequent choice is having a virtual assistant that is permanently present and guides the user. This assistant can be a 3d object, in the form of an animated 3d character, or just a voice. Children are used from an early age to the

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<sup>46</sup> Aziz, N., *Children's Interaction with Tablet Applications: Gestures and Interface Design*, International Journal of Computer and Information Technology, 2013, p. 449

narrator concept. Parents read bedtime stories, the teacher explains notions, they listen to audiobooks with various types of content. Having such help is familiar to children even from a narrative point of view, in all children's stories someone helping the main hero throughout his journey. Being supported by a guide can greatly improve the quality of a kids' experience with the application, because this will give them the feeling that they are not alone. Moreover, the guide can give them feedback, similarly to what an adult would do, and this adds another visual and auditory dimension to the experience.

## **4. Methodology**

### **4.1. Game engines**

In the previous chapter I argued that any application is mostly a game. Any application contains a set of rules that need to be followed in order to find out pieces of information, completing levels and ultimately achieving the final goal. There are many possibilities of creating an augmented reality application. Recently, Adobe launched a new service called Aero, which greatly facilitates the creation of augmented content. In addition, there are other platforms that focus on predefined simple content using a target image, these platforms being especially dedicated to people who do not have the know-how or do not want to invest time in creating their own application.

However, if we need a customized content and a type of gamified application, these platforms are limited in use and do not offer the possibilities of a real game engine. This main tool contains the core algorithms that control a game that reads the input from the user, drives characters, fabricates behavior, generates sound and real-time display, as stated by Herwig, Paar (2002).<sup>47</sup> Likewise, Cowan, Kapralos (2014) identify the main features that all the game engines provide: scripting, rendering, animation, artificial intelligence, physics, audio and networking.<sup>48</sup> Sarathi, Goon, Bhattacharya (2012) show a comparison table of a major number of game engines

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<sup>47</sup> Herwig, A., Paar, P., *Game engines. Tools for landscape Visualization and planning?*, Trends in GIS and Virtualization in Environmental Planning and Design, 2002, p. 4

<sup>48</sup> Cowan, B., Kapralos, B., *A Survey of Frameworks and Game Engines for Serious Game Development*, IEEE 14<sup>th</sup> International Conference on Advanced Learning Technologies, 2014, p. 662

and their usability. These game engines are Cryengine, Hero Engine, Source Engine, Torque, Unity, Unreal Engine, Vision Engine. Their research took into consideration platform dependencies, interface supports, API supports, inbuilt physics engine with pathfinding capabilities. In a survey done on 100 respondents from the game-industry, they found that the most popular, at that time, was Unreal Engine, followed by Torque and Cryengine.<sup>49</sup>

There are two major game engines that can be used for creating augmented reality applications, namely Unreal Engine and Unity. My choice for making the applications described in the case studies chapter was the Unity platform, due to several reasons that I will further explain.

Unity was first officially launched in 2005 in Denmark by David Helgason, Joachim Ante and Nicholas Francis.<sup>50</sup> The goal was to liberalize the growing gaming market, but also to provide content for creators with a simple and accessible engine. At first, they founded the company under the name Over The Edge Entertainment. The first experimental game created on this platform was Goodball, and the obtained profit was reinvested for further developing it. The first official version offered support only for MacOS systems, and with version 1.1 they included support for Windows, but also for web browsers, at a time when casual computer games were on the rise. There were several important stages in the evolution of Unity. Version 2.0 was a big step in 2007, with much greater support for Windows, DirectX and web player. In version 3.0, launched in 2010, many technical functionalities which increased the quality of the engine were added, such as deferred rendering, occlusion culling, but also very good support for mobile platforms.

Unity 4.0 brought a major change, adding Mecanim animation, flash deployment, shuriken particle system, but more importantly, with version 4.4, real support for 2d games. In 2015, version 5.0 innovated through Unity Cloud, real-time global illumination and a new audio system. From this point in time, things have grown exponentially, and in 2017 the version naming system changed, moving to the name of the launch year. With the releases in 2018, 2019, even 2020, the improvements are substantial, such as color grading, world building, timeline, Cinemachine, scriptable render pipeline, visual programming, ray-tracing etc.

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<sup>49</sup> Sarathi, P., Goon, S., Bhattacharya, A., *History and Comparative Study Of Modern Game Engines*, International Journal of Advanced Computer and Mathematical Sciences, 2012, p. 248

<sup>50</sup> Haas, K., *A history of the Unity Game Engine*, Worcester Polytechnic Institute, 2014, p.1

As we can see, this game engine has evolved very quickly, immediately embracing the new technologies that appear, such as sensors, virtual reality, have improved its rendering engine which is considered to be “the crown jewel of a game”, according to Michael, Jeffrey (2002), but also augmented reality.<sup>51</sup> The two main reasons for choosing this game engine at the expense of Unreal Engine was the integration of the augmented reality Vuforia platform and the Playmaker visual programming system.

Vuforia<sup>52</sup> is the largest augmented reality content support platform that, starting with the Unity 2017 version and until this year, is an integral part of Unity. I will describe Vuforia in detail in the next chapter, and in this section I will refer to the Playmaker visual programming system which, from Unity 5, also offers support for Vuforia. Visual programming systems are widely used in many software that use C sharp, Javascript or C ++ programming languages. Visual scripting was invented for artists, but also for people who do not know how to code, but are interested in creating their own content. It contains a friendly, node-based interface, which involves connecting several cells together through cables that receive certain inputs and trigger various actions. We also find such node-based systems in animation software such as Maya, compositing software and effects such as Nuke, interactive music such as Max MSP.

Playmaker is one of the visual scripting systems used in Unity, created by Huttong Games<sup>53</sup>, which is based on C sharp language programming. Its use facilitates the realization of a whole game, regardless of the complexity level, with an easy learning curve. This system is similar to the blueprints system in Unreal Engine. For any interaction, in any game engine someone needs to write a few lines of code. For example, when we press the left mouse button in order to display a text on the screen, without Playmaker we have to open Visual Studio and write about 4-5 lines of code. Using Playmaker, this is done using two nodes. The only disadvantage of using Playmaker is that it is not free of charge, the user has to buy it, as opposed to Visual studio and C sharp, which are systems that come with Unity for free.

When it comes to Vuforia, it would be much harder to create an augmented reality application without Playmaker, because in order to track and interact, we need references to

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<sup>51</sup> Lewis, M., Jacobson, J., *Game engines in scientific research*, Communications of the ACM, 2002, p. 28

<sup>52</sup> <https://engine.vuforia.com/engine>

<sup>53</sup> <https://hutonggames.com/>

specific names and methods from Vuforia. In the case of Playmaker, in order to augment a 3d object on a target image we only need a node with the OnTargetFound transition and a common programming type for any other kind of application.

The interactivity involved in the applications I have created is complex. In the case of SpaceAr, all 12 pages contain 12 mini-games, all in the same scene. The interactions are touching, swiping, dragging, taking screenshots, voice recording. Being closer to the games area, the choice of a game engine is obvious. Moreover, two other reasons for choosing Unity over Unreal Engine are the community support and Asset Store. Although Playmaker has built into it almost everything needed to build such an application, there are specific things that a user needs to write code for.

This is where the Unity forum comes in, a whole community composed of numerous members, who offer support and respond to issues caused by the engine itself, but also to queries related to programming methods. The second concern is related to the construction of assets, those 3d objects that we import into the project. As it can be clearly observed from the applications that I have created, almost all the assets are created in a 3d software, in this case Autodesk Maya, optimized and imported into Unity. However, there are times when in order to achieve a certain operation, it is easier to import or buy that framework, that specific type of interaction that is already created and ready to implement. Thus, the execution time of the application is greatly shortened, compared to the time required to write from scratch such a plugin.

In this area, Unity is superior thanks to Asset Store, an online store dedicated to 3d models, plugins, frameworks, music, all dedicated specifically to Unity. Once an augmented reality application is created, it needs to be exported to a specific mobile platform, Android or IOS. Unity makes this process very simple, with a single click everyone being able to switch from one system to another without damaging the project. In the settings required for export, there are already default fields that later help to publish the application on some of the official stores, Google Play or App Store. In short, for Android systems, the final file of an application is of the apk type and can be installed and used on any Android device without having to be published on Google Play. In the case of IOS, the same can be done for testing purposes, but outside the Apple Store the final ipa file can be uploaded to an IOS device only with the help of a Mac computer and an Apple developer account.

The content of an augmented reality application can be the same as any other games, but with certain limitations. In order to achieve the best look and to be visually appealing, the content, depending on the chosen aesthetics, must be adapted to the target audience, but also to the final platform. From a visual point of view, Unity has incorporated in its latest releases more and more content creation possibilities, at a very high graphic level.

In 2019, the Shader Graph and the Visual Graph were introduced. The ability to create materials that are the foundations of the appearance of a 3d object was limited in Unity until then. One material offers the possibility of adding more textures with different properties. For more complex functionalities, coding is required. Shader Graph is similar to Playmaker, but it addresses exclusively the way objects look and materials they contain. Thus, being based also of visual and modular nodes, anyone can create their own shader, with multiple functionalities. Likewise, adding visual elements to a scene, like visual effects in movies, involves programming or buying assets that help the programmer achieve the intended outcome. The recently introduced visual graph offers the possibility to create magical elements, particles, portals etc., also through a visual system.

Unreal Engine is a game engine very focused on graphics at a very high level. Unfortunately, it is not so responsive when it comes to third party plugins, sensors or services. Although I have not explored all the possibilities that this engine offers, the lack of support for the Vuforia platform is the main reason why I chose Unity Engine. For people who were first familiar with animation software such as 3ds Max or Maya, the interaction mode, navigation, user interface and controls in Unity are similar to those from the animation software, which offers the opportunity to focus on interaction and gameplay, rather than on understanding how a new game engine works.

## **4.2. Augmented reality platforms**

Augmented reality applications require an algorithm to deal with the overlapping of the virtual world over the real world. Depending on the algorithm, but also on the usage conditions, the quality of the overlap may increase or decrease. We can make a comparison with the visual effects from the movies. When we see a scene that contains visual effects such as explosions, overlapping characters, destruction etc. the human eye immediately notices what does not look

good, what is artificial and does not seem to be perfectly blended over that scene. Even for untrained people, the most frequent element that can reveal the real quality of the videos is the scale, or in other words, whether the overlapping objects are undersized or oversized, usually compared to the size of a person. Another issue is the integration in the real environment, which can happen if for example a 3d character does not have a shadow or a reflection, and if that shadow is not identical in position and intensity with the other shadows in the scene. Other details that make a difference are the animations, the quality of the textures or elements such as motion blur.

Although in augmented reality the goal is not to convince people that the objects that appear are real, there are certain aspects that can destroy an AR experience, such as tracking quality, integration with the real environment or, similarly to any other application, unresponsive interface. Regardless of the type of recognition of an image or a surface, the virtual overlay must be blocked on the specific place where it was programmed to happen. If we talk about the augmented reality used in medicine, if through the optical tracking glasses the detection is not perfect, serious medical problems can appear. In advertising, in general the 3d objects that appear are blocked on a certain target image for commercial purposes. For example, on a poster of a car manufacturer the user scans the poster with a phone to see the latest model of that car. If the overlap is not perfect and the 3d image shakes or the model jumps from one place to another, or if the car moves when it senses the phone movements, this will result in a negative user experience.

As previously mentioned, there are many criteria to ensure a good AR experience. These criteria can be divided into two categories: those related to the user and those related to the developer. The latter has the obligation to offer a well-built application, optimized for the target platform, with very responsive buttons and almost perfect tracking. In the case of image-based tracking, the developer must ensure that the image is optimized with many tracking points. In the case of the users, they must follow the specific indications of the application, such as the recommended platform or version of the operating system and more detailed things, such as keeping the target image in the visual field of the phone or using the application in a well-lit room.

Augmented reality is mostly done using mobile devices. With the evolution of mobile phones and tablets, augmented reality has seen a substantial increase in the number of offered possibilities. Until 2017, developers were using their own augmented reality algorithms or were relying on existing systems, but there were no unified systems generally valid and usable for the

wide public for the two major existing platforms: Android and IOS. Google and Apple developed specific augmented reality platforms, ARcore and ARkit. Google launched the software development kit for Arcore in August 2017. This was developed mainly on top of the AR Tango platform, which used special sensors to track. Google's goal was to give developers the ability to create augmented reality applications for anyone, without special sensors and on any Android device. ARcore uses 3 fundamental elements to achieve augmented reality, as described by Lanham (2018): motion tracking, environmental understanding and light estimation.<sup>54</sup>

Motion tracking refers to the way the system understands and perceives the change of the user's position in 3d. This is done by identifying points in real space, which can be chosen to establish the 3d position of the user. Like Vuforia, as we will see later, the image is preloaded in the system and those tracing points are predefined. In this case, the tracking is performed in real time and without prior training. Environmental understanding means that the software need to be familiar with the objects that exist in reality through a technique called meshing. This technique is applied most often to a flat surface, such as the floor, ARCore overlapping on this surface the desired objects.

Light estimation has an important role in adding details that make that 3d object merge with reality. The lighting of the object and how the shadow falls on the floor depends on how the algorithm understands the ambient light in the room. The adaptation happens in real time, thanks to the way ARcore is optimized. Both ARcore and ARkit technologies use this technique, together with spatial mapping, meaning the scanning of a place or of a room, which is then reconstructed in a 3d mesh. Thus, the algorithm recognizes the real environment and knows where the objects are positioned. We can use this type of tracking to create, for example, a path through a room and place various other 3d objects on it, or we can transform that room by painting the walls differently, because we already know the edges of the room.

ARcore can be accessed through several development environments, such as Android Studio, Web based, Unreal Engine and Unity. ARkit requires an Apple system and a programming environment such as Xcode or Swift. The third platform that allows the realization of augmented

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<sup>54</sup> Lanham, M., *Learn ARCore – Fundamentals of Google ARCore*, Packt, 2018, p. 9

reality is Vuforia Engine, part of the PTC company since 2015. It is the most used medium for augmented content creation because it automatically handles all the details related to tracking, as long as the user inserts in the database the image they want to use, which means the focus is kept on developing the application and not on understanding it. Vuforia has a direct and easy integration with Unity and uses several types of recognition and tracking, being mainly used with image tracking. It is very useful if we take into consideration that any graphic content can be augmented. Most of the time the image is a simple, plane, 2d picture that is recognized.

Image tracking can be done through Vuforia also on large surfaces, such as Cuboid, as defined on the Vuforia website. This refers to any square or rectangular object, with six sides, side containing a different image that can be recognizable. Other types of surface are cylinder and cup types. Likewise, the image on this object is uploaded in advance on the Vuforia website. Last, but not least, another possible surface is a 3d object. With the help of an Android application, the object we want to recognize must be scanned, and the final result, having the .od extension, must be downloaded into a database. Vuforia also supports a tracking system similar to ARcore and ARkit, the ground detection, formerly called Smart Terrain, and in the latest updates called Ground Plane. This system detects horizontal surfaces, creates anchors for tracking, approximates the scale for sizing and performs surface hit testing for the correct positioning of objects on the surface.

Next, I will briefly describe a complete workflow for integrating a target image in Vuforia, integrating into Unity and creating a build for Android. The first step in this process is creating an account on the Vuforia website, which is free for non-commercial use, but the application will contain a watermark. The second step is choosing a target image. For this step we must consult the indications on the site in order to have an optimal image. This means the image should contain multiple contrast points, such as dots, lines, curves, but also color differences. The richer an image is in detail, the better the tracking will be.

After choosing the image, this is uploaded to a Vuforia database. This image is automatically categorized with a number of stars, ranging on a scale from 1 to 5, where one or none stars means the image is unusable, while five stars means that it is ideal for tracking. From Vuforia, we can download a package file that we will further use in Unity. Here, we need to create a new project, initialize support for Vuforia in Player settings and create a Vuforia Engine camera. At this point, all the necessary assets and scripts will be imported into the project.

Next, we import the package file that contains the image we chose and we will be able to view it in Unity. The next step is importing the 3d model that we want to overlay on the target image. This model can be created in any 3d software, or if we just want a cube or a sphere, we can add it directly from Unity. To test in Unity, we press Play and we can point the webcam to the image that we need to have physically, or on another display, and the 3d object will appear over that image. Next, we will export the application for the chosen device, in this case, Android. We need to make sure that the chosen platform is correct, and we have to choose some settings for the application to work properly, such as the minimum version of Android operating system. Then, we press the build button, and the application will be created as an .apk file.

## **5. Practical augmented reality applications**

### **5.1. AugMath**

From the very beginning I knew that for my dissertation project I would work on a project that will focus on children and interactive technology. I initially thought about focusing on virtual reality, being more tender in terms of possibilities of realization, and having practically no limits. After reconsidering all possibilities, I realized that if I want to create something that not only targets children directly, but can also be used by any of them, augmented reality seemed a much more appropriate option. As an argument, we can only think of the number of children who own a virtual reality headset, compared to those who have a mobile phone. In 2019 I participated in the Bucharest Binar New Media exhibition, where I exhibited a virtual reality work, but I also managed to slip in a prototype of augmented reality application. I used a tablet and a map, and when scanning the map, the users could see 3d animals or monuments, or visualize different details, such as distances between cities.

Even if it was on an experimental level, the application not being in a final form and the exhibition conditions being far from ideal, I managed to draw some conclusions from that presentation, related to augmented reality. By watching the dozens of children who tested the application for two days, I noticed that they were most attracted to the view of the Earth, which appeared like a hologram and had an interface with buttons that changed its appearance. This observation came in addition to my thoughts of creating an application that would transform

theoretical notions learned in school, into visualizations that would help children understand the concepts.

In my view, the school will see transformations due to technology, but not in a negative and extreme sense – I am not an adept of the theory that teachers will be replaced by robots. Instead, I believe the school will change in a complementary sense – any notion that cannot be shown visually or is not observed through a real experiment, in the laboratory or in nature, will be demonstrated with the help of a mobile application or a virtual reality headset. In the current context, related to the Covid-19 pandemics that took place while writing this thesis, there were numerous debates about digitalization in education. However, the discussions took place at a basic level, talking mainly about students who do not own computers or mobile phones, or do not have access to internet. All these basic issues will be solved in a short amount of time and only afterwards we will be able to see a much greater openness to the implementation of new technologies in education.

Before starting to describe the first application I created, I want to emphasize a few details related to visualization. In my opinion, visualizing is one of the most important aspect that leads to understanding a new notion. As an example, students learn integrals during math lessons in high school, but for most of them it remains a mystery what exactly integrals represents and why they learn those things. Therefore, I make a distinction between seeing something and visualizing. In my view, seeing is done in a basic, superficial way, as a distant observer would look at a phenomenon or an action. The visualization has a deeper level, being able to penetrate the object, to associate it with a notion and to be able to interact with it. In this way, visualization leads to understanding, which should be the most important goal during education.

For the first application, which is called AugMath, I tried to identify which are the subjects that can benefit the most from augmented reality, both through research and from my personal experience. In most schools, there are minimal laboratories in physics, chemistry and biology. Depending on the existing school facilities and the involvement of the teacher, students can see and interact directly with certain substances, bodies, and can observe chemical reactions. In mathematics, on the other hand, in the eighth grade there is a subject called space geometry, but this subject is taught in a flat way, 2d, on paper.

The main topic is about geometric bodies that, by their nature, are three-dimensional and we can find them in the real world in different forms. These bodies fall into two categories, shapes that we recognize directly, such as the cylinder, sphere, pyramid, cube etc., but also their extensions that we find more difficult to identify, such as the trunk of the pyramid, cone etc. Given these observations, I started to build the first augmented reality application and I chose space geometry as a central element. In the construction of the application I focused on two directions: visualizing these bodies in the real environment, but also learning and verifying theoretical notions through practical examples.

The first step was documentation. As I did not want to rely on my memories, from the Internet searches, I chose the website [www.lectii-virtuale.ro](http://www.lectii-virtuale.ro), where I got the basic technical information, I understood the formulas and the visual representation of all objects. I chose to represent in 3d the sphere, the cone, the parallelepiped, the pyramid, the cylinder, the cone trunk and the pyramid trunk. I had to choose from several types of displays for these bodies. This decision-making process was closely linked to the target image that I will further describe in this. I have chosen a type of a linear display, so that the user can view and access the objects easily (Fig. 3). I built a virtual assistant, with a minimal aesthetics, having a humanoid shape, but with body elements composed of geometric shapes.

When opening the application, the assistant greets the user with a waving hand animation, and the user has to press a button in order to actually start the application. Another important decision-making process was related to the buttons to be used. In the case of augmented reality, the interaction can be done through the touch screen or using virtual buttons, placed in the air. The latter is more applicable for optical see-through devices, such as HoloLens glasses.

When the target is represented by mobile phones, the objects we interact with, the buttons in other words, can be of two other types, buttons made of real 3d elements, placed in the scene, or user interface (UI) type. The choice goes unnoticed most of the time by the viewer, but it is an important aspect for the developer, depending on the desired outcome. In other words, in my case, I had to figure out if the user should click on the geometric body directly, or on a text on the screen. I chose the second option for buttons, but I wanted them not to consist only of a plain text. Therefore, I created 3d buttons that have an animation when being pressed, just to give the illusion that the user really pushes a button.

Most of the time, in a mobile application, the objects that appear can be magnified by the user on the screen by pinch or twist touch screen movements. I chose not to offer this possibility precisely because, by its nature, augmented reality allows users to physically approach the phone to the 3d objects, which makes it redundant to be able to scale on the display. It was probably not the best decision, because after asking some children to test the application, their first tendency was to scale the objects on the screen, but I think this happens because it is a new technology and no one is used to how augmented reality works. When the first button is pressed, the geometric bodies placed on the target image appear.

Each body has a different button, and when it is pressed, that body comes in front and the others disappear. In this moment another feature comes in, being able to do a 360-degree rotation of each body on a single axis. Again, the same thing can be done by physically rotating the user around the image, but I decided to keep this option in the application. For each body that appears I placed several buttons. The first category of buttons places the composing elements in the 3d space, elements such as the generator, median, height, radius etc. The other category displays the formulas, such as area and volume. The same buttons are applicable to all seven geometric bodies I have included in the application.

For all of them, with the exception of the pyramid trunk and of the cone trunk, I added another functionality for helping students solve a problem using formulas, but in a non-traditional way. I used a set of questions similar to those appearing in the PISA tests that I described at the beginning of this thesis. I placed the emphasis on logical understanding and resemblance to real-life facts and objects. Thus, I added a button called "test your knowledge". When pressed, the virtual assistant introduces through an animation an object that resembles the chosen body. I associated the pyramid with the real pyramid of Keops, the parallelepiped with a block of flats, the cylinder with a barrel, the cone with an ice cream, and the sphere with the Earth. The difficult part was formulating a verification question that was related to that shape, but containing real details and dimensions of the object.

I will offer next two examples to better explain how I related to space geometry through these questions. In the case of the pyramid, I provided the side and height of the pyramid and the user had to calculate how much water would fill in Keops' pyramid. The solution is simple, the user having to just calculate the volume. The second example is the parallelepiped, resembling a

block. I offered the length and width, and the question was what how much terrain should be cleared of a forest if we want to build the block. This answer is also simple, the user having to just compute the area. In all examples, there are three answer options. In case of an incorrect answer, the user will receive an auditory and visual feedback through an animation from the assistant, and in case of a correct answer, there will be an auditory signal and an animation in which the assistant applauds.

The formulation of problems is simple, their aim being not to confuse, but to create analogies with well-known things, so that children can realize that those bodies are not abstract, and learning formulas can have correspondence and applicability in real life. The target image I used played a decisive role in how the final version of the application looked. All 3d objects and elements on the UI were created and placed according to the target image. There were two types of models to choose from. First of all, I could have chosen an abstract graphic form, with some elements of mathematics, or letters, or any other shapes not directly related to mathematics. This could have resulted in something pleasant visually, a more artistic type of application, but also more abstract.

The advantage is that this image allows visually to represent the bodies differently, or introduce in non-traditional ways the formulas or analogies of the exercises. The downside was that the target image was created by me and was unique. This meant that all future users needed that specific image, which I had to provide in a physically printed format to them. Alternatively, I could electronically transfer the image, and ask the users to make the effort of printing it themselves. My vision was different and even if I did not yet reach this stage, I imagined that one day a version of this application would be used during a math class, which would make it complicated for all students to get in possession of that image.

The solution I found was to choose as a target image something that already exists and is accessible to almost all eighth grade students, therefore I used the cover of the math textbook published by Teora. This textbook, written by the authors Dana and Eugen Radu, is the most widespread when it comes to this level of education. Thus, I went for the more classic, simpler idea, but which offered easier access to use the application. I adapted all the application content, the location of the 3d objects and the user interface elements to the image. The cover has a portrait, vertical layout.

However, from my experience, people tend to turn the phone landscape, to see as much as possible in the visual field. In Unity, an application can be locked in a certain orientation or it can rotate when the phone is turned. I chose not to block the orientation, although this can cause some issues. Rotating the screen can distract attention from the content, the target image can be lost from the visual field and thus the tracking can disappear or the user may need to move further backwards to be able to view the entire content. However, I chose to take these risks because everyone is used with the rotating screen, which is ultimately a way of interaction that provides immediate and natural feedback to the user's actions.

Not all things worked perfectly from a technical point of view. On a closer inspection, there are two main problems, one easily observable, the other one more difficult to notice. The buttons were initially placed as 3d objects and they remained locked in a position on the target image. Following the feedback, I decided to place them on the display, as UI elements. This complicated my work, as I had to redo the buttons in a new way for me. The result is acceptable from a visual and functionality point of view, with some minor glitches - from time to time there are moments when the main buttons do not respond immediately to commands, if pressed very quickly. The second problem is more technical, and I was able to resolve it only when building the second application.

In Playmaker, in the programming section, there is the OnTargetFound action, where we can add what we want to achieve when the image has been recognized. There is also the OnTargetLost action, which determines what happens when tracking is lost. As I discovered, there is an intermediate state between the two, undefined, when the target image comes out of the visual field of the phone. Normally, OnTargetLost should be initialized in this moment, but this state only starts when the camera is completely covered, the screen turning completely black. Thus, when the phone left the image and returned to it, the application entered this intermediate stage, which made visible some elements that were declared active, but invisible until that moment. Until finalizing the application I could not find a solution to this issue, so I decided to leave the application unchanged, because it does not affect the main functionality of the application.

Initially, I decided to be able to test the application in at least one full classroom, with eighth grade students, during the "Scoala Altfel" program. This program takes place mainly in the second semester of the academic year, but the Covid-19 pandemics interrupted all the classes and

thus prevented me from being able to test the application on a larger scale. At the time of the actual completion, in mid-March, I asked a high school math teacher to certify that the formulas and other elements were correct, but also that the problems and what I intended to present made sense to an eighth grade student. For an entire week, the teacher showed the application to students she was tutoring, a total number of eight students. I did not offer her a questionnaire, or a means for evaluation, because the initial test plan was different. The results were quite relevant to what I wanted to convey and what I actually achieved. Thus, the eight children referred to the application as attractive and easy to use, as a general experience. The interesting things were the ones I already knew, but I hoped no one would notice. Two out of eight users found small delays in pressing some buttons, and four of them noticed that when the phone loses sight of the image, other things appear, that were not initially there.

Although the number of testers is relatively small and the conditions were not ideal because I was not actually present during the testing, the feedback, both positive and negative, is aligned with my expectations. An important aspect is the way in which an application of this type is presented and introduced. If it were used during a school class, downloaded from Google Play or the AppStore and presented by the teacher as an additional compulsory material that must be treated seriously, students would probably take the application very seriously, as they would do with a regular textbook.

The possibilities for making educational applications are endless. My attempt is just scratching the surface in this direction. The final goal is that in the future such applications will be adopted in an official circuit, as part of the study curriculum. Even in mathematics, in addition to geometry in space, there are other chapters that can be translated visually and interactively, for a better understanding. Much more rich from this point of view are subjects such as chemistry or biology. With imagination, almost any important part of a field of study can be seen through a phone or a virtual reality headset. We often say that a picture is worth a thousand words, similarly, a video, animation or application could be worth as many as 1000 images.

## 5.2. SpaceAR

The experience of creating the AugMath application meant acquiring a lot of technical information, but also optimization and aesthetics for an augmented reality application. In order to further develop the second application, which is much more complex from a technical perspective, I have structured the most important principles that are generally used in a gamified application and even in a game. In a few words, these are: triggers, collisions, variables, activation/deactivation, get/set, input press. Knowing that I will use all these principles, I deepened my learning and understanding so I could use them with Playmaker in Unity. On the visual and user interaction side, I worked on improving the buttons' responsiveness, scaling the user interface elements on different devices and better framing the augmented elements.

The beginning of the creation process meant the search for an idea that would contain both the augmented reality experience for children, but also a narrative component of another nature. Initially, I wanted to create an immersive physical environment, in a room where I would place 4 panels, and on each panel I would stick 4 large posters. The user had to use an optical see-through augmented reality device to view the AR content and interact with it using virtual buttons. I gave up on this idea for several reasons.

First of all, I failed to create an optical see-through device that would work ideally, and the best option was Hololens. This device, as previously mentioned, is very expensive, but even if I were able to create an application for it, I would have greatly limited the access to people who would have tested the application. This would have remained at the prototype stage, valid only for examination and it could probably never have been used on a large scale. As my goal was to create something that had as many testers as possible, especially children, I chose to create an illustrated book as a support for the augmented reality application. I will continue by dividing the explanations according to these two elements of the project, the physical book and the application.

In the first application, Augmath, the creation process involved making changes along the way and observing what works and what still needs improvement. For SpaceAR, I chose a much more professional and clear structure from which I did not deviate, maybe only with small exceptions, for technical reasons. Similarly to working on a movie, I firstly created the storyline, which consists of a humanoid-shaped character who leaves from a distant planet and must reach

Earth safely. On his way, he first reaches the planets in the solar system, then the Moon, he also visits the Space Station and finally reaches Earth.

With this basic narrative thread established, I began to structure what would happen when each page was scanned. To achieve this, I needed a structure that was easy for any user to understand. I wanted the experience to look like a game, but to be also educational, the users being able to learn real things about planets, space and Earth. To combine the two goals, the gaming part and the learning part, I doubled the time that the character spends in each location and I divided it into two parts: the left page has a learning purpose, while on the right page, the user can apply the acquired information in the form of a minigame. Also from this phase of the project, I thought about what the book's layout and how the pages will actually look like. Even if these things might be seen as minor details, they are actually much more important.

First of all, the surface of the image target should not be reflective, in order to guarantee a good tracking. Secondly, the pages must be thick, in order to stay straight, and the user should not have to use his hands in order to keep the book opened at a certain page. In a normal book, the pages bend, because they are very thin, and the book closes if not being held in a person's hand. Thirdly, I structured the number of pages and I reached a number of twelve pages that will have scanned content. Eleven of these pages are two-sided, and the last image is enlarged on two pages, representing the image of the character returned to Earth. I decided that the final product will be a photo book, like the ones used for wedding albums, as this was meeting all the requirements mentioned above. Once this was done, I could start to realize the actual design of the images.

However, before working on the pages I made the design of the character. This is the central element, being placed on almost all the pages, but especially on the cover. I started from a semi-humanoid character downloaded for free from a website specializing in 3d models. I changed the character many times, I added new elements and especially I created a rig to animate him. On the Mixamo website<sup>55</sup> I added the animations that I thought I will need, depending on the scenario. Among these animations, I can mention: waving, jumping, sitting in an idle position, being sad or happy and dancing on different music styles.

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<sup>55</sup> <https://www.mixamo.com>

The cover of any book represents the interface that communicates with the potential buyers (Fig. 4). The design of the cover, but also of the other pages, was done 90% in Maya animation software and 10% in After Effects for compositing. I had in mind the fact that the cover must communicate the title, an attractive image, but also the fact that it is a book that uses augmented reality technology. I chose a simple design, with a title, a character, a rocket, a mobile phone, all in a uniform color palette with combinations of white and blue.

The first page is actually not having anything to do with the story, but it is only informative (Fig. 5). It explains to the users how to download the application and how to use it. In general, but especially in Romania, there are not many augmented reality books, and if the interaction is not done properly, the experience can have a low quality. I tried to insert using text the most important things that the user needs to know, but I also left other important things to be discovered along the way, such as the fact that the user cannot return to a previous page. I consider I will be able to understand if there are more things that need to be added only through the experience of as many users as possible. The first page with augmented content is the second page of the book and it represents the launch and departure point of the character and of his rocket (Fig. 6). In Maya, I used an HDRI (high definition range imaging) which is a 360 degree image that serves both as the background and for lighting the scene. The rocket used in the image was created from scratch, with the aim of optimizing it as much as possible, especially keeping in mind I had to use it for a mobile application.

The third page depicts the character inside the rocket, travelling through the solar system (Fig. 7). From this moment onwards, we will be able to see the mechanism previously described: the page on the left containing information, and the one on the right a game. I wanted to create as much content from this page directly from Maya so that the image looks realistic. Usually, when elements are added at a later point in time, it becomes difficult for the reflections and shadows to fit very well. This is the reason why for this page I have placed all the planets in the Maya scene in their real position, including the sun in front of the character so that its reflection could be visible on the helmet. I wanted these elements to be visible in the image just to make a direct connection with the content to be augmented. The following page is located on the right, and this time it shows the rocket in the middle of the planets (Fig. 8). Also in this case, the image results directly from

the 3d software. I tried different positions of the planets to obtain a depth effect as strong as possible, but I had to give up on this idea, due to several reasons that I will explain at the end.

The fifth page is represented by the rocket that reaches Mars (Fig. 9). Here, the virtual camera is positioned very close to Mars and this is the reason why I used a texture with a large size of 12k. I tried to change the HDRI every time, for a greater dynamics of the image backgrounds, but I ended up using different parts of the same HDRI, because the ones I found on the Internet had a poor quality or the cost was too high.

Moving further, on the sixth page, the character reaches Mars' surface (Fig. 10). This surface, along with the one on the Moon were quite difficult to do directly in 3d because I needed a texture of Mars and the Moon containing many details. After many unsuccessful attempts, I chose a solution not very often used, but which achieved its goal. I bought an HDRI with Mars and placed the character at the right angle. Using a plane with shadowmatte material (a surface that is invisible, but which retains the shadow) in the Arnold rendering engine, I created the illusion that the character really sits on the surface of the planet. Without such solutions, it would have seemed much more artificial, especially without those small details such as ambient occlusion or the small reflections on the character's body.

In the seventh image, the rocket approaches the Moon (Fig. 11). I also positioned the Earth in the back, but in the end I rendered the image without a background because it would have been too similar to the previous one, and in post-production I had to add a suitable background in After Effects. For the Moon everyone can find high quality textures free of charge on the Internet, but with the Moon as we see it from a distance, not with its actual surface. In the next image, the eighth, the character arrives on the moon (Fig. 12). I solved the problem using the technical situation I applied on Mars' surface, but I finally used an image with a terrestrial surface, with many rocks and craters, an image that I transformed and on top of which I placed the character.

In the next step of the mission, the user arrives at the International Space Station (Fig. 13). I started by creating it from scratch, at a low-poly level, ideal for a mobile application. But what I created was not good enough for the final image, so for the book I bought a high-poly model with a space station, with a lot of details. I positioned the camera very close, making almost a close-up, this being the reason why I needed a high quality version of the 3d model. For the next page, that

is the gamified version, I created a part of an interior of the space station, the famous window where photos are taken with the Earth (Fig. 14).

I placed the character in this scene so that it seemed to float and I also positioned the Earth in the distance, just to announce the fact that the user is close to its destination. The tenth image was made from several pieces because the result from Maya was not satisfactory (Fig. 15). Here, I positioned a dinosaur on a surface, rendering it with the shadow and compositing the result in After Effects over a landscape with a hill on Earth. It was quite a difficult process because I wanted to get a static frame directly from Maya from an animation of a burning asteroid, but the whole process of testing and rebuilding would have taken too long. The penultimate page shows several asteroids approaching the earth (Fig. 16). The image is obtained 100% from 3d software because a good asteroid texture is easy to find on specialized websites.

The last image is the one that stretches over two pages and depicts the rocket and the character that reached their destination on planet Earth (Fig. 17). Here I used the largest texture of the Earth I could find, 16k. To create the illusion that the two central elements are located on the surface of the earth, I first tried an HDRI, but it was not enough, so I created a sphere with real texture. The image was rendered without background and composited afterwards. All the final variants of the Maya images have undergone many transformations because technically it would have taken a long time to render, would have required a lot of modeling or would have cost too much to import certain assets. The problems in the 3d software were mostly related to the Arnold rendering engine which was not compatible with certain materials, effects or stopped working in fullscreen previews.

After making all the images, as I described in the workflow in the previous chapter, I inserted the images in the Vuforia database to analyze them and see how optimized they are for tracking, on a scale from one to five stars. Throughout the creation process in Maya, I took into account the conditions of a good tracking, such as a lot of contrast and many points to which the software can be connected. When testing the images, I found that almost all images had a maximum of three stars, therefore they contained too little information for good tracking.

Afterwards, I started the compositing process in After Effects, but more, I had to overlay on the images different icons and text, as a pretext for offering information, but in fact to support the tracking algorithm. For uniformity, I created a text system placed at the top and bottom of each

image, where I explain where the user has arrived and what he has to do. I also added icons that represent the information and the game activity, on the corresponding pages. All these extra graphics helped to get four and five tracking stars for each image. At that point, the process of creating augmented content on each page began. I will continue to discuss again about each page, around what the user actually sees on the phone and technical aspects related to the interactions.

The first interaction introduces the user to the character and the 3d rocket that appear on the first page. Also here, I created a 3d interface that includes some information about how to use it. I tried to create and maintain a futuristic, sci-fi look, but closer to children's aesthetics, through materials and colors. At the beginning I created an inputfield where the user has to choose a name for the character and that name will appear several times in different stages of the application. I created this option to personalize the augmented experience as much as possible.

Auditory, the whole application contains ambient music and sounds specific to the buttons and types of interaction. The solar system follows, and here, when scanning, the planets and orbits appear, arranged in a circle. Automatically, the planets move on their orbits. When pressed, each planet scales and reaches the foreground and information about each one appears. At any time the user can return to the initial state of animation or he can move on at the touch of a button. In this way the user can find out information from each page, and also can continue whenever they feel ready to continue.

The next page contains the first minigame. It is designed to place the planets in the correct order, the first time based on the distance from the sun. The planets are arranged linearly randomly, the rule is to press on each of them and then on its corresponding place. After this is successfully completed, the second stage follows where the user has to align the planets according to their size. Only when this game is completed, the user can move on to the next page.

Now, the user reached the page with information about Mars. When scanning the page, planet Mars appears. It can be zoom-pinchd on the screen. On the left side there are two buttons entitled 'Orbital missions' and 'Missions that have landed'. By clicking on each one, the user can find the most relevant information and images about the historical missions that arrived on and near Mars. The next section is the gamified part about Mars. Here, I created a plane as the surface of Mars on which I placed a Rover. The user must press in three places to move the Rover in different directions with several missions. In one of these places I chose to offer the user the

opportunity to press a button to take a screenshot of the virtual camera placed on the Rover. At the time of writing, the game still contains this functionality, but it will probably be removed because it does not always work perfectly and the place where the respective image is saved in the device is quite difficult to access.

On the next page, the user needs to scan the image with the surface of the Moon. Here I attached the texture of the moon to a 3d sphere and offered information about it. There is a button that allows the user to visualize the famous image of the 1969 Moon landing and also to listen to the original voice of Neil Armstrong after landing. I also created the ability to visualize the phases of the moon. The buttons at the bottom are for each phase of the moon, and when pressed, the directional light attached to the scene changes its rotation, simulating the crescent effect, the first square etc. The gamified part of the pages related to the Moon first involved the creation of the lunar surface. Then, the humanoid character has the mission to position the Romanian flag next to the American flag that already exists on the Moon. Before this, the user must record a ten-second audio message that he will listen at the end of the mission. From a technical point of view, it turned out to be a rather complicated option due to the fact that it requires the application to request user access to the camera and microphone again, an essential condition for publishing on Google Play.

The Space Station turned out to be difficult to create, but I chose a very low poly version, taking into account the optimization for performance. For the first page, the information one, I have attached the space station created in 3D and the user can click on each module to find out information about that component, but he can also view real images with them. The gamified page is still being transformed. In the current stage, the user finds eight modules arranged randomly, and he must place them correctly through the touch and drag interaction mode. I have not yet found the best technical solution because this kind of interaction is normally used in conditions where the virtual camera is fixed. In augmented reality, the camera is the phone that moves on the Z axis too, in front and behind, and this means that the moving elements move in the same way, which makes the correct placing of the modules very difficult.

Moving next to the asteroid and dinosaurs page, I chose a simple 3d version, an asteroid that rotates automatically, and when pressed, several boxes with information text appear. It also contains a dinosaur with a loop animation for a more dynamic look. The next page also related to asteroids is very similar to a game. As it says in the text written on the page, I placed the 3d rocket

at the bottom of the page and the user has a button that launches projectiles at the asteroids approaching the rocket. He can move left and right by pressing two arrows that are immediately close. Being the penultimate interaction, I wanted to make a mini-game, as children are used to, in the shooter genre.

The last page is the most complex, from the point of view of the augmented content. I created planet Earth, with an animated texture and a few buttons. Here, I borrowed some functionalities from the application I described previously, the one from the Binar exhibition. There are several buttons that allow the user to view animals placed on Earth and change the appearance of the planet. The last functionality that is obviously related to Earth leads to a puzzle that the user has to complete. The pieces of the puzzle consist of 16 random images of the planet Earth. The user must touch a piece, and then the place where it corresponds.

Although this seems like the last feature, when the puzzle is completed, all the pieces now formed rotate and display the message "Bonus. Scan the cover. " I wanted to create the illusion that the experience was over and to still offer an additional activity. When scanning the cover, only the character appears, together with six buttons containing different dance styles. When they are pressed, music of that specific style begins to be heard and the character dances accordingly. I made these animations, as I said at the beginning, through a rig built in Maya and with the help of the Mixamo website. This concludes the augmented SpaceAR experience.

Technically speaking, there are many other features that I would have added to the entire augmented content. However, there is a big limitation related to the device on which the application is to be installed. Regardless of the generation and performance, all phones or tablets have limited mobile processors. The content must be extremely adapted and optimized. The number of polygons must be reduced, the materials reused etc., all this to keep a frame per second ratio constant and high. At the moment, the application is quite complex for a mobile application and an indicator is its size. Now, it occupies about 150 Mb, and my goal is to reach a size below 100 Mb. This again involves a process of optimization, reduction of textures, all in direct relation with the Profiler, the main optimization tool available in Unity.

## 6. Conclusions

The two projects described in this thesis represent for me a culmination of the theoretical and technical knowledge accumulated during the last two years of study. Very often, student projects, but some other projects as well, are launched while they are still in the research stage. Under the pretext of experiment, the normal circuit of a project does not end every time. By this circuit, I mean establishing the starting point, the purpose of the project, the execution time and most importantly, the target audience. My main goal was to carry out any type of project, but having in mind a clear purpose.

I kept the children as the central element of the chosen theme, and the focus remained on them when thinking about the design and the technical construction. Whether we discuss about educational applications or just entertainment, there is a very large number of such applications addressed directly to them. This trend is maintained among other children's products, from classic toys to smart cars. Manufacturers of such products rely on the fact that regardless of the global and personal financial situation, parents will always sacrifice other expenses in favor of those intended for children. In 2000, Behrman, Shields (2000) discussed about a study that shows children between 2 and 17 spends around 35 minutes per day using computers.<sup>56</sup> Now, in the first years of life, the phone is mostly used for watching cartoons, and immediately after, with a sudden transition, the little ones download their own games.

Very quickly, the phone becomes the second nature of children. Handwriting will probably be eliminated soon, any information will be transmitted only digitally. If we think about the latest augmented reality technology that will probably be fully experienced by the next generations, smart glasses will probably take control. Over the reality we will be able to see different types of information in real time, overlapped and accessible with voice commands. What I want to emphasize is not a discussion about whether we will have or not the opportunity of accepting these technologies. Instead, I want to raise the awareness that they will exist in a short timeframe and it is important to focus on understanding how they can help in the process of educating children.

In formulating a general conclusion, I started from the idea that this modern trend cannot be changed or reverted, but we can only continue to improve it. An important discussion that arises

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<sup>56</sup> Behrman, R., Shields, M., *Children and Computer Technology*, The future of children, 2000, p.5

is about the quantity of educational content of the applications currently existing on the market. Because it is an industry, the companies that create the applications aim to increase their revenue by creating content that is easily addictive.

In order to have an increased number of applications that also offer the educational component, the problem is also related to supply and demand. If the demand for the mobile games that aim only to shoot targets or jump as high as possible would decrease in the detriment of other types of applications, the content creators would try to reshape the applications in order to adapt the offer to what is demanded. The problem is largely with parents, who often prefer to give their children the phone often just as a sparetime activity, hoping the children would stay still for a few hours.

Augmented reality is a fairly new technology and it has only recently started to be introduced on a large scale. However, similarly to the trend I described above, it is subject to the same development rules. The most common augmented reality applications are in the area of entertainment, games or applications adjacent to other games. In the education system, the mobile phone, as a standalone tool that can be used at any stage of teaching, is not used at all. Moreover, students are often forced to turn off the phones or put them in a special place at the beginning of a class. The effect, in this case, is the opposite, children wanting to use the phone even more, similarly to small children who are forbidden to do something without being explained why.

The most important idea in this discussion is that there is technology available to almost anyone and more than that, it is freely accessible. In order to have as many augmented reality applications as possible with direct use in education, there should be a demand for this. A multitude of subjects could benefit from this technology, such as mathematics, chemistry, biology, physics, chemistry, other subjects related to science, but with imagination it can be transposed to other subjects. Augmented reality does not isolate the user in an individual environment, with a headset on their head, like virtual reality, but on the contrary, it can be used in various ways, collaboratively, allowing socialization.

As Billinghurst and Kato (2002) discuss, this technology enhances face-to-face communication.<sup>57</sup> AR interfaces blend the physical and virtual worlds so real objects can interact with 3D digital content and improve users' shared understanding. Another advantage is that it comes as an auxiliary material, it does not replace textbooks or teachers. It can serve as a support for courses, allowing to better visualize some phenomena, for example. The use of augmented reality should be used only at key moments, when certain concepts cannot be understood by classical methods. Compared to other types of technologies, augmented reality best fulfills the purpose for which new technologies should be created, to help, not to replace.

The discussion is more complex about the primary and secondary school environment, because this was the target of my projects. We must not forget that augmented reality can be used at a more advanced level at the university level. Laboratory-specific activities can be improved and supervised by HoloLens type of devices, as well as future smart glasses. Another aspect is that augmented reality is not only visual, it can also be auditory. In the case of visually impaired people, those glasses can send rays like echolocation that trigger auditory signals when they encounter an obstacle.

Returning to the practical projects I have done, there are a few details worth mentioning. I really wanted to be able to combine physical reality with augmented reality, but more than simply using a target image. This is why I chose to create an illustrated book and not just an application - precisely to meet the parents who may be reluctant to only an application, some of them probably appreciating more the physical content, allowing them to touch something material and to see real images. The information the user finds on each scanned page is certainly not new and anyone can find it with a simple internet search, but the interaction way is new. Like toys, most are just variations of the same prototypes, with different functionalities. However, in the case of augmented reality, the advantage is the extra layer that exists, the fact that a 2d image is close to what science-fiction movies have proposed for a very long time, namely the hologram. Augmented 3d objects come alive. There are many other types of applications where objects can be rotated by

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<sup>57</sup> Billinghurst, M., Kato, M., *Collaborative augmented reality*, Communications of the ACM, 2002, p. 66

a 360-degree swipe, but the fact that the user can physically move around that object, in my opinion greatly increases the viewing potential and the degree of interaction.

Augmented reality is a young technology in general use, and in the educational environment it is non-existent, to the best of my knowledge. As I have shown both theoretically and practically, the possibilities in which it can help are limited only by imagination. There are many creators who can make available such content, and the time required to develop an application is not very long. At the moment, Facebook, Apple and Google are competing to develop augmented reality glasses. Being the largest IT companies in the world, we can say with certainty that in the near future we will use this technology on a very large scale, but it is up to us to direct the content as much as possible to the education system.

## 7. Annexes

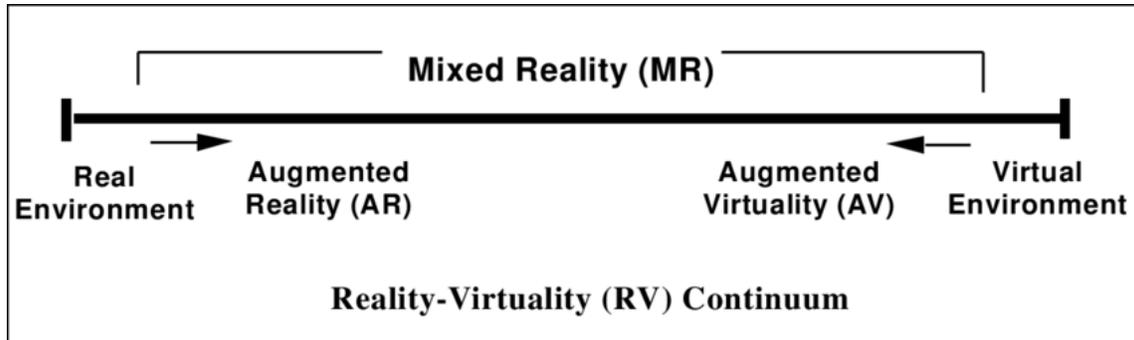


Figure 1. Mixed-reality scheme

Source: <https://www.researchgate.net/figure/Simplified-representation-of-a-RV-Continuum>

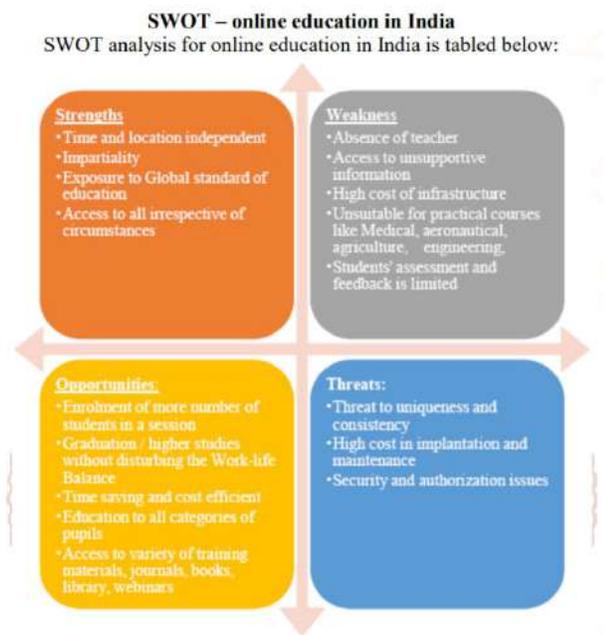


Figure 2. SWOT analysis

Source: Marathe, S., *Digitalization in education sector*, International Journal of Trend in Scientific Research and Development, 2018, p. 54



Figure 3. AugMath, screenshot from Unity Editor



Figure 4. SpaceAR bookcover



Figure 5. SpaceAR 1<sup>st</sup> page

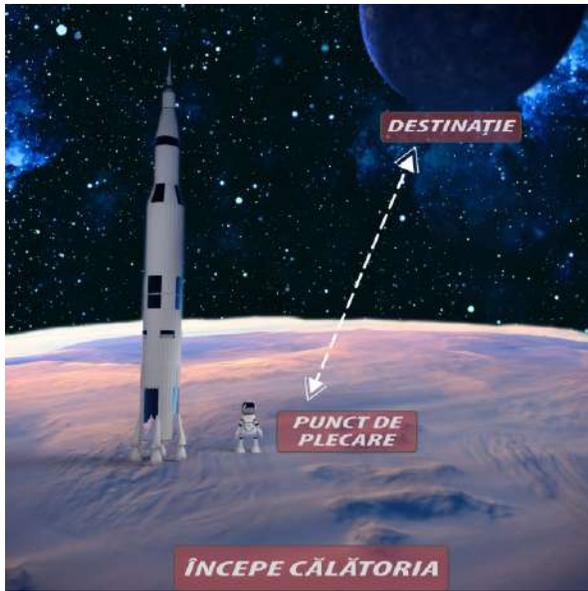


Figure 6. SpaceAR 2<sup>nd</sup> page



Figure 7. SpaceAR 3<sup>rd</sup> page



Figure 8. SpaceAR 4<sup>th</sup> page



Figure 9. SpaceAR 5<sup>th</sup> page



Figure 10. SpaceAR 6<sup>th</sup> page

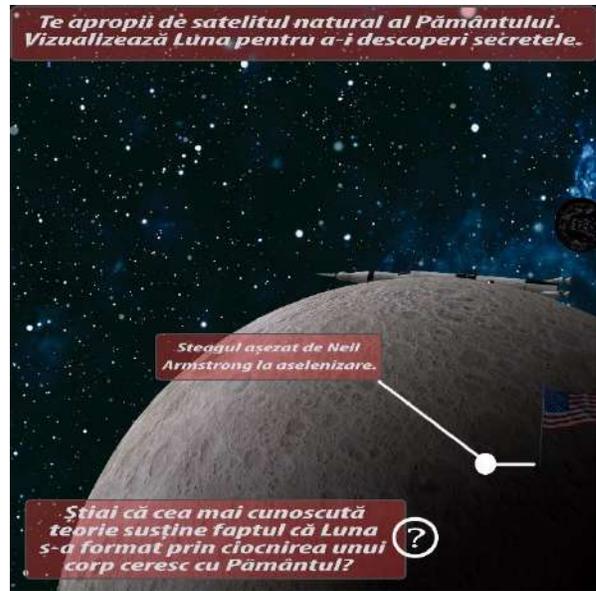


Figure 11. SpaceAR 7<sup>th</sup> page



Figure 12. SpaceAR 8<sup>th</sup> page

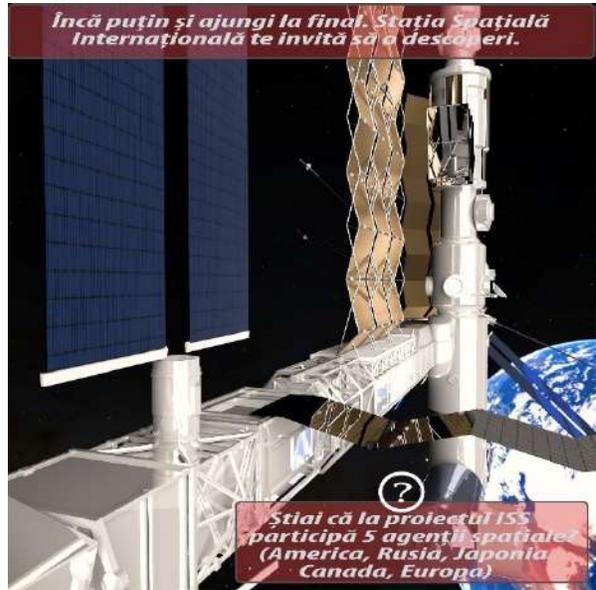


Figure 13. SpaceAR 9<sup>th</sup> page

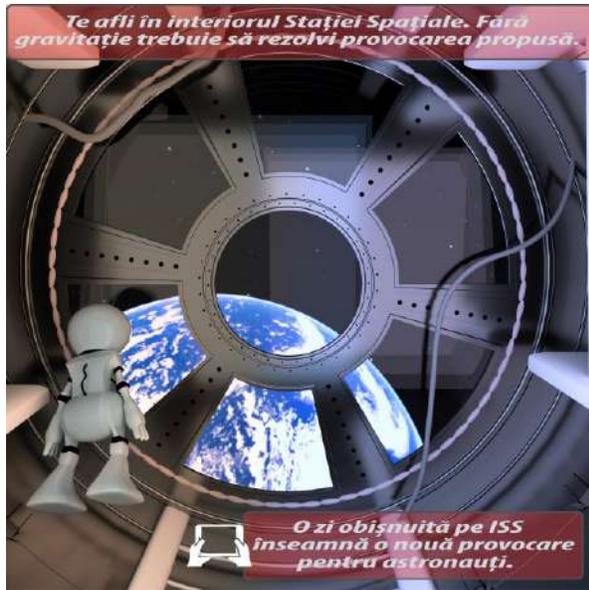


Figure 14. SpaceAR 10<sup>th</sup> page

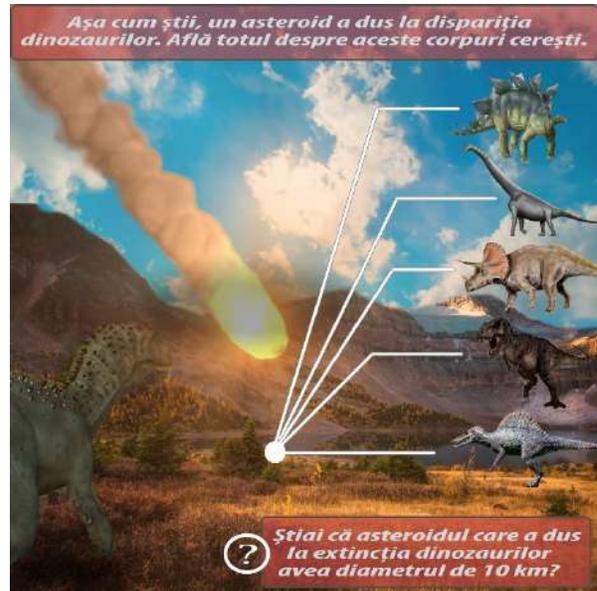


Figure 15. SpaceAR 11<sup>th</sup> page



Figure 16. SpaceAR 12<sup>th</sup> page



Figure 17. SpaceAR 13<sup>th</sup> and 14<sup>th</sup> pages

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