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USE OF MIXED REALITY TO TEACH STEM SUBJECTS

Guidelines for the use of Mixed Reality to teach STEM in Portugal

Bruno Marley Francisco Pataca

Dissertation presented as partial requirement for obtaining the Master's degree in Information Management

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by

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Advisor: *Vitor Santos, Ph.D.*

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ABSTRACT

Many organizations and countries are appealing for the information system to innovate and disrupt their legacy systems in many sectors, to be more effective and distinguished from their competitors. The education system is one of these areas that should be innovated since it is one of the key tools for any society's success. Due to rapid changes and increased complexity, the present world demands for a new education system, aiming to improve the students' agility and flexibility in a highly demanding environment. Our study aims to propose the use of Mixed Reality (MR) in the Portuguese education system, namely to teach STEM subjects to high school students, given its proven benefits to both teachers and students' performances. Based on a specific case study, related to the creation of the HoloAnatomy app by the CWRU and the Cleveland Clinic (USA), as well as on this technology's successful learning outcomes, we present our own suggestion of MR technology to implement in the education system, comprising four subjects and some corresponding contents, based on a similar development path.

KEYWORDS

Augmented Reality; Education; Mixed Reality; Virtual Reality

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LIST OF ABBREVIATIONS AND ACRONYMS

AR	Augmented Reality
AV	Augmented Virtual
CWRU	Case Western Reserve University and Cleveland clinics
DSR	Design Science Research
HMDs	Head-Mounted displays
MR	Mixed Reality
OECD	Organisation for Economic Co-operation and Development
PC	Personal Computer
PISA	Programme for International Student Assessment
RE	Real Environment
TALIS	The OECD Teaching and Learning International Survey
USA	United States of America
VE	Virtual Environment
VR	Virtual Reality
WHO	World Health Organization

1. INTRODUCTION

1.1. FRAMEWORK AND PROBLEM IDENTIFICATION

Nowadays, many institutions, organizations and countries are appealing for the innovation of the information system, as well as for the disruption from legacy systems in several sectors, aiming not only to be more effective, but also to be distinguished from their main competitors. The education system is one of these sectors to be innovated, considering that it is one of the key factors for any society's success.

Contemplating the fast modifications and the increased complexity, the present worldwide scenario demands for an innovative and distinctive education system, aiming to better prepare students in terms of agility and flexibility and to develop their digital skills, especially to better adapt and live in such a challenging and competitive environment. Thus, it is essential to analyze the current system's complexity, as well as to consider that a single or simple approach is not enough to fulfill such ambitious task (Bar-Yam et al., 2002).

As a result, the emphasis must reside on both theoretical and empirical skills that are required by the general marketing and in the implementation of teaching practices that will help students to develop the most adequate and necessary skills to fully adapt and thrive in the current world environment (Dimitrios et al., 2013).

It is noteworthy to mention that the existing platforms, such as e-learning and webinar, only offer a passive experience to students (e.g., watching a video or listening to lectures), thus implicating that they do not actually help students to develop the necessary skills for the present high demanding environment.

Nevertheless, the use of the Mixed Reality (MR) technology, comprising both the Virtual Reality (VR) and the Augmented Reality (AR), is a conceivable solution to solve this problem, considering that it consists in an immersive technology, thus allowing people to come together and to collaborate with each other, regardless of their location and time zone, as well as to see each other while communicating (videocalls) and to do simulations in a safe digital environment (Volkow & Howland, 2018).

Additionally, within the education sector VR has been recognized as a tool that truly improves students' performance and increases their own capacity to better understand different contents and/or subjects (Lee & Wong, 2008).

In the present study, we are mainly going to focus on the MR technology, despite being a daunting task to discuss it without confusing it with the predecessor technologies (VR and AR) since it refers to a combination of both (Marr, 2019).

Subsequently, the aim of this investigation is to ultimately propose the use of the MR technology in the Portuguese education system, considering that this specific technology has been proven to effectively increase both the students and the teachers' performance, thus pertaining to a specific sector, and consisting of a case study designed to be implemented in a near future.

1.2. MOTIVATION AND JUSTIFICATION

The global increase and acceptance in terms of the use of information technology within the education system allows both teachers and students to have a more efficient and inclusive learning environment, breaking language barriers and geographical location, thus creating a more motivated, innovative, and appealing learning environment for students.

As it was pointed out in a report presented by the OECD, the number of Portuguese students that leave school before they graduate is still very high (Liebowitz et al., 2018). In the 21st century, students seem to desire to be connected to the world, which emphasizes the importance and effectiveness of information technology.

Consequently, the MR technology is a legitimate option for both teachers and students to rediscover the world, especially by connecting people from different countries and with distinct cultural and geographical backgrounds. Moreover, this technology is also referred to as the 4th wave of technology, providing its users a higher level of innovative and new experiences and interactions, which have never been seen before (Devon & ClassVR, 2021).

It is important to add that VR, AR, and MR are being used for collaboration and education purposes in several different domains, such as healthcare, military, and construction. For instance, Microsoft HoloLens headsets were used to work on the frontline during the COVID-19 pandemic, especially as a tool that could assist healthcare professionals when providing care to their patients (Abineri, 2020).

On the other hand, and within the vehicle manufacturing industry, Ford is currently using the MR technology to construct the company's prototypes, rather than building physical models, thus saving several resources, especially time and money (Marr, 2019).

Therefore, by considering the increased use of information technology, as well as its widespread implementation in several sectors (healthcare, construction, industry, and military), it is relevant to address its implementation and use in the education sector/systems mainly due to the inevitability of its evolution on the long term, being implemented in more areas and sectors to improve the effectiveness and sustainability of the sector itself, but also due to the modifications that had to be done in education systems during the COVID-19 pandemic, which implied a combination of traditional education methods with more innovative methods, thus comprising the use of technology to facilitate the learning environment and process.

It is becoming increasingly evident that information technology will be further developed and implemented in several other sectors, given its economic benefits and societal advantages in general, with education systems being a key factor to explore with this regard. After all, education is an important structural factor of society, providing and developing contemporary skills (in this case, digital skills) that will ultimately be considered as fundamental in a globalized world, both in terms of success and profit, and in terms of personal growth and fulfillment.

1.3. Study Objective, research questions and structure

The main objective of the present study is to propose a specific framework for the use of MR technology to teach STEM (abbreviation of Science, Technology, Engineering, and Mathematics) subjects and to develop the main guidelines for its implementation in the Portuguese education system.

In order to fulfill this objective, the study will be based on two different approaches: a theoretical approach, based on the development of a literature review, aiming to provide further insights and contextual backgrounds regarding several pertinent concepts (MR and Education); and an empirical approach, based on the proposition of the MR technology to be implemented to teach STEM subjects in the Portuguese education system, thus applying the theoretical knowledge presented in the literature review. It is important to add that an existing case study will be discussed in the literature review section, since it provides better insight regarding the relationship between its main characteristics and its successful implementation (in the USA), thus potentially helping in the development of concrete guidelines to effectively implement the proposed MR technology.

Considering the goals of this investigation, several research questions were designed with the aim of efficiently addressing the problem under analysis, more precisely:

- RQ1: How can Portuguese students improve their score mark at the PISA exam?
- RQ2: How can the Portuguese education system become more attractive to students?
- RQ3: How do we decrease the number of early school dropouts?

Regarding the structure of the study, it basically comprises five main sections:

- This introductory section, which provides a contextualization of the conducted investigation, namely in terms of the framework and problem identification, the study's motivation and justification, and the study's objectives, research questions, and structure.
- The literature review section, providing further insights and background about relevant concepts, such as MR (definition, different technologies, and main challenges), Education (its role in the world, in Portugal, STEM, opportunities and challenges of the use technology, and MR in education), and a case study that implements MR technology in Education (USA).
- The methodology section, based on the discussion of the used methods to develop this investigation (Design Science Research – DSR, and the used research strategy).
- The proposal section, which presents the study's contributions in terms of the framework of MR technology to be implemented in the Portuguese education system to teach STEM.
- The bibliography section, which lists all the references mentioned throughout the study, comprising different types of information sources (articles in scientific journals, thesis, books, conferences, reports, and important websites) in a wide time range, thus contributing to the overall sense of evolution up until now.

2. LITERATURE REVIEW

2.1 MIXED REALITY

2.1.1 Concepts

The concept of Mixed Reality (MR) has been defined by several researchers differently, despite most of them basing their definition on the one provided by Paul Milligram. For this author, the concept of MR refers to the place where virtual and genuine world objects are introduced together in a display, more often Head-Mounted Displays (HMDs), thus comprising any point of the virtual continuum (Real Environment – RE; Augmented Reality – AR; Augmented Virtuality – AV; and Virtual Environment – VE), with a real-time interaction (Milgram & Kishino, 1994).

Bray et al. (2018) present a more recent definition of the concept, claiming that MR is a mix of physical and advanced universes, opening the connections between humans, Private Computers (PCs), and environment cooperation. However, to obtain such type of reality it is necessary to have an advanced computer vision, a graphical processing power, any type of display technology, and input systems.

Focusing on the concept of virtual continuum, it basically refers to a taxonomy where both the virtual and the real world are combined in several ways, with one edge being associated to a completely real environment (RE), while the other edge comprehends a completely virtual environment (VE), along with its technologies (AR and AV), which are found between both edges. It is important to mention that the AR combines the real and the virtual environments, with the RE being more evident, while the AV refers to the addition of real elements into the VE (Wu et al., 2013). The virtual continuum is graphically represented in Figure 1.

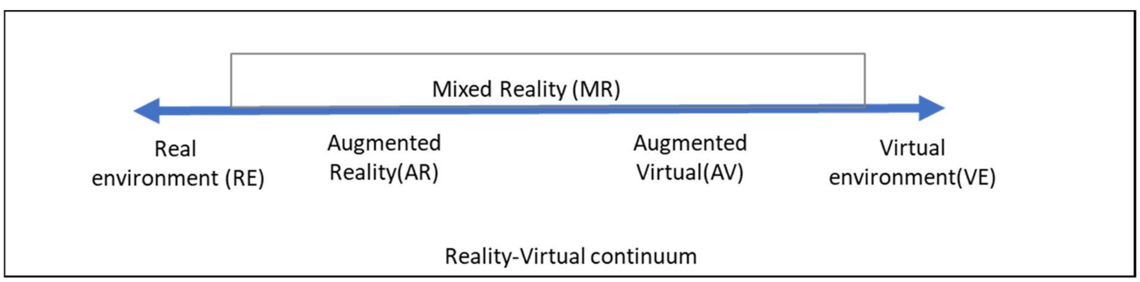

Figure 1, Virtual continuum(Milgram & Kishino, 1994).

The AR is also considered as a sub-mode of MR, even though it contains more realism, thus supplementing reality rather than completely replacing it, allowing users to see the world around them with 3D virtual objects placed over into the real world, but without degrading it (Azuma, 1997; Khan et al., 2019).

Furthermore, Azuma (1997) claimed that he preferred to not define the AR as a technology that requires the use of HMDs, since it would limit it to specific technologies. Instead, he defined AR based on three specific characteristics, namely: it combines the real and the virtual, it is interactive in real time, and it is registered in 3D.

Considering these aspects, MR is also defined as the situation that combines both real and virtual elements, as it is pointed out by Khan et al. (2019). Overall, it is possible to conclude that the concept of MR has several definitions, which end up establishing a sense of evolution through times.

Nevertheless, among distinct and different definitions there are some common aspects when it comes to defining MR, more precisely the following three:

- The notion of integration of the virtual object within the RE, which is also in line with the definition of the term “mixed”.
- How to display the virtual objects in the environment, not referring to a simple augmentation, but to the relation, or not, between virtual objects and real objects, and to whom they can interact.
- The importance of the notion of environment since each definition of MR emphasizes the pertinence of improving the user’s experience. That is, to improve the environment while simultaneously avoiding its disruption with reality (Rokhsaritalemi et al., 2020).

In turn, the VR and VE refer to a more complete immersion of the users, who are blinded to the real world and immersed in an artificial one, which might not apply specific physical laws of the real world, such as time, space, and materials’ properties (Milgram & Kishino, 1994). Based on Fuchs and Guitton (2011), the concept of VR has two different definitions: 1) VR is a vessel through which an individual can change the place, time, and interaction of an environment by simulating reality (functional definition); and 2) VR is characterized by five specific elements, namely computer science, behavioral interfaces, virtual worlds, real-time interactions, and pseudo-natural immersion (technical definition).

All these elements refer to several specificities of VR, which is why it is pertinent to make a brief and individual reference to all of them. Thus:

- Computer science is related to the expertise that makes VR come to life, more precisely by combining hardware with software, thus resulting in the creation of a system that simulates objects and characters based on physical laws of the RE (i.e., mechanics, acoustics, optics, or behavioral laws).
- Behavioral interfaces result from sensorial interfaces, which basically use the human’s five senses in the virtual world, as well as their motor and sensorimotor interfaces, associated with their movement and action in the virtual world.
- Virtual worlds are essentially the computer-generated environments, which allow a real-time interaction between users.
- Real-time interaction, key aspect of a VR system, is possible when there is no lag between the user’s action in the real word and the virtual world.

- Pseudo-natural immersion, referring to the immersion that users of VR systems build while using such system. However, immersion in VR systems is dependent on several factors, such as software programs and interfaces (Fuchs & Guitton, 2011).

Still, MR is more advantageous than VR, considering that it provides both immersive and interactive scenarios in its activities. Therefore, the interactivity that is offered by MR provides a richer user experience than VR systems. Also, MR systems are beneficial because they support more direct interactions between users, both with real or virtual objects, which is a key aspect for an active participation and the acquisition of skills by students (Bosché et al., 2016; Wang et al., 2004).

As it is claimed by Topal (2021), MR systems have more components than just a headset. Firstly, there are two sides of any MR system: the hardware and the software. In terms of the hardware, there is usually a computer/engine to run the program, with other input and output devices gathering data from the user through sensors and providing data back to users in the form of visuals, audio, or haptics, respectively. In turn, the software refers to a program or application that serves as the foundation of the VE or the virtual elements, as well as to database that contains all assets of the virtual world (Figure 2).

In other words, a computer runs a specific program, with the software's visuals being displayed on a monitor, either in a headset or in a physical surface with projectors, with speakers providing sound and controllers allowing the user's interaction with the system itself.

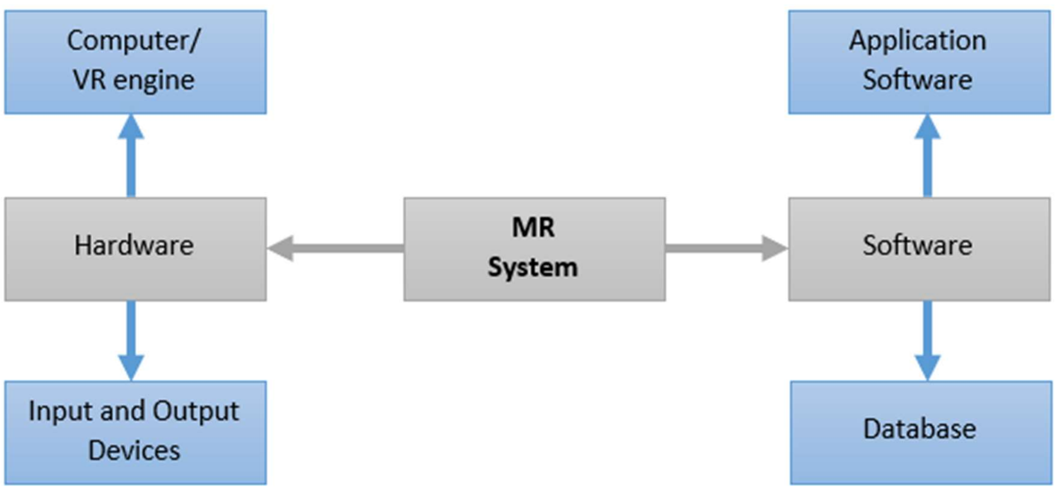

Figure 2, MR system's components (Topal, 2021)

According to Parveau and Adda (2018), MR excels it precursors (AR and VR technologies) based on its comparative fundamental standards: Immersion, Interaction, and Information, which is also known as 3iVClass. The definition of each criterion is the following one:

- Immersion: corresponds to the description of the immersive experience that is brought by the MR technology during the user's experience. The user environment must then be processed and interpreted in real time, which is called spatial mapping/spatial understanding.

- Interaction: the description of the type of interaction that is provided by the MR technology. Natural user interactions must be processed both in real time and immediately.
- Information: refers to the types of information and data that are managed by the MR technology. Thus, virtual objects must be registered in time and space, being placed according to the user's position, or the environment/other objects. Still, every virtual or physical object must be intractable in real time (Rokhsaritalemi et al., 2020).

Table 1 presents the comparative fundamental standards of each technology (MR, AR, and VR), while Table 2 establishes a comparison between all three technologies (AR, VR, and MR) in terms of their key specifications.

Table 1 - Comparative fundamental standards of MR, AR and VR(Rokhsaritalemi et al., 2020).

Fundamental Standards/Technology	**MR**	**AR**	**VR**
Immersion	Real time mapping (real and virtual)	Augmenting real world	Full virtual
Interaction	Physical and virtual objects	Physical objects	Virtual objects
Information	Registered in 3D, Correlation to user, and time persistence.	Registered in 3D, no correlation to the user, and no time persistence	Registered in 3D, no correlation to the user, and no time persistence

Table 2 – Comparison between AR, VR, and MR based on their key specifications (Rokhsaritalemi et al., 2020)

Features/Specifications	AR	VR	MR
Display device	Headsets optional	Mostly using special headsets or smart glasses	Headsets optional
Image source	Combination of computer-generated images and real-life objects	Computer graphics or real images produced by a computer	Combination of computer-generated images and real-life objects
Environment	Both virtual and real-life objects are seamlessly blended	Fully digital	Both virtual and real-life objects are seamlessly blended
Perspective	Virtual objects behave based on user's perspective in the real world	Virtual objects will change their position and size according to the user's perspective in the virtual world	Virtual objects behave based on user's perspective in the real world
Presence	Feeling of still being in the real world, but with new elements and objects superimposed	Feeling of being transported somewhere else with no sense of the real world	Feeling of still being in the real world, but with new elements and objects superimposed
Awareness	Virtual objects can be identified based on their nature and behavior, such as floating text that follows a user	Perfectly rendered virtual objects that cannot be distinguished from real objects	Perfectly rendered virtual objects that cannot be distinguished from real objects

2.1.2 Technologies

MR technologies comprise two different groups: AR and AV, as it was demonstrated in Figure 1. To better understand the main differences of MR technologies/systems it is important to consider four specific components, namely: 1) media representation; 2) input mechanism; 3) display device; and 4) tracking technology (Wang & Dunston, 2011).

More precisely, media representation refers to the system's component that helps to provide more detailed information, thus assisting in the user's comprehension process. Overall, AR systems frequently use a long variety of media, from abstract (schematic) to realistic (3D), including indicators, platforms (tablets and screens), 2D image, wireframe 3D, 3D data, and 3D objects. The input mechanism is used to manipulate the digital information that is being inserted into the real environment (RE). Such input mechanisms can be joysticks, haptic inputs, or voice commands. However, for a better performance, the input mechanism cannot be an intermediate mechanism placed between the users and the environment (Wang & Dunston, 2011).

In turn, display devices are often characterized as being see-through, acoustic, and tactile displays, with the most common ones being HMDs, handheld devices (tablets and mobile phones), desktop displays, and ambient projectors (Dascalu et al., 2014). Lastly, tracking technology refers to the orientation system, aiming to know the user's position (the hands, head, and eyes) to accurately register/track the virtual objects' position in the RE (Wang & Dunston, 2011).

When it comes to the development of the MR space, the two main types of technologies that are often used are the optical see-through and the video-see-through. In the first technology, the real world is directly seen through tools, such as transparent glasses. In turn, in the second technology both virtual and real objects are presented through a Liquid Crystal Display (LCD). Overall, the main display tools in MR technologies are categorized according to 4 different groups, namely: 1) head-mounted displays (HMDs); 2) handheld display devices; 3) monitor-based display devices; and 4) projection-based display devices (Claydon, 2015).

However, it is noteworthy to add that the use of a display tool in the MR space requires special attention to two central concepts: immersion and comfort, the former being associated, for instance, with the field of view, and the latter with thermal management. Basically, both concepts provide a certain ease of use, thus enabling the scenario's execution in an appropriate manner to the user (Claydon, 2015).

According to Rokhsaritalemi et al. (2020), there are some specific steps that must be taken to create a MR environment via see-through technologies (Figure 3). In more detail, in the device recognition step the type of MR tool is identified, accordingly to the project's main goal, with the chosen devices being set by using a calibration model. In the space recognition step, the space is modeled to model some part of the real world in the VE to run the user scenario. Then, in the object and tracking recognition steps, the real-world object is both identified and tracked. In the mapping recognition, registration, and mapping step all these processes are performed so that the real object communicates with the virtual object, thus providing an interaction between the RE and the VE. In the visual recognition step, a MR service is implemented and then visualized by using an appropriate computer graphic technique, thus overlaying virtual objects in the real-world scene. Lastly, in the portable recognition step an appropriate model is used for delivering the data and reconstructing the scene, reducing all unnecessary information, and being often developed for mobile devices.

Figure 3, MR steps (Rokhsaritalemi et al., 2020).

Furthermore, the concept of algorithm is pertinent in this discussion, mainly because it refers to an important part of any MR application and comprises all the MR steps represented in Figure 3, being based on different analytical mathematical models that aim to ultimately improve the MR system's accuracy. Table 3 summarizes some of the most crucial characteristics of each MR step based on the notion of algorithm.

Table 3 – Characteristics of the MR steps based on the notion of algorithm (Rokhsaritalemi et al., 2020)

MR steps	Goal	Benefits	Pertinence	Challenges
Calibration	Set MR devices (ex.: See-through tools, cameras).	Solves tools' instability. Good interactions user-virtual object. Exact estimate of camera parameters.	Improves scene reconstruction from camera images. Important for user interaction.	Low stability between user-MR device. Extra parameters to raise accuracy. Sensibility to changes.
Model of Space and Simulation	Modeling large spaces and real objects.	Preservation of relationships (objects-users). Perception of object's modeling deformation.	Offers information about users and their location in the MR space. Builds 2D and 3D scenes and maps. Arranges virtual objects in real scenes.	Sharing between coordinate systems. Chance of using an authoring system. 3D using appropriate tracking systems. Use of proper settings of the model and parameters.
Object Recognition	Insert a virtual object in a real space to implement a MR scenario.	The recognized object can be static or dynamic in nature. A good example of a dynamic object recognition is moving human recognition.	Detection of moving objects to insert the virtual object in a real scene. Object detection from images. Displaying information based on the user field of view.	Choosing the right data set to identify the MR system's object. Method precision depends on good synchronization of voice commands-gaze. Spatial object detection errors caused by tracking tools.
Object Tracking	Place objects for interaction between virtual-real objects.	MR tracking method has 3 classes: sensor-based (uses sensing devices), vision-based (use of computer vision techniques based on image processing), and hybrid (combination of both).	GPS can determine users' relative positions. Person tracking. Planning the layout of buildings.	Correct installation of the device. Power management. RE's digital model to map sensor data to an exact location. Eliminating defects of important methods. Use of markers and cameras to increase accuracy and coverage.
Registration and Mapping	Interaction between virtual-	Locates an object in a real scene.	Overlays a building's virtual model in a	Requires a device with good accuracy

MR steps	Goal	Benefits	Pertinence	Challenges
	real objects by mapping and registering the virtual model in a real space.		real space using the user's position. Matches the tracker's coordinate system to the virtual object. Registers a virtual object in a real object.	and a well-designed interface. Use of high-resolution device to manage complex tasks. Alignment methods require the simultaneous use of sensor fusion and occlusion.
Visualization and Rendering	Display MR content.	Close-to-reality visualizations in MR applications.	Immersion of virtual objects in video images. Processing of raw images. Real world simulation with a virtual globe.	Use of appropriate analytical algorithms that handle different aspects/needs.
Information Transfer for Portable Devices	Transfer information for reconstructing scenes using mobile camera images.	Enhances the necessary objects.	Sending video files for scene reconstruction. Enabling uniform data gathering, processing, and interaction for diverse sources (sensors and media). Handling display information based on its importance.	Lossless decoding of object information. Creating a virtual model based on user preference in multiple CPUs in real-time. Preservation of data integrity between layers.

2.1.3 Challenges

There are many challenges when creating a MR platform, considering that it is a relatively new system and that it truly requires several technologies, such as a specific display technology and a tracking technology. Indeed, the type of display that such platform requires must provide a rich output, with appropriated resolution and contrast. Furthermore, a MR platform also requires a good tracking system, especially to provide to its user the illusion that the object is in a specific position, with the user's point of view being important in some specific cases (Costanza et al., 2009; Rokhsaritalemi et al., 2020).

Nevertheless, Moser et al. (2019) also emphasize that there are still some challenges related to the availability of the MR products, which in many cases are still prototypes, with the time of production being higher, in addition to compromising the products' benefits. Moreover, it is also frequent that most of the existing devices are still in an early development stage, meaning that they present a limited battery life, an uncomfortable feeling when being worn for several hours, and a small field of view. Another challenge is related to the risk of real-time representation of complex data within the MR environment, since it requires a minimum refresh rate of 60fps (Moser et al., 2019).

According to Boring et al. (2009), another challenge regarding MR platforms is related to the interaction in both augmented and virtual realities. In more detail, the authors emphasize that while most MR devices support interactions through hand gestures, physical remotes, or speech, it still lacks devices that support implicit hands-free interactions, thus allowing collaborations with peers and with virtual elements.

Finally, in more recent research, conducted by Jabil (2023), it was found that the main challenges regarding MR technologies are the following ones:

1) Managing the high prices of developing new technologies. From a consumer perspective, MR technology is highly priced, tethered to game addicts, tech enthusiasts, and early adopters. This is mainly because MR technology requires the combination of several disciplines to create immersive experiences, often meaning that the development of devices and/or technologies implies a large investment.
2) Limitations in AR and VR devices, with the field of view being the biggest one. Currently, the existing devices have a field of view of up to 90 degrees, which is significantly lower when compared to normal human vision (190 degrees horizontal and 120 degrees vertical). Therefore, devices must provide a more immersive experience to users, ultimately being more comfortable and enjoyable to use.
3) Limited AR and VR experiences provided by consumer electronics. In fact, most consumer electronics lack a depth of understanding and the full potential of MR experiences, with users only having access to limited MR immersion/experience.
4) Current form factor needs to evolve, since there are currently three or four types of headsets. Overall, these headsets' form factor is comfortable to a certain extent but are difficult to use for prolonged amounts of time. Hence, more sustainable devices must be developed in the future.
5) Impacts of connectivity in AR and VR experiences, especially of 5G. It is expected that with 5G there will be more stability in MR experiences in mobile devices, as well as access to more and better-quality content.

6) Multiplicity of ecosystems. Up until now, MR technologies are geared toward enterprise-use or consumer-use, but there is not even one that goes across these ecosystems. Therefore, it would be important and beneficial for MR technologies to be successful across multiple ecosystems, despite guaranteeing their trendiness and mass adoption by users.

2.2 EDUCATION

2.2.1 The role of education in world

Globally speaking, education is an important tool to people and communities since it improves their quality of life and assumes a more prominent responsibility for people's own fates. As a matter of fact, a country that cannot improve the information and its abilities regarding their people and not use them to grow and thrive economically will not progress at any level. Thus, the role of education is inevitably to empower people, providing them with important information and skills, so that they can contribute to society in the future, either in terms of scientific and technological improvement, or of economic success (Chimombo, 2005).

As it was said by Nelson Mandela, "The power of education extends beyond the development of skills we need for economic success". Hence, the role of education in the world goes way beyond of an individual developing a skill to perform a specific activity, aiming to be successful, since it also comprises the capability of thinking, analyzing different types of subjects, and being creative. Moreover, UNICEF claims that "every child has the right to learn", regardless of their economic status. Thus, without a proper education, children won't develop a "lifelong skill" that they need to overcome future barriers, either related to a good job or to a general contribution to their community. So, it is important for all children to have access to the "digital learning as an essential service", as it was emphasized during the pandemic of COVID-19 (United Nations Children's Fund, 2020).

The World Bank (2022) has pointed out that COVID-19 has disrupted societies and economies, aggravating the already existing global education crisis and impacting education in an unprecedented manner. In most countries, children and youth suffered major learning losses during the COVID-19 pandemic, being estimated that each month of school closures led to a full month of lost learning, thus stressing the limited effectiveness of remote learning.

In this same context, COVID-19 also resulted in a catastrophic inequality, in the sense that remote education was not a possibility to every child. In fact, "children from disadvantaged households were less likely to benefit from remote learning than their peers, often due to a lack of electricity, connectivity, devices, and caregiver support" (The World Bank, 2022, par. 11).

Moreover, the associated unprecedented global economic contraction on family incomes worldwide has increased the risk of school dropouts and contracted government budgets and strains on public education spending. In other words, the COVID-19 pandemic made youth suffered a loss both in terms of skills and jobs, with their future possibly being more disadvantaged than previous generations, considering that they might not achieve their full education and/or earnings potential. According to The World Bank (2022), it is crucial for worldwide governments to implement more ambitious Learning Recovery Programs, with the goal of getting children back to school, to recover from the lost learning during COVID-19, and to accelerate progress, especially by building better, more equitable and resilient education systems.

In sum, with the type of disruption that is currently happening in education systems worldwide, one can highlight the importance, or even the major opportunity, of introducing MR as a new and innovative technology in the Portuguese education system.

2.2.2 Education in Portugal

Even though the OECD has found that Portugal has managed to make its 15-year-old students to stay on top of the average in the areas that are carried out by PISA, it is still far from occupying the first place among the 72 participants in total, considering that Portugal is ranked as it follows: 17th place in Science, 18th place in Reading, and 22nd place in Mathematics (Figure 4). Despite being considered among the best, Portugal is still behind several countries, such as Singapore, Finland, Canada, and Switzerland, which are known as the reference in terms of the best educational systems.

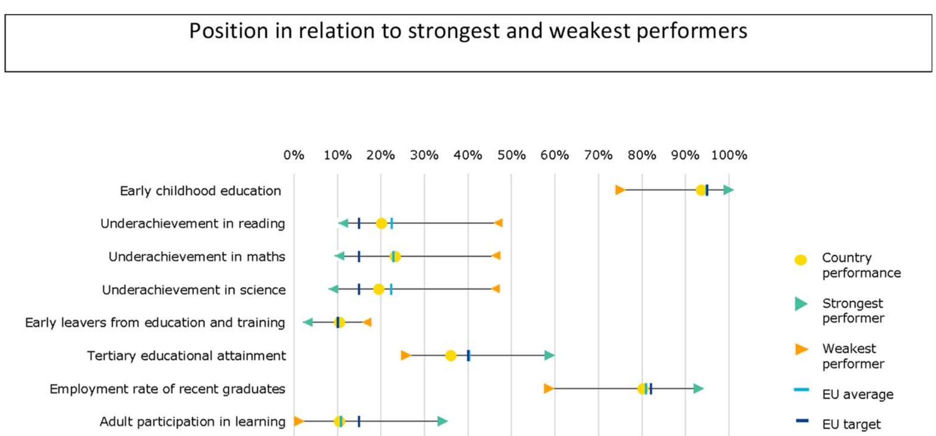

Figure 4, Position of Portugal in relation to the strongest and the weakest performers Source: DG EAC, based on data from Eurostat (LFS 2019, UOE 2018) and OECD (PISA 2018).

In Portugal, education is free for students until they're 18 years old, including their graduation from high school. Overall, the Portuguese education system comprehends the following stages/institutions:

- Nursery and Kindergarten: destined for children aged between 4 months and 5 years old.
- Elementary school: destined for students aged between 6 and 14 years old.
- High school: destined for students aged between 15 and 18 years old.

Even though MR can totally be implemented in all of these stages/institutions, in this study we will focus on its implementation in high school, considering that this is the stage that corresponds to the students that are submitted to the PISA exams, that presents more problems related to the lack of interest in continuing education, and that consequently presents a higher percentage of early school dropouts, as mentioned by the EU (EU, 2016).

Another problem in the Portuguese education system refers to the level of digital skills, which is still low when compared to the other members of the EU. In fact, the European Commission's Digital Economy and Society Index (DESI), in 2020, ranked Portugal in 20 of 27, thus being below the EU's average (EU, 2016). Thus, Portugal needs to reinforce their information and communication technologies' competencies, mainly at the level of the use of internet and of human capital. In other words, Portugal needs to requalify its infrastructures and to train people as a part of the program of "National Digital Competences Initiative e.2030, Portugal INCoDe.2030", which was proposed by the governments.

As a matter of fact, Bond et al. (2018) demonstrated that poor digital skills, both of teachers and students, are often mentioned as one inhibitor to the use of technology in the classroom, with the educational technology's use being limited to emails, Learning Management Systems (LMS), and multimedia presentations. Moreover, the use of educational technology might also be limited due to different perceptions, considering that in some cases students might find the use of technology as beneficial to the learning process, while teachers do not see those educational benefits due to their poor digital skills (or vice-versa).

During the COVID-19 pandemic, learning processes suddenly shifted from present to remote learning, being based on the use of digital technologies. Hence, teachers had to adapt their courses in a quick period of time, sometimes with very little training in the available digital technologies. However, and students' perspective-wise, it has been demonstrated that online students do marginally better than students in classroom contexts, with blended learning approaches possibly being more fruitful to students in general, despite some concerns among teachers (Zimmerman, 2020).

According to Du Toit and Verhoef (2018), High Education Institutions (HEI) can benefit from investing in digital technology, especially in terms of digital literacy, cost-effectiveness, access and equality, integration of technology into curriculums, and technological training of educators/teachers. Nevertheless, this investment also comprises some additional challenges, such as lack of attention/focus by students, plagiarism, unpredictability of the teachers' role in the future, and problems related to teachers' ability to stay contemporary and organized, especially while educational needs, hardware, and software evolve at a quick pace.

In sum, digital technologies assumed an increasingly important role in higher education methods and digital transformation initiatives have been the focus of a new generation of EU policies since 2020. Thus, the challenges of innovation involve the strengthening of both the European and the Portuguese higher education area, as well as the insurance of its quality through external and internal resources. Ultimately, HEIs are institutions that have adapted to several social, political, and technical changes, and currently need to adapt to a more dynamic and technological environment, in a constant digitally evolving world (Lašáková, Bajzíková & Dedze, 2017; Pinho, Franco & Mendes, 2020; Pinto & Leite, 2020).

2.2.3 STEM

According to Gonzalez and Kuenzi (2012), STEM is the abbreviation of Science, Technology, Engineering, and Mathematics. Over the past years, several definitions of STEM education have been developed, comprising different perspectives. For instance, Morrison (2006) argued that STEM education is a meta-discipline, in the sense that in addition to being a new discipline, it also integrates other disciplines. Similarly, Dugger (2010) suggested that STEM education integrates those four disciplines intertwined with people's daily lives, hence allowing individuals to perceive the world.

Based on a different approach, Çorlu, Capraro and Capraro (2014) defined the concept of STEM education as referring to the manner both teachers and learners structure thoughts, skills, and knowledge, including the cooperation of more than one STEM field. Moreover, STEM education is also defined as an interdisciplinary teaching and learning approach that removes traditional barriers between all four disciplines (Science, Technology, Engineering, and Mathematics) (Vasquez, Sneider & Comer, 2013).

Overall, and based on all these different definitions, it is possible to infer that STEM education is a teaching and learning approach that aims to teach all four courses in an interdisciplinary manner, with the goal being to help students to develop their academic performance, as well as to gain cognitive competencies.

The STEM education approach dates to 1990s, especially to the USA's efforts to adopt a holistic approach to education in the curriculum, thus introducing the paradigm that all four disciplines are addressed together to raise younger generations with 21st century skills (Bybee, 2010).

Indeed, it was precisely the trend of raising young people with 21st century skills, as well as the scientific and technological competition between developed countries, that led to the emergence of several STEM schools in the USA, where teachers integrated engineering into their lessons. In turn, in Europe several STEM projects were being developed, aiming to both apply science education based on questioning and to increase students' interest in science. In a different direction, Turkey began to develop several STEM studies in several universities, which is why a STEM Center was established at Istanbul Aydin, Hacettepe, and a STEM laboratory was established at the Bahçeşehir University (Akgündüz et al., 2015).

In 2016, the Ministry of National Education General Directorate of Innovation and Educational Technologies published a report designated as STEM Education Report, which basically demonstrated that the 2015-2019 Strategic Plan aimed to strengthen the STEM approach, since STEM education became extremely important, as well as indispensable, for the 21st century education programs (National Research Council, 2013).

The pertinence and relevance of the STEM education paradigm is associated with the need for individuals to acquire and develop competencies and skills that will make them able to produce and solve problems. In more detail, STEM education focus on several literacy skills, namely collaborative work, problem-solving, critical thinking, and creative thinking, which are all important to people's development and to promote innovation, growth, and competitiveness in the global knowledge economy (Özdemir, 2016).

21st century skills are different from 20th century skills, mainly due to the quick development of information and communication technologies. Hence, in this new century, individuals are expected to acquire and develop a specific set of skills, all directed to solving daily problems and to contributing to society's needs in general. According to Alwis (2018), the 21st century skills are basically the following ones:

1) Information literacy.
2) Critical thinking.
3) Problem-solving.
4) Collaboration and teamwork.
5) Innovative and designing.
6) Technology literacy.

7) Entrepreneurship.
8) Leadership.
9) Adaptability to live in a multicultural society.
10) Social responsibility and ethics.
11) Global and cultural awareness.
12) Civic literacy and responsibility (graphical representation in Figure 5).

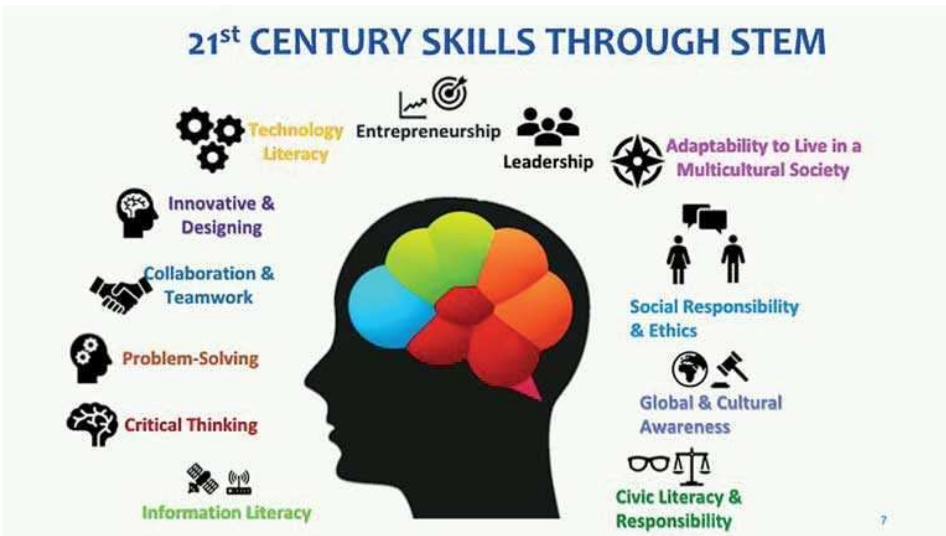

Figure 5, 21st century skills through STEM (Alwis, 2018).

Therefore, in the 21st century the emerging science and technology are shaping both the education system worldwide and the expectations for future individuals to develop specific current skills, with the STEM education being considered as a pertinent approach to make the education system itself to keep up with the rest of developments and to meet the individuals' expectations.

In sum, it is possible to conclude that the STEM education develops students' problem-solving skills, allows them to think logically and critically, gives them the opportunity to develop their creativity and design in Engineering by using their basic skills and knowledge, and allows them to develop an interdisciplinary perspective, thus enabling them to both understand and explain the nature of technology, while simultaneously providing them with 21st century skills (Lin, Wang & Wu, 2019).

2.2.4 Opportunities and Challenges for the use of Technologies in Education

Technologies in education can be used to significantly improve the productivity of both teaching and learning. For instance, the introduction of computers and portable devices in classrooms allows the expansion of courses, knowledge, and information, being available 24 hours a day, as well as the improvement of students' motivation and rapid learning in several subjects. In terms of teaching, technology transforms this process by providing a platform that connects teachers, students, and resources, thus allowing an adaptation to meet several ends. For instance, it can reduce repetitions and allow teachers to reuse the contents in different classes, thus reducing costs and time for teachers in general. Table 4 summarizes the main differences between traditional teaching methods and modern teaching methods, the latter including the use of technology.

Table 4 – Traditional and Modern teaching methods adapted from (Dimitrios et al., 2013).

Traditional teaching methods	Modern teaching methods
• Reading texts and problems • Formulate questions. • Attending lectures • Monitor discussions. • Writing and reply brief or extensive questions and objective type questions. • Solving short or lengthy unstructured problems and cases • Oral presentation of topic and reply to short questions from the audience. • Studies	• Video Watching • Attendance and participation in lectures using interactive whiteboards. • Accounting applications using simple systems. • Role Playing • Simple modeling • Emphasis on practical knowledge more

Furthermore, technology use in the classroom also creates an inclusive environment, assisting students with cognitive or motor disabilities, thus making it more difficult to learn through more traditional teaching methods. For instance, students that suffer from dyslexia have some difficulties in reading and writing, which can be somewhat surpassed by specific learning tools, such as those provided by Microsoft.

As it is mentioned by Iqbal, Mangina and Campbell (2022), the latest innovation in teaching refers to the use of AR in the classroom, with several applications based on this technology being deployed successfully in STEM education, thus delivering practical and creative benefits to teaching. Based on their research, the five main directions of AR education that have been explored so far are related to the following categories: 1) AR books; 2) AR educational games; 3) AR discovery-based learning applications; 4) AR projects that model real-world objects for interaction; and 5) AR projects that explore skill-based training.

Moreover, Iqbal et al. (2022) also focus their investigation in four specific types of AR learning, thus providing further insight in terms of this technology being applied in Education. The AR learning types are:

- In formal classrooms, allowing students to learn through the combination of real and computer-generated images and to understand different topics with different scenarios.
- In special education, creating a learning opportunity for special children, since they can overcome physical barriers by using AR technology. Hence, this technology provides a high-quality educational experience for students with special needs.
- Outside the classroom, considering that by using AR smartphone applications the AR learning experience extends outside the formal classroom, including self-assisted learning.
- Collaborative learning, since AR provides the opportunity to support the multifaceted world of scientific exploration. The need for collaborative learning has recently increased, especially due to the growing demand for independent and remote learning, where both students and teachers need to connect with each other in different ways (Iqbal et al., 2022).

However, the study conducted by Iqbal et al. (2022) is also important to our research because it presents major opportunities of AR technology applied to Education, approaching 11 different domains where those opportunities are quite evident. To facilitate the comprehension of all these opportunities accordingly to their domains, Table 5 summarizes the important aspects that must be considered to understand the main benefits of using AR technology in Education.

Table 5 – Opportunities/benefits of using AR technology in Education (Iqbal et al., 2022)

Domain	AR Technology	Opportunity/Benefits
Interactive AR books for early classes (Primary and Elementary School)	AR in general	Allows students to be actively engaged in the learning process
	ARGarden (interactive flower gardening AR system)	Creates a positive learning engagement by adding visualization in the learning process
	Toys++ and AR magical playbook	Shows the role of AR as an engaging factor in the learning process
	AIBLE (inquiry-based AR learning environment)	Helps to prove the concept of tasks mobilization and active learning in AR
Interactive books for higher classes (High School and University)	Multimedia Augmented Reality Interface for E-learning (MARIE)	Superimposes Virtual Multimedia Content (VMC) Information. Enables students to interact with VMC composed of 3D objects and animations
	miBook (Multimedia Interactive Book)	Shows an impact on learning outcomes by adding up visualization to a regular textbook
	ARCS model (Attention, Relevance, Confidence, Satisfaction) of motivation	Significantly improves the learning motivation and the students' creativity in creative design courses
	SESIL (combines book pages and handwriting recognition using the AR camera)	Robust and reliable for practical use in education, yielding positive results
STEM education	ARChemist, and through gestures tested in CHEMOTION	Learning chemistry with a virtual interaction with chemicals using hand-tracking technology
	Augmented Chemistry (AC)	Reports higher user acceptance by interacting with the 3D models in the lab
	Situated Multimedia Arts Learning Lab (SMALLab)	Powerful approach to learn in a design experiment with secondary earth science students
	AR to learn the Earth-Sun relationship, Earth-Moon System, and Live Solar System (LSS)	Helps to enhance meaningful engagement in learning astronomy concepts and conceptual thinking
	Interactive Simulation to learn gravity and planetary motion	Increases the learning gain significantly and increases students' positive attitudes

Domain	AR Technology	Opportunity/Benefits
	Science Center To Go (SCeTGo)	AR pedagogical efficiency is very constructive to both teachers and students
	AR anatomy learning systems	Helps to learn the interior and exterior of the body by introducing an innovative, hands-on study of the human musculoskeletal system
	Learning Physics through Play Project (LPP)	Helps to learn concepts of physics about force and motion
	LightUp	Helps to learn concepts of electronics, such as circuit boards, magnets, and plastic sheets
	ElectARmanual and AR-based flipped learning system	Helps to achieve better learning outcomes by using the AR guiding mechanism
	AR and Internet of Things (IoT)	Creates productivity in Engineering education with different scenarios
	AR with Construct 3D and GeoAR	Supports learning in geometry. Shows a highly positive impact concerning educational potential
Language and vocabulary learning	AR flashcards to learn the English alphabet and animals	AR as a tool for motivation and visual presentation when learning languages
	AR games – HELLO (Handheld English Language Learning Organization)	Improved retention of words and increased student attention and satisfaction
	TeachAR, using kinetics	Teaching basic English words (colors, prepositions, and shapes) and for foreign language learning
	Microsoft Hololens	Higher productivity and effectiveness in vocabulary learning
	Explorez (mobile learning tool)	Improving foreign language skills, being useful and motivating for students
Collaborative learning	SMALLab – Student-Centered Learning Environment (SCLE) based on interactive digital media	Promising results in collaboration and social aspects

Domain	AR Technology	Opportunity/Benefits
	ARClassNote (save and share handwritten notes over optical see-through HMDs)	Makes it easier to communicate between teachers and students by sharing written class materials
	LookingGlass and Hololens	Allows collaboration between students and teachers and share 3D content between devices
Environment and History learning	CI-Spy (inquiry-based learning application)	Enables a comprehensive understanding of historical inquiry for students by combining AR experiences with strategic learning
	Game-based learning	Helps students to learn in the virtual context, deepening their involvement in the learning experience
	EARLS (Ecosystems Augmented Reality Learning System)	Promotes a positive learning attitude among students over Keyboard/Mouse-based Computer-Assisted Instruction (KMCAI) approach
Special Education	3D Learning Objects using AR – Web-based AR learning system	Potential of AR for interactive learning. Allows students to become more engaged with the learning content. Provides opportunities for educational engagement and process reiteration for learners
MOOC (Massive Open Online Courses)	AR used to generate interactive and extra appealing online content	Helps to create more productivity by improving visualization, supporting individualism, and enlightening the interest factor
Technical training	Intelligent Tutoring Systems (ITS)	This adaptive guidance helps an intelligent AR to show faster performance
	AR in technical training workshops	Facilitates better learning and helps to improve students' learning experience and understanding of the complex concepts
Authoring tools	Immersive AR authoring tool	Allows users to create AR content. Reduces the workload for the teacher in creating and managing AR learning experiences

Domain	AR Technology	Opportunity/Benefits
Multi-agent systems	AR Puppet, validated in AR Lego	Helps in autonomous decisions based on the students' perception of the real environment
	Multi-agent system (SRA)	Increases the motivation by using the principle of "learn by doing" of kinesthetic learning
	Kid Space	Children are actively involved with the projected character during exercises (Math in this case)
	FenAR – AR system that follows the Problem-Based Learning (PBL) approach	Improves students' learning achievement and increases their positive attitudes towards physics subjects
	Augmented Reality Teaching Platform (ARTP) developed with Augmented Reality in School Environments (ARiSE)	Perceived usefulness and ease of use as extrinsic and perceived enjoyment as intrinsic for this news learning environment

Concerning the opportunity to use MR in the Portuguese education system, the Portugal INCoDe.2030 (Portugal INCoDe.2030/Iniciativa Nacional de Competências Digitais e.2030, n.d.) can be mentioned, because this specific program aims to improve the existing educational and training infrastructure. Thus, it is a great opportunity to invest in innovative technologies that will ultimately improve the digital competences, while simultaneously providing new ways of experiencing within some subjects, not involving the actual waste or harm of resources and/or the environment.

Nonetheless, the use of technology in schools is often a confusing discussion, considering that the benefits of technology in the education and learning process are also controversial. According to some studies conducted based on the "State of Education 2019", more than 50% of the teachers in Portuguese schools are aged above 50 years old, with teachers aged under 30 years old being less than 1% (Rodrigues et al., 2020). In turn, the "TALIS 2018 report" showed that 12% of the teachers need training on information and communication technology.

Therefore, the major challenge about using technology in education refers to the teachers, who need to be adequately trained and motivated to use these new technologies in their classes to improve their teaching process, as well as the efficiency of the learning process among their students.

2.2.5 Mixed reality in Education

MR has been identified as a great tool, being used for information visualization, remote collaboration, design tool, human-machine-interface, education, and training. Regarding education and training, which is the most important focus to the present research, several studies have been developed that suggest the use of MR in different sectors of these areas, not being exclusively limited to schools, but also applied in multiple companies and military organizations to better train and prepare their subordinates.

However, before implementing a MR system it is important that teachers and/or instructors are adequately prepared, especially by acquiring the necessary digital skills and pedagogy, aiming to facilitate the communication process and to create a good atmosphere, thus ensuring an effective interaction with their students (Călin, 2018). The goal of a good communication between teachers/instructors and students is to effectively transmit the information to students, using MR in a beneficial manner in every subject.

Thus, in order to obtain the results of pedagogical-formative processes using the VR, AR, and MR technology, and to gather information regarding its advantages and disadvantages, Călin (2018) submitted a brief questionnaire to 186 students (fresh graduates of the teacher training course), aiming to obtain their answers to the following two questions:

- Q1: If you were to use and implement technologies in teaching, such as those associated with the concepts of virtual reality, augmented reality, or mixed reality, which skills do you believe you'd develop?
- Q2: In your opinion, what are the advantages and disadvantages of using and implementing virtual reality, augmented reality, and mixed reality technologies in teaching?

Considering the first question, the answers demonstrated that *Communicative – clear, coherent communication* for this device was the most chosen option (74%). However, this technology seems to make it difficult to obtain an objective evaluation (12%), even though this was the last rank opinion. Table 6 summarizes the answers provided to the first question, which are grouped by competency description, the opinion percentage, and the corresponding rank/importance.

Table 6 – Competency description table (Călin, 2018)

Competency description	Opinion percentage (%)	Rank
Communicative – clear, coherent communication	74	1
Informative – relevant and actual information	53	2
Technological – understanding and using new technologies	50	3
Instrumental – the transition from theory to practice	42	4
Decisional – efficient decision-making skill	32	5
Evaluation – objective evaluation	12	6

Regarding the second question, which comprised both the advantages and disadvantages of using technologies (VR, AR, and MR), the provided answers are summarized in two tables (Table 7 and Table 8), respectively.

Table 7 - Advantages of using technologies (VR, AR, and MR) (Călin, 2018)

Advantages of using technologies (VR, AR, and MR)	Opinion percentage (%)	Rank
A new perspective on the learning process	57	1
Encouraging practice over theory	49	2
Developing imagination and creativity	45	3
Long-term, powerful motivation	33	4
Efficient long-distance learning	26	5
Affordable technology	22	6
Exploiting domain easier	13	7

Table 8 - Disadvantages of using technologies (VR, AR, and MR) (Călin, 2018)

Disadvantages of using technologies (VR, AR, and MR)	Opinion percentage (%)	Rank
Lack of trained teachers (in using the technologies)	56	1
Inexistent digital infrastructure	46	2
No subsidizing for digitalization	33	3
Medical affections caused by VR, AR, and MR technologies	25	4
Technology addiction and ignoring other types of teaching	19	5

Therefore, Călin (2018) concludes that the use of VR, AR and MR technologies maximize the collaboration between students and teachers, even though most teachers are not currently ready to implement this technology in their education methodology, since the majority underscored more the hipothetical than useful aspect of its implementation, truly showing some dread towards the difficulties of innovation.

In the scope of the MR implementation and use in education, it is also possible to analyze the eLearning application/tool presented by Callaghan et al. (2008), namely the MiRTLE (Mixed Reality Teaching and Learning Environment), which consists of a tool that introduces the MR environment to a more sophisticated education system.

Basically, MiRTLE augments the current education practice, allowing students to be remotely located across several locations and to participate in the classroom with a better level of interaction, either with the lectures or other students, thus representing the legacy of eLearning systems in general. Nonetheless, this tool also enhances the teachers' productivity, specifically by removing the repetition of work, and saves several resources, such as time and costs (Callaghan et al., 2008).

For instance, in the military education field MR has been used by the United States Army, especially for tranining purposes, simulating military operations that mimic the experience of real life combat, because students need to acquire and develop the skills that are required in decisive circumstances in real combat (Hughes et al., 2005).

Still, it is important to add that these simulations are quite expensive to create, namely due to the amount of technology that is needed to blend both real and virtual environments (Stapleton & Hughes, 2006).

More recently, Dascalu et al. (2014) surveyed the application of MR in education, highlighting its importance in this field due to its modernity and efficiency during the learning process and pointing out its flexibility to be implemented in a wide range of educational fields. The authors analyzed multiple applications and the MR's versatility, which actually supports the learning paradigm, based on the technology's characteristics that are directly linked to its applications that support multi-client and training networks, as well as the comprehensive disseminated standards.

More precisely, the MR applications and the several fields of implementation that were analyzed by Dascalu et al. (2014) were the following ones:

- MiRTLE, 3dUPB, and MAVT, which can be used in several education fields.
- Mixed Reality Solar System, used to learn earth science.
- Plant system, MR Sea Creatures and Savannah, used to learn biology.
- MR MOUT, used for military education.
- InterReality Portal, used to learn computer science.
- Robostage, used to learn a foreign language.
- Magic Story Cube, used for storytelling.
- FaiMR, used for furniture assembling.
- MR Mechatrinics and Engineering Virtual Lab, used for engineering education.
- And MR Collaborative Design Review, used for architectural education.

Nevertheless, some generic considerations that must bear in mind before implementing the MR technology in the education system, and that are considered to be crucial elements for its success, are:

- To understand the reasons behind the implementation of the MR technology in the school.
- To set out the goals to achieve, to define the success criteria, and to know how to measure them.
- To research the existing options, consider the current options that are available, and to seek for advice from technology suppliers.

- To plan the technology's implementation and to understand its requirements (technology and infrastructure-wise).
- To consider how teachers in general will manage and use the technology in the classroom.
- To understand how the MR technology will be used to supplement the teaching curriculum.
- To run pilot trials to test the technology and to receive feedback from teachers and students.
- And to ensure that sufficient tranining and support is provided to all parties (teachers and students).

2.3 CASE STUDY

The goal of using a case study in this research is to have a support reference to the investigation being conducted, based on previous models that already use the MR technology in the education system. Bearing in mind that each case has its own particularities, it is still useful to take other researchers' investigation as the basis of our work, because we can avoid committing the same mistakes during our own investigation.

To better understand the potential of this technology, we present the "Case Western Reserve University and Cleveland Clinic" in the USA, considering it is a pioneer study on the use of MR technology in education systems, especially in the anatomy curriculum.

According to Workman (2018), this initiative uses the MR technology to avoid using cadavers within the institution. Therefore, this University did an exhaustive investigation in order to find a technology that could fulfill this goal, finding the Microsoft HoloLens. Afterwards, and with the assistance of Professor Mark Griswold, the University created an institution that was called Interactive Commons (IC), basically being responsible for the creation of the app HoloAnatomy, starting with all the necessary tests for a full anatomy curriculum (Figure 6).

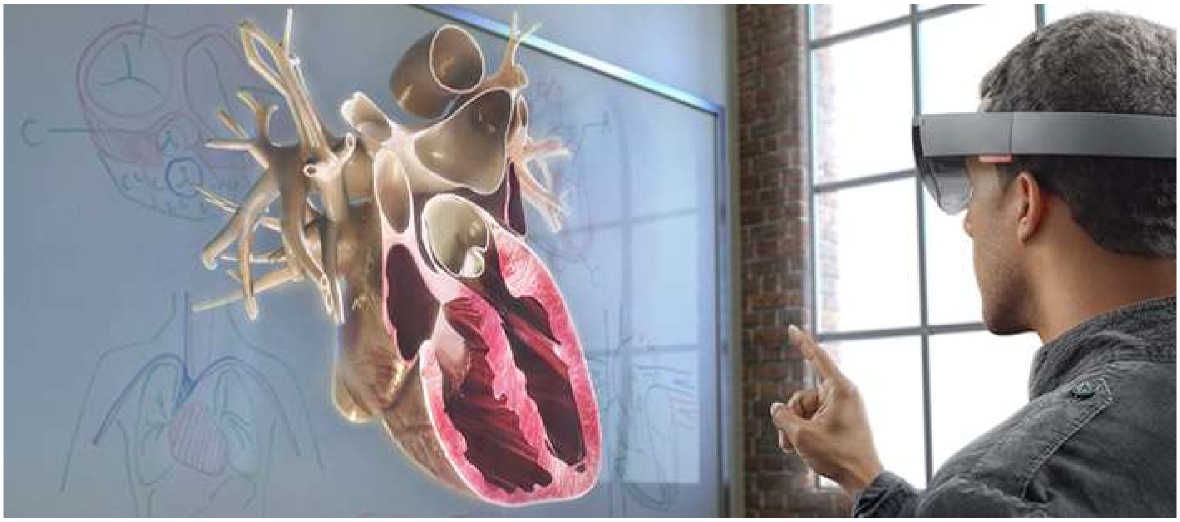

Figure 6, HoloLens being used for anatomy curriculum

Microsoft provided the University with access to the developers' kit, as well as to the training materials, to devices with the Microsoft Windows 10 (software), and to an ubiquitous platform to apply the graphics. Furthermore, the University also used the Microsoft Azure Cloud to host and storage their developments. The normal wireless environment on campus was also beneficial, thus supporting the content delivery. Ultimately, the investment made by the University was minimal, especially after the access to HoloLens.

In general, students are able to explore the specificities of the human anatomy through a more dynamic journey of the body itself. As it is mentioned by Workman (2018), the results are extremely positive, demonstrating that students learn better and faster when compared to the use of cadavers in the lab. Even though lab lessons are important for the anatomy curriculum, lessons that use the MR technology can be quite productive and effective as well.

In a more recent study, Wish-Baratz et al. (2020) assessed the initial experience of an anatomy lesson delivered remotely by using teleconferencing and MR technology, more precisely a modification of the HoloAnatomy Software Suite developed by the CWRU, during the COVID-19 pandemic, which placed restrictions in terms of presential class assistances. Based on the answers provided by the 185 students that participated in the survey, Wish-Baratz et al. (2020) obtained the following assessment outcomes:

- Only 16% reported to have experienced technical issues that they did not have in in-person classes.
- 81% claimed that remote anatomy sessions were equivalent or better than in-person class.
- 58% preferred remote sessions to in-person classes.

- 84% affirmed that students can effectively learn human anatomy by using remote MR technologies/applications.
- 81% reported seeing advantages of remote sessions compared with in-person sessions.
- Most frequent advantages of remote sessions are the ability to study on their own time (51%) and having more physical space to move around the anatomical models (24%).
- The most common disadvantage mentioned by students was the difficulty of interacting with the teacher and with other students (to ask questions) (24%).

Even though past studies demonstrated that students can achieve the same level of knowledge in half the time by using MR technologies, both in medical and nonmedical contexts of education (Barsom, Graafland & Schijven, 2016; Henderson & Feiner, 2011; Stojanovska et al., 2020; Wish-Baratz et al., 2019), the study conducted by Wish-Baratz et al. (2020) was the first one to demonstrate positive learning experiences for an entire class of medical students by using MR technology remotely, thus its pertinence to the present investigation.

Overall, the case study under discussion provides insightful feedback to our own investigation, since CWRU did create a MR technology (the HoloAnatomy software) that facilitates students' learning process, either in terms of better quality or of wider access to the course's resources and contents. Essentially, the goal of this study is to propose a MR technology/application that can be applied to STEM education, integrating important contents in order to provide a better-quality education system and a more effective study tool for students in general.

3. METHODOLOGY

3.1 Design Science Research (DSR)

The present research was conducted based on the Design Science Research (DSR) methodology for the information system, considering that this method's main intention is to deliver new artifacts and/or a new theory to improve the existing knowledge of one specific area (Baskerville et al., 2018; Kuechler & Petter, 2012).

Moreover, and as it is pointed out by Gregor and Hevner (2013), the DSR is a method that is also used to address unsolved issues in more imaginative and innovative manners and with more effective ways, which is what drives the present study, considering that it aims to implement the existing technology to improve the current education system in Portugal, namely by adding a digital system (the MR technology).

With this information in mind, while simultaneously considering the research's objectives, it is important to specify the six main activities of the DSR methodology, which were followed in this study. Figure 7 presents a graphical representation of these activities, being immediately followed by a brief individual explanation of each one.

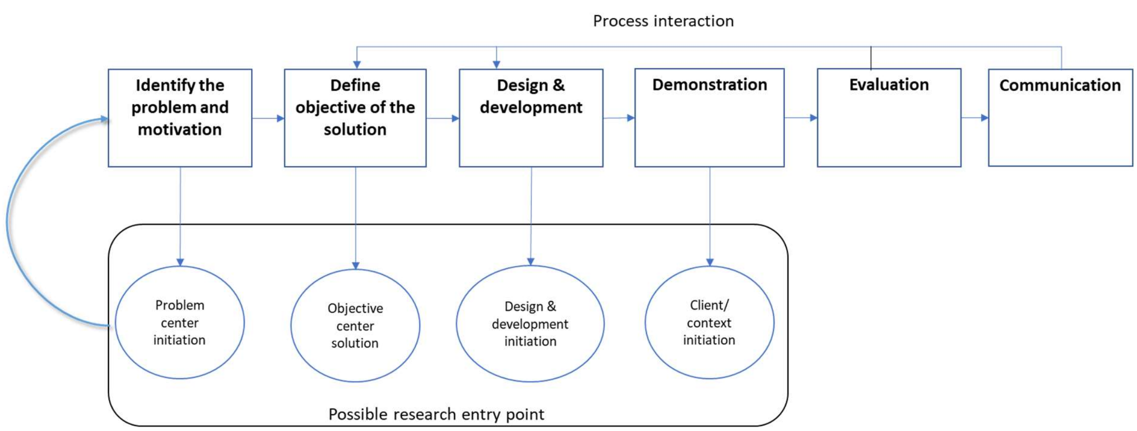

Figure 7, The DSR Methodology – adapted from (Peffers et al., 2007).

Activity 1 - Identify the problem and motivation:

The first step is related to the identification of the research problem and the motivation to justify the value of the solution. The problem must be well defined for an effective implementation of the artifact and to solve the problem itself (Peffers et al., 2007).

In the present study, the problem was identified as referring to the urgency in innovating the information system in general, but specifically the information system in education, mainly due to the current necessity of implementing more effective technology in order to be more competitive worldwide. Moreover, there is also the need to better prepare students for the future, which includes the acquisition and further development of digital skills, considered as fundamental in the 21st century.

In turn, regarding the motivation towards finding a valuable solution, in this case the implementation of a MR technology in the Portuguese education system, it is associated to the number of Portuguese students' dropouts, which is still significant in the present, as well as to the current inefficiency of the education system, either in terms of its results or related to its attractiveness towards' young students. Thus, the solution is motivated by the necessity to decrease Portuguese students' dropouts and to increase the education system's effectiveness, both in terms of results (students grades) and of innovativeness/attractiveness towards this specific population target.

Activity 2 - Define the objective of the solution:

The second step proceeds from the identification of the problem, considering that the aim is now to find a solution to solve it (Peffers et al., 2007). The solution must be feasible and achievable, as it was previously defined in section 1.3, since the goal of this thesis is to recommend a framework to use the MR technology in the Portuguese education system, more precisely to teach STEM subjects, and to develop the main guidelines for its implementation.

Activity 3 - Design and develop:

The third step assumes that all the necessary requisites regarding the problem are met, proceeding to the creation of the artifact (Peffers et al., 2007). In this study, one adds the existent information about the artifact (the MR technology) that is being recommended to solve the identified problem.

Throughout the literature review one acknowledges that the MR technology is still in its early ages, despite being very promising in the education system. Currently, this technology is more commonly implemented in large organizations, aiming to quickly train new employees to develop their professional roles.

Furthermore, the literature review also highlights the high production costs of HDMs, mainly due to the specific hardware and software that is needed (high quality display, tracking technology, high quality cameras, etc.). Thus, it is quite expensive for individuals or developers to use or create more applications that use the MR technology.

Hence, it is important to acknowledge that the implementation of this technology may bring additional costs when creating devices or applications that aim to fit the educational curriculum.

Activity 4 – Demonstration:

According to Gregor and Hevner (2013), the contribution of the designed and developed artifact can be demonstrated by thinking, confirming the idea, showing evidence of the added worth, or by verifying the acknowledgement and use of it.

Thus, for the demonstration of the feasibility of the implemented artifact one refers to the case study that is presented in this investigation, which proves that the MR technology was well and successfully implemented in the CWRU in the USA, in joint conjunction with Microsoft (Microsoft HoloLens), with the development of an application that allows the study of the human anatomy, reporting very satisfactory results.

Activity 5 – Evaluation:

The fifth step refers to the evaluation, which implies a real implementation of the developed artifact and some time for its use, with the aim of comparing the results both from before and after the artifact's implementation/adoption.

Hence, the goal is to confirm if the artifact did improve or solved the identified problem, based on a clear evaluation method, such as surveys or client feedback, to fully validate the contribution of the implemented artifact (Peffers et al., 2007).

Activity 6 – Communication:

Lastly, the sixth and final step is related to the communication of the obtained results after the implementation of the artifact, or even to the correction of the developed artifact if it didn't fully align with the problem, eventually proposing a newer and more valid solution to tackle the problem (Peffers et al., 2007).

The present study's goal also comprehends its own publication at the Nova IMS University, as a part of the dissertation program to obtain a master's degree in information management, and to provide a significant and valid contribution to future research and knowledge.

3.2 Research Strategy

In this section one need to explain step-by-step the action performed on findings of the literature review, by giving direction that others may replicate this work(Walia & Chetty, 2020).
For this paper one used an empirical research strategy, where one uses the key words, research questions and snowball techniques in different database, to find papers with more significance (more cited) this research, namely the Mixed Reality in Portuguese Education.

In this section one will be explaining, step-by-step, the performed actions based on the findings resulting from the literature review, especially by providing guidance for other researchers to replicate this work in the future (Walia & Chetty, 2020).

In this study, an empirical research strategy was implemented, namely by using keywords, research questions and snowball techniques in different databases, aiming to find papers with more significance (most cited ones within the existing literature) to this research and focusing on the MR technology use in the Portuguese education system.

The search process to obtain such papers was based on the use of multiple academic databases, with some of them being more used than others, namely: *Nova Discovery, Scopus, Google Scholar, Springer Link*, and *Google*. The keywords that were mostly used and combined in these databases were: "*Augmented Reality*", "*Virtual Reality*", "*Mixed Reality*", "*Education system*", and "*Portugal*".

Even though these keywords helped to find some important papers, another strategy was needed, referring to the use of Boolean operators for the search engine "AND" to limit some results and "OR" to obtain more options. No time limit was defined to the search, meaning that all papers were valid to the study, which also helps to establish a sense of evolution and modification throughout the years, especially when it comes to the use and implementation of technology in education systems in general.

Finally, the other research method that helped to find even more papers was the snowball technique, which consists in a method that identifies potential subjects from the papers' bibliography. This research method is also frequently designated as snowball sampling, as pointed out by Walia and Chetty (2020).

Still, this sampling technique is quite convenient because it allows researchers to recruit more participants or to find other sources of information, which increases the study's value and pertinence. However, this method of recruitment (either of participants or of other sources of information) is also criticized, especially due to its selection bias and lack of representativeness, generalizability, and external validity.

4. A FRAMEWORK FOR THE USE OF MR TECHNOLOGY TO TEACH STEM (SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS)

4.1 ASSUMPTIONS

This proposal for the development of a MR technology to teach STEM and to be implemented in the Portuguese education system is based on the conducted literature review, more precisely on the studies developed by Iqbal et al. (2022) and by the CWRU and Cleveland Clinic in the USA.

The study developed by Iqbal et al. (2022) suggests several types of AR technology that can be implemented for education purposes, being based on currently existing technologies and their added value for this educational purpose. In STEM education, Iqbal et al. (2022) mention several types of AR technology, being used to teach the following subjects:

- Chemistry (ARChemist; Augmented Chemistry).
- Science (SMALLab).
- Astronomy (AR to learn several relationships: Earth-Sun, Earth-Moon, Live Solar System).
- Anatomy (AR anatomy learning systems).
- Physics (Learning Physics through Play Project).
- Electronics (LightUp).
- Engineering (AR and IoT).
- Geometry/Mathematics (AR with Construct 3D and GeoAR).

In turn, the CWRU and Cleveland Clinic, in the USA, created a MR technology to teach anatomy in collaboration with Microsoft, namely by using Microsoft HoloLens. Such joint collaboration resulted in the creation of the app HoloAnatomy, which essentially allows students to explore the specificities of the human anatomy through a more dynamic journey of the body. Workman (2018) has highlighted the positive results of this app, with students learning better and faster with this MR technology when compared to the use of cadavers in the lab. Similarly, Wish-Baratz et al. (2020) proved that the HoloAnatomy app is very effective and successful to teach students, who reported very positive outcomes after some remote lessons based on the use of this app. Overall, HoloAnatomy facilitates the students' learning process, with better quality and wider access to the course's resources and contents.

4.2 Proposal

Therefore, and based on both of these studies, more precisely on their suggestions technology-wise and on their proven opportunities/benefits, the proposed MR technology to teach STEM in the Portuguese education system must integrate contents pertaining to all the subjects (Science, Technology, Engineering, and Math), which were defined to be following ones: 1) Human body organs; 2) Electronic circuits; 3) Industry production chain; and 4) Trigonometry, respectively (Table 9).

Table 9 - Proposition of the subjects and pertaining contents to be integrated into the MR technology

Subject/*Content*	**Science**	**Technology**	**Engineering**	**Math**
Human body organs	a)			
Trigonometry				b)
Industry production chain			c)	
Electronic circuits		d)		

With regard to the actual MR technology to be applied for each content/subject, it is possible to try to firstly assess if there is already a program or app that is based on these contents, either using it or modifying it to better serve our proposed learning purposes. Based on Iqbal et al. (2022), there are several technologies that can be adapted to MR in order to facilitate STEM learning process, comprising different characteristics and goals to better represent the content being taught to students.

It is important to mention that every technology that is referred by Iqbal et al. (2022) can be useful to every subject, considering that there are many possibilities of integrating the subject's contents in MR technologies. The purpose of mentioning these technologies is to provide some insight about the possibilities to teach STEM among high school students by using these modern applications and technologies that combine the real and the virtual worlds. Table 10 summarizes such technologies accordingly to their perceived purposes and benefits.

Table 10 - Technologies to be adapted to MR to teach STEM (Iqbal et al., 2022)

Technologies/Applications	Learning purpose
ARChemist and CHEMOTION	Provides a virtual interaction by using hand-tracking technology
AR to learn Astronomy	Interactive simulation, increasing students' positive attitudes and learning gain
ProteinScanAR and AR anatomy learning systems	Introduces an innovative, hands-on study of the human musculoskeletal system
Leapmotion for 3D body anatomy learning	Allows hand tracking for interacting with 3D models
Tangible User Interface (TUI) called Augmented Chemistry (AC)	Allows the interaction with the 3D models in the lab
SMALLab	Helps students to learn in a design experiment
Learning Physics through Play Protect (LPP)	Helps to learn concepts of physics about motion and force
LightUp	Helps to learn concepts of electronics, such as circuit boards, magnets, and plastic sheets
Mobile AR technology and pedagogical inquiry activities	Useful to teach Nuclear Power Plant activities with more productive digital visualization
ElectARmanual and AR-based flipped learning system	Useful to learn electronic concepts and leading to better learning outcomes by using the AR guiding mechanism
AR and Internet of Things	Creates productivity in Engineering education with different scenarios
Construct 3D and GeoAR	Supports learning the geometry

Another possibility in terms of using existing MR technologies and applications is associated with the collaboration with ClassVR (Devon & ClassVR, 2021). In fact, this company currently collaborates with several schools around the world, providing them with a VR and AR solution that includes the provision of a MR set, comprising hardware (ClassVR Headsets), software (ClassVR Teacher Portal), content (curriculum-aligned VR & AR Resources), storage, charging, and product training (Devon & ClassVR, 2021). Table 11 further details each component of the MR set provided by the ClassVR, as well as the included services and contents.

Table 11 – Components of the MR set provided by ClassVR (Devon & ClassVR, 2021)

Component of the ClassVR	Services and contents
Hardware – ClassVR Headsets	Provides a safe and secure way for students to explore VR and AR in the classroom, with the teacher controlling each device. The headsets are simple to use and were designed for students of all ages
Software – ClassVR Teacher Portal	Ensures that teachers can confidently manage students and add value to lessons when using VR and AR. They can search and build VR playlists, deliver lessons simultaneously, and guide students through experiences using set dynamic points of interest. Teachers are always in control during the real-time class
Content – Curriculum-aligned VR and AR resources	The ClassVR Portal contains thousands of pedagogically sound, curriculum-aligned VR and AR resources, including content, downloadable lesson plans, guides, and worksheets to boost student engagement in every lesson. Teachers can upload their own content, access the community of educational resources shared by existing ClassVR users and other parties (content providers)
ClassVR storage and charging	ClassVR headsets come in a custom design case with a foam interior and strong ABS shell to keep the headsets safe. The cases are compact and light, being easily transported between classrooms. Also, the storage cases include a built-in charging facility, where headsets charge even when the case is closed, being ready to be used at any time
ClassVR product training	Online CPD course for teachers to learn to use ClassVR in the classroom, consisting of comprehensive bite-sized lectures and quizzes to learn how to conveniently use ClassVR. Educational specialists are on-hand to provide training on how to use ClassVR successfully in the classroom

On the other hand, and if eventually no MR technologies are found based on the proposed contents/subjects, we possibly can develop an app or program by using the Microsoft HoloLens (similarly to what was done by the CWRU and the Cleveland Clinic in the USA).

Nevertheless, this second path does require a larger investment, of time and especially financial resources, considering that this latter path means to create an app or program from scratch. Furthermore, it means that technological knowledge is a must in this process, related to the process of creation of a MR technology to tackle each content and subject, as well as some devices (such as HMDs, controllers, or smartphones, depending on the app's format and compatibility), which inevitably increases the investment financially wise.

However, it is possible that even though there may not exist MR technology that already implements these contents/subjects, some of them might actually be easily modified, in the sense of transforming the current form and content to fulfill our learning requisites. Therefore, and if this the actual case, one might easily develop a MR technology to be implemented in the Portuguese education system to teach STEM subjects, especially among high school students.

4.3 Use Case

Based on the information presented on previous the previous sections of this chapter, the main goal is to implement the MR technology in the classroom of high school students in Portugal. Considering the steps mentioned and followed by Iqbal et al. (2022) and by the CWRU and Cleveland Clinic in the USA, the implementation of this innovative MR technology will imply the collaboration with other organizations/companies, in the sense of adapting the technology to the STEM learning purpose. Even though such collaboration might diverge from the one presented by the CWRU and Cleveland Clinic in the USA, being associated with the Microsoft HoloLens, it is expected to be beneficial for both parties, as well as cost-effective.

The goal is to adapt existing MR application to teach STEM content, namely related to human body organs, electronic circuits, industry production chain, and trigonometry, using simple and cheap hardware and software, given the significant number of devices that are going to be needed within the classroom. The MR technology will either be applied on computers or smartphones/tablets, accordingly to the school's own material resources, with the collaborating organization providing the extra hardware and software (such as headsets, for instance).

Given the novelty of such innovation, the MR technology must be firstly implemented in a small number of high schools, consisting of a case study itself. The focus of this study is to propose the implementation of a MR technology in a few classrooms, aiming to fully assess every step of the implementation process, as well as the obtained outcomes, which include several different aspects, namely: the existence of sufficient material resources (technology-wise), the teachers' knowledge about the use of the MR technology, the students' acceptance of this innovation as a teaching material, and students' grades by learning with a new teaching method.

Therefore, it is suggested that the MR technology must be implemented in 2 or 3 classes of high school students, having the corresponding classes as the control group. The MR technology must be implemented in each STEM subject in different classes, in order to obtain a more homogeneous sample. Thus, among those 2 or 3 classes different STEM subjects must comprise traditional learning methods, while some should include, on a normal basis, the use of the MR technology. Throughout a semester, all students must be assessed (the students learning with MR and the students learning with traditional methods). The goal is to ultimately estimate the difference between the grades and the motivation of both groups of students, in order to verify if the use of MR technology in the classroom helped students to be more focused and motivated to learn, with a direct impact on their grades.

4.4 Evaluation

Lastly, the implementation of the MR technology must be evaluated in different ways. Firstly, it is important to assess if the proposed technology did solve the identified problem. In this specific case, if the MR technology did solve the urgency in innovating the information system in general, but more precisely in the Portuguese education system, if it did decrease the number of Portuguese students' dropouts, and if it did increase students' grades.

Secondly, it is also important to analyze the teachers' perspective about the implementation of this technology, especially in terms of its effectiveness, easiness of use, and convenience as a teaching method. Thirdly, the cost-benefit analysis must be conducted within the high school, in the sense of establishing if the implementation of such technology was cost-effective and profitable for the institution, or if, in turn, it was a very expensive innovation, affecting the management of the other resources (human and material).

In order to effectively evaluate the implementation of the MR technology within the classroom it is pertinent to question both the teachers and the students, considering that they are the ones who used this technology throughout the semester. Therefore, a questionnaire must be implemented among this specific population, asking their opinion about this newer learning method, its effectiveness in educating students, and its easiness of use. The goal is to gather information from the technology's main users, in order to understand if this innovation can work in the Portuguese education system.

Moreover, it is important to compare the students' grades and levels of motivation before and after the implementation of the MR technology, aiming to verify the contribution of this innovation in terms of increasing their grades and of decreasing the number of dropouts in the Portuguese education system. In fact, it is precisely by comparing this data that we can truly evaluate the MR technology's efficiency and effectiveness, rather than just focusing on the perception and opinion provided by teachers and students.

After assessing the technology's implementation, namely the obtained outcomes in terms of students' grades and dropouts, the results must be communicated, either to provide further insights for future developments and implementation of more MR technologies or to correct the implemented technology, with the goal of improving it in order to implement its reformulation in the future. The important aspect is definitely to tackle the problem, solving some of the everlasting problems in the Portuguese education system.

5. CONCLUSIONS

5.1 SYNTHESIS OF THE DEVELOPED WORK

The main goal of the present study was to propose the use of MR in the Portuguese education system, more precisely to teach STEM subjects to high school students, given its proven benefits to both teachers and students' performances. In fact, based on a specific case study, directly related to the creation of the HoloAnatomy app by the CWRU and the Cleveland Clinic, in the USA, as well as on this technology's successful learning outcomes, we presented our own suggestion of MR technology to implement in the education system, comprising the four subjects of STEM and some of the corresponding contents, based on a very similar development framework and guidelines.

The conducted literature review defines the concept of MR and MR technology, distinguishing it from AR and VR and establishing that it comprises a mixture of both. It also presents the main technologies that are associated with MR, the MR steps, the MR characteristics based on the notion of algorithm, and ultimately the main challenges in terms of its development and implementation. Overall, it is quite evident that this innovative technology is still in its infancy, with very few applications and technologies being used worldwide due to its cost. In fact, it has been demonstrated that both the technology itself and the corresponding hardware are very expensive, with few people being able to access and owning them.

The role of education in the world is highlighted as being extremely important, referring to the formation and development of society. However, the education system needs to evolve from its past framework, being innovative and including new skills and competencies, considered as vital in the 21st century. Specifically in Portugal, students' grades are above the average in the areas that are carried out by PISA. However, the rate of school dropouts among high school students presents some major problems, in addition to the lack of digital skills. In accordance with the new generation of EU policies since 2020, this scenario needs to change, namely by innovating and strengthening the Portuguese higher education area.

STEM is very important in this scenario, with its relevance being associated with the need for individuals to acquire and develop competencies and skills that will make them able to produce and solve problems. In fact, STEM education focus on several literacy skills, all of which are important to people's development and to promote innovation, growth, and competitiveness in the global economy. Moreover, the use of technology in education has been widely discussed, with several studies stressing a broad scope of opportunities and challenges within the classroom. However, it has been noted that technology as a method for teaching and learning is extremely beneficial, given the fact that it develops those 21st century literary skills and competencies.

The analyzed case study, which focus on the implementation of the HoloAnatomy Software Suite, developed by the CWRU, precisely demonstrates the importance and relevance of introducing technology in the classroom, with major benefits for both the teachers and the students, with significant increases in terms of grades and performance. This is precisely the basis for the development of our own MR technology, with the goal of teaching STEM subjects to high school students.

The proposed MR technology to be implemented in the Portuguese education system to teach STEM must integrate contents pertaining to all the subjects, namely: human body organs, electronic circuits, industry production chain, and trigonometry. Based on the previously analyzed case study, as well as on the study conducted by Iqbal et al. (2022), there are several AR technologies that can be adapted to MR in order to teach those contents/subjects. Thus, that is precisely one of the routes to develop the aimed MR technology. Still, it is also possible for schools to look for collaborative work with other organizations, namely those who have MR technologies, potentially providing some software and hardware to assess the pertinence of such implementation within the classroom. Finally, another solution to implement MR technology within the classroom is to create an application or technology from scratch. Nonetheless, this option is extremely costly and requires a significant number of resources (both human and material) to develop a technology/application.

The MR technology must be implemented in 2 or 3 classes of high school students, with the corresponding classes as the control group. The goal is to implement the technology to teach STEM subjects for a period of six months. Afterwards, the classes that had access to this technology must be compared with the ones that did not, establishing the main opportunities and challenges regarding the implemented MR technology. The purpose is to assess if the students' grades increased and if the number of school dropouts decreased, as well as the perceived effectiveness of this innovative teaching method by teachers and students.

5.2 Study Limitations

Some of the main limitations of this study are related to the lack of research about the implementation of MR technology within the classroom since this is still a very recent artifact within the education system. Hence, this study is considered to be among the first case studies to assess and implement such innovative educational methodology. Moreover, the fact that it comprises a pilot intervention in the Portuguese education system also limits the investigation, considering that there are no past interventions to follow, meaning that there is no comparison with previous studies or experiences. It's also relevant to add that in evaluation phase we could not add interviews because of the lack of experience/knowledge on this technology from the contacted teachers.

Finally, another limitation refers to the fact that it solely focusses on high school students, which does not allow for future generalization of the results nor the applicability to students of all ages.

5.3 Future Work

Based on the characteristics and limitations of the present study, future work should be conducted to develop more MR technologies to be implemented for educational purposes. It would be beneficial if future research developed more MR technologies for students of all ages, implementing this powerful teaching and learning method from early ages in order to fully understand their impact on the development of students as individuals, acquiring and developing the 21st century skills and competencies. Furthermore, future work should focus on developing beneficial and more easily accessible MR technology to be implemented in the education system, promoting equality and integration of every single student, and providing each one of them with the right skills to grow and evolve, ultimately impacting the economic growth.

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