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Using Mixed Reality in the Educational Practice: An Inquiry-Based Process of the Fluid Expansion–Contraction Phenomena by Pre-Service Teachers

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Abstract: Students often find it difficult to understand phenomena of everyday life that occur in the natural world, such as the phenomenon of expansion and contraction of liquids, in which there are many misinterpretations. To address this difficulty, this paper suggests another perspective on the didactic approach based on Mixed Reality, the attunement of the two worlds, the virtual and the real, and examines its effectiveness in teaching the phenomenon of fluid expansion. The main pillar of the educational process is teachers and the practices they use in the teaching process. For this reason, the sample of this survey consisted of 54 University students and prospective elementary education teachers. The mixed research approach was followed to collect the data. Through a Mixed Reality environment, using HoloLens 2, students followed a well-structured scenario and worksheets and observations to investigate the phenomenon of expansion/contraction of different fluids. The results demonstrate that through the interaction and direct feedback of the Mixed Reality environment, students gained a deeper understanding of the phenomenon. At the same time, the device was characterized as a particularly useful educational tool that should be accessible to all students for a better familiarization with complex scientific data.

Keywords: Mixed Reality; prospective teachers; thermal expansion; thermal contraction; microcosm

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1. Introduction

Man's perpetual attempt to understand the natural phenomena observed in daily life has created multiple alternative ideas due to a lack of knowledge and scientific background [1,2]. In fact, some of them are very strong; they do not change easily, and trying to address them is a difficult task [3].

The attempt to understand and deal with these alternative ideas of natural sciences over time was initially made with the help of real experiments and then, with the development of technology, with virtual experiments [4]. To this end, the integration of technology in science teaching, combined with innovative teaching methods and the latest trends, is causing a fundamental transformation in learning. This transformation aims to enhance active student participation, develop critical thinking skills and improve access to educational resources [5].

Over the years, Physics Education Research (PER) has highlighted both benefits and challenges arising from different experimental settings and the way these contribute to the improvement of teaching, the understanding and the assimilation of physics concepts under each study [6–9]. The importance of experimental science teaching in real environments and, in particular, experiments that use real and daily life materials and self-made devices, which form the basis of experimental methodology, as well as the efficiency of contemporary virtual environments in learning science concepts, have been pointed out by researchers [10–12]. At the same time, the integration of technologies, such as sensors, data recording systems, processing and visualization of software in real laboratories, has contributed significantly to the enhancement of physics learning, allowing the development of new skills and improving the interpretation and understanding of data [13–15].

The controversy between real-world environments, used for the best learning outcomes in science teaching, did not reveal a winner but highlighted the tendency of both experimental environments to coexist, with researchers exploiting and making use of each environment's advantages and minimizing the disadvantages [16,17]. In addition, research has revealed that the creation of virtual environments that simulate, as closely as possible, the real conditions of conducting experiments (Virtual Reality, Augmented Reality, Mixed Reality) can lead to better learning results [18,19]. Based on the above, the tendency of the co-existence and attunement of the two environments (virtual and real) in the experimental practice is significant for the users who focus on the exploitation of each environment's positive characteristics for teaching purposes and needs [20,21].

In this context, the use of Mixed Reality, where the real and virtual worlds coexist and interact, is a challenge in the educational process, aiming to emphasize and reinforce the contemporary 4Cs learning skills (critical thinking, creativity, collaboration and communication) [22] that allow learners to adapt to the modern world and innovative ideas to emerge. The main problem posed in this research is the utilization of Mixed Reality technology in the educational process in a context that is familiar and innovative in the teaching of science concepts. Is there an improvement in the learning outcomes of a teaching intervention using MR technology?

2. Theoretical Framework

2.1. The Four Realities

Extended reality (XR) is an "umbrella" term that includes the combination of all virtual and real environments, where the term "X" changes depending on the technology we are referring to [23] (Figure 1).

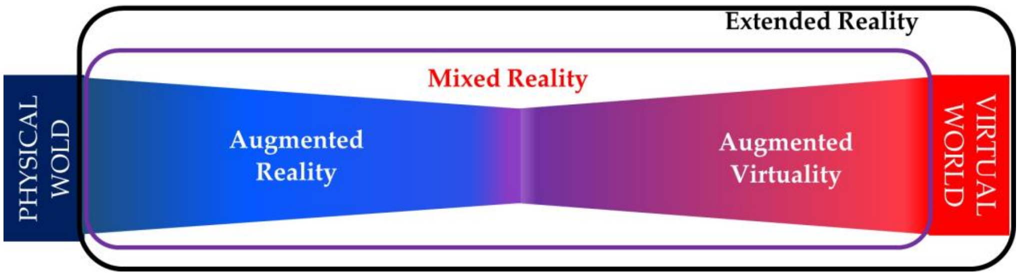


Figure 1. Immersive technology environments spectrum.

The term "extended" reality is often misleading (in Virtual Reality, the reality is not extended but rather replaced), so it is more appropriate if we consider that X—in XR—represents a variable X as in algebra for any form of new reality [24].

Virtual Reality is based on a fully immersive technology where the user interacts with objects that often simulate the real thing, but this happens in a virtual digital environment, completely created by a computer, without having direct contact with the physical environment in which it is found [25,26]. Virtual Reality (VR) is the use of computer technology to create a simulated environment, or it is the term used to describe a three-dimensional computer-generated environment that can be explored and interacted with by someone [14,27].

Augmented Reality (AR) is based on the superimposition of virtual digital objects such as, for example, images, videos, and sounds of objects of the real world, creating a reality where the virtual objects seem to coexist in the same space with the real world [28,29]. The augmented information it provides leads the user to a more interactive individual learning environment through a combination of virtual and real objects [30]. Augmented virtuality (AV) is a term that refers to environments where the largest part is virtual but includes real objects or real-world data. This is achieved through the use of sensors, cameras and other technologies that enable the input of real elements into a virtual environment. The features of augmented virtuality are the virtual environment, where most of the experience is digitally created; the incorporation of real-world data such as objects, people or data that are incorporated into the virtual environment; and interactivity, where users can interact with both virtual and the actual elements within the environment. There are many applications of augmented virtuality, among which, in education, it is used in simulations and tutorials with learners interacting with real tools or objects within virtual scenarios [31].

Mixed Reality (MR), often referred to as hybrid reality, integrates the virtual world into the physical world to incorporate new information, such as new environments or visualizations. MR, which combines AR and VR, allows users to tangibly interact with virtual objects in the physical environment [32,33] in contrast to AR's ability to place a virtual or digital object in the real world [33]. In Mixed Reality, virtual objects are fully integrated and blended into the user's physical environment (e.g., digital holograms can hide behind real objects or even collide with them), while the user is not only able to visualize the virtual object within an MR environment but can also haptically manipulate it. This ability to interact with virtual/digital overlays on the physical environment distinguishes AR from MR and addresses the limitations of Virtual Reality (VR) and Augmented Reality (AR) by allowing the creation of a more advanced virtual world [25,34,35].

2.2. Metaverse

In its original form, the metaverse was conceived as a network of virtual worlds where users communicate and interact with one another through avatars, traveling effortlessly between these worlds [36]. The development of immersive technologies has resulted in the introduction of a new version of the metaverse into the modern technological landscape. The second version of the metaverse refers to Mixed Reality, a constantly developing social platform of immersive technology where users will be able to interact with each other as 3D holograms or avatars in physical or virtual spaces without limitations [37,38]. Metaverse is defined as a "3D virtual environment where augmented and Virtual Reality technologies enable all activities" [39]. Metaverse can frame the connectivity of social media with the unique capabilities of immersive AR and VR technologies within the context of MR [40] (Figure 2).

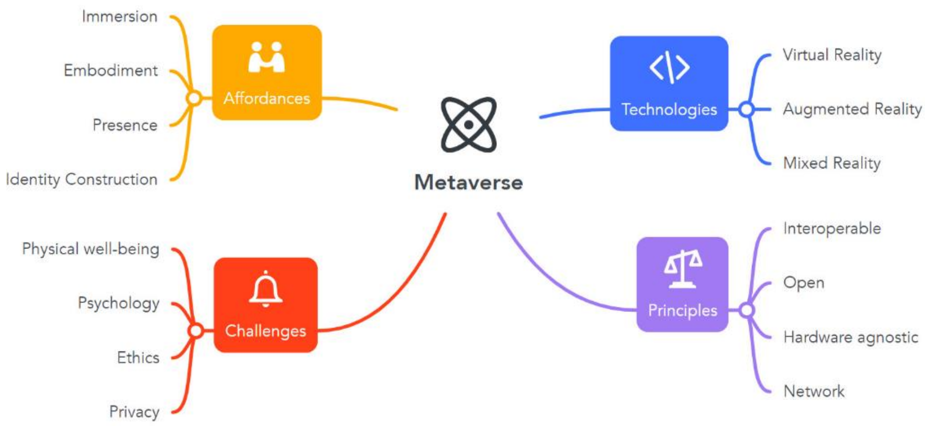


Figure 2. Metaverse technologies, principles, affordances and challenges [39].

2.3. Internet of Things

The term "Internet of Things" (IoT) refers to a network of interconnected services, devices and users. The Internet of Things enables computer-interfaced sensors to facilitate the development of new products and services by reducing costs and improving the performance of existing systems [40,41]. The Internet of Things (IoT) connects Internet-enabled devices in order to exchange data and information with each other and with the physical environment in which data and information reside regardless of their geographic location, thereby enabling intelligent interactions. Today, the Internet of Things (IoT) has expanded far beyond the original intentions of its programmers, and its emergence has brought about easy access to real-time data regardless of location or time of access [42,43].

3. Literature Review

3.1. MR in Education

MR was the topic of interest in research that studied the way in which students perceive the use of this technology in the teaching of chemistry and investigated the challenges learners report when using it [44]. The research involved two groups of organic chemistry students, a total of 19 people, who had the opportunity to "see" a holographic 3D structure of a molecule using MR glasses (e.g., Microsoft HoloLens 1). Learners described the experience as "exciting" and stated that the amount of information from the 3D object was greater than its 2D counterpart. The challenges of the teaching intervention were mainly the rather narrow field of view of the MR glasses and the somewhat familiarity that was required for the use of the device.

Another research introduced a gamified Mixed Reality environment, which was adapted to create educational Escape Rooms [45]. The researchers discussed the positive attitude of high school students regarding the use of Educational Mixed Reality Escape Games in the classroom for the repetition and the embedding of their science courses' cognitive content. The usability of a Mixed Reality device (Hololens 2) addressed to elementary school children, using a standardized teaching scenario with multimodal interaction in MR, was also investigated [46]. Based on the findings, the students displayed a positive attitude towards the use of Mixed Reality in the teaching intervention. Elsewhere, the enhancement of vocational education students' interest regarding the cognitive object of their courses in a teaching intervention using the Serious Game Mixed Reality was recorded [47]. In addition to the aforementioned benefit, the pedagogical value of the visualization of the concepts taught in the classroom was also reported by the vocational education students' teachers.

Of particular interest is the study on the effectiveness of using HoloLens 2 smart "glasses" through an interactive Mixed Reality learning environment, which was investigated in a laboratory experiment that concerned the polarization of light [48]. The increase in learning outcomes after the intervention was significant and strengthened the researchers' original hypothesis about the effectiveness of the Mixed Reality environment. In similar research, six different concepts of physics were studied by students in an MR environment [49]. The findings pointed to the change in the participants' attitude towards science, and the development of positive learning outcomes was observed. Another study investigated the impact of Mixed Reality technology in the educational environment and the understanding of its role in enhancing student academic performance through innovative learning experiences and student satisfaction [50]. The findings of the research showed that the application of Mixed Reality, which allows experiential learning through interactivity, can significantly and directly strengthen students' attitudes towards learning and the learning environment, as well as indirectly enhance their academic performance.

The use of Immersive Interactive Mixed Reality (I^2MR) in Special Needs Education in Singapore was the topic of investigation [51]. The engaging environment of Mixed Reality was found to prevent students from getting distracted, leading to their engagement, increasing their interest and enhancing their social skills. At the same time, however, certain limitations were observed, such as the overstimulation of some students and the less effective application of I^2MR in some activities compared to other tools.

The opinion of pre-service special education teachers about Mixed Reality simulations was investigated in eight surveys [52]. The results revealed that the use of Mixed Reality simulations offers prospective teachers a safe, low-risk environment (especially for K-12 students), enabling them to implement a variety of teaching practices. However, according to the research, although the use of MR is a promising technological tool, its integration into courses requires careful planning to ensure meaningful practice. Additionally, successful implementation requires consideration of many logistic aspects, such as duration of the simulation, number of sessions, individual or group use of MR and mode of feedback.

In another research, 64 articles were reviewed in regard to the more general use of Mixed Reality in education during the years 2010–2021 [53]. The survey highlighted the ever-increasing trend of MR use per year, mainly in North American and European countries. The use of Mixed Reality in creating simulations helped the learners gain a broader understanding of difficult and abstract concepts through activities within the school classrooms. Nevertheless, some difficulties were reported during its practical application, which were largely related to the cost of MR devices, the stability of the internet connection and the ease of use and operation of these devices. These factors can play a decisive role in the wider spread of Mixed Reality applications in education.

In a recent literature review process, 40 papers were reviewed, and the initially ever-increasing trend of Mixed Reality applications in both the pre- and post-COVID-19 era was recorded [54]. The majority of the applications took place in K-12 education, while the smallest percentage of applications of MR was observed in vocational education. The special importance of the use of this technology in professional education is emphasized, which will lead to the further increase and cultivation of the abilities of its graduates. The research focused especially on experiential learning and creating and carrying out safe and complex experiments, resulting in improved learning outcomes and the cultivation of new skills. Nevertheless, the absence of a specific methodology during the application of Mixed Reality in the educational process was mentioned. Furthermore, the main reason for the difficulty was the development of appropriate content that would take advantage of the capabilities of the Mixed Reality device. The particular importance of MR in education is emphasized in the research due to the increased degree of interaction, individualized and collaborative learning, and improved access to educational resources. However, the research suggests that for the effective application of technology in teaching interventions to take place, school curricula, learning objectives and students' special characteristics must be considered.

The effectiveness of using Mixed Reality in Higher Education was examined by researchers who conducted a literature review [55]. The research sample consisted of students from various educational departments such as Engineering, Pharmacy, Social Sciences, etc. The research demonstrated that the disciplines that mostly adopted the educational application of this technology were Medical Sciences and Health Sciences, as well as the Scientific disciplines of STEM (Science, Technology, Engineering and Mathematics). The widespread use of head-mounted displays and, more specifically, Microsoft HoloLens was found to create immersive learning environments characterized by great interactivity while simultaneously promoting collaborative learning. The great possibility of modeling and the significant reduction in the time needed to understand concepts in certain subjects, such as anatomy, were highlighted. At the same time, emphasis was placed on the auxiliary use of MR in the teaching practice and the value of conventional educational material. The research claims that the use of new technologies such as MR leads to improved learning experiences, increases motivation for learner engagement, and improves student performance and learning outcomes.

3.2. Materials and Methods

The Research Framework

High school learners, as well as students of higher education, hold alternative ideas about the concepts of temperature, heat, thermal energy and thermal expansion, which do not concur with scientific data. Indicatively, students use a single non-material entity, heat, to explain various thermal phenomena [56]; they believe that the concepts of temperature and heat are identical [57,58] or that temperature can be transferred from one body to another [58,59]. They also believe that as the concept of heat exists, there is also the concept of coldness [60], that water always boils at 100 °C [61], and that the kinetic theory does not actually interpret thermal energy and heat transfer [62], or that during thermal expansion the molecules of the materials grow and at the same time they move away from one another [58]. However, thermal phenomena, and especially the phenomena related to the contraction or the expansion of materials due to temperature changes, are an inevitable part of students' daily lives [63,64]. After all, the phenomenon of thermal expansion is extremely important in the field of engineering during the construction of buildings and bridges and even in the design of more everyday objects such as thermometers and thermostats. Consequently, we could argue that the understanding of thermal expansion represents an important aspect of scientific literacy, and therefore, it is included in academic curricula.

The present research was conducted in the framework of two university science courses during the academic year 2023–2024 by the corresponding professor/researcher with the assistance of the other members of the research team. The authors/researchers used MR as a contemporary teaching tool for teaching the concepts of thermal expansion and contraction of liquids. The participant students used an appropriately structured scenario, worksheets, hands-on activities and a Mixed Reality environment to investigate the phenomenon of thermal expansion/contraction of liquids. A basic tool in the teaching intervention is the HoloLens device, an important element of which is its usability by the users.

3.3. Schematic Layout

3.3.1. The Hardware Used

Microsoft HoloLens

Microsoft® HoloLens is developed and manufactured by Microsoft (MS) (Redmond, WA, USA) and is a pair of Mixed Reality smart glasses capable of depicting an environment in which real and virtual elements appear to coexist [65]. Microsoft Corporation released HoloLens 2 (Figure 3) in November 2019, which was upgraded in terms of hardware and software compared to its predecessor regarding the field of view, weight and battery life [66]. It is used in a variety of applications, such as medical and surgical systems, medicine, education, architecture and various fields of engineering [67–70] (displaying many advantages over traditional teaching methods) [71,72].

(**a**) (**b**)

Figure 3. (**a**) Side view of Microsoft HoloLens 2, (**b**) Front view of Microsoft HoloLens 2.

BBC Micro:Bit

The Micro:Bit is a tiny, pocket-sized computer with 25 LEDs and two programmable buttons. Its circuit is powered by an external source (batteries or power bank), making it extremely portable, while it is possible to interface it with the programming platform using a mini-USB port cable [73]. This microcontroller was chosen due to advantages over other similar microcontrollers (Arduino, Raspberry Pi), such as its small size and easy portability, its low cost, the direct use of its built-in sensors for measurements, the possibility of simultaneous connection of external sensors and its interconnection through the BLE (Bluetooth Low Energy) standard with other devices for wireless data transfer [74,75].

TMP36 Temperature Sensor

The external sensor used in the research was the TMP36 analog sensor, which was chosen due to its high durability, wide temperature measurement range (−50–130 °C), low cost and easy connection to the Micro:Bit.

3.3.2. The Software Used

MIT AppInventor

MIT App Inventor is an online programming platform that can be used effectively as a tool to develop mobile device software and educational applications [76–78]. The MIT App Inventor user interface includes two main editors: the drawing editor and the block editor (Figure 4). To help with app development and testing, the App Inventor provides a mobile app called the App Inventor Companion (or simply "the Companion") that developers can use to test and customize the behavior of their applications in real time [79].

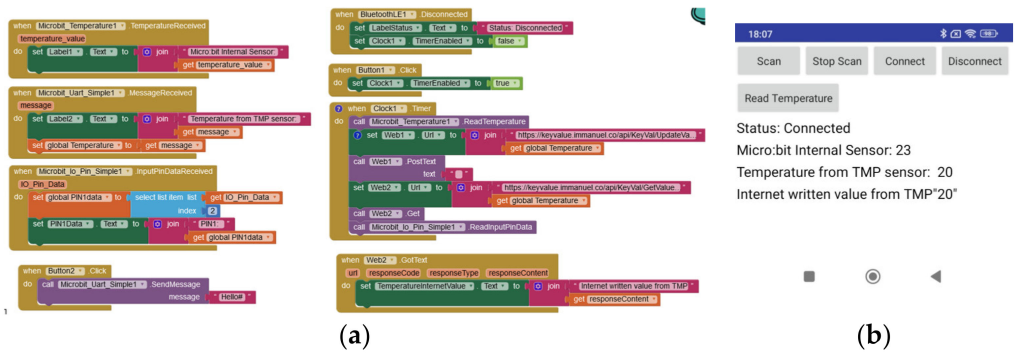


Figure 4. (**a**) Programming environment MIT AppInventor; (**b**) final application.

Unity 3D

Unity was developed under the umbrella of Unity-Technologies, which is a cross-platform game engine released in June 2005 at the Apple Inc World Congress as a dedicated game engine (Mac OS X). In 2018, it expanded and facilitated more than 20 platforms [80]. This game engine can be used to develop Augmented Reality, Virtual Reality and Mixed Reality applications along with simulations to promote gamified learning in education [81,82].

The main functions of Unity are as follows:

- Realistic rendering engine (rendering engine);
- Physical engine;
- Object behavior script execution engine (script engine);
- Light mapping.

Unity, combined with the Vuforia SDK, which is a software development kit from Qualcomm, allows developers, through real-time recognition of flat images or simple 3D objects, to place virtual objects and adjust the position of objects in the natural background in front of the lens [80,83]. Unity 2021.3.18f1 and Vuforia SDK 10.13.3 were used in this research.

3.4. Research Setup

The setup used for the research is shown in the Figure 5 below:

The purpose of the implementation was the interconnection of the real and the virtual world through IoT. The first part of the research includes the actual experimental setup, with the help of which the phenomenon of fluid expansion was studied through hands-on activities (Figure 6). The liquids used were water, alcohol and sunflower oil.

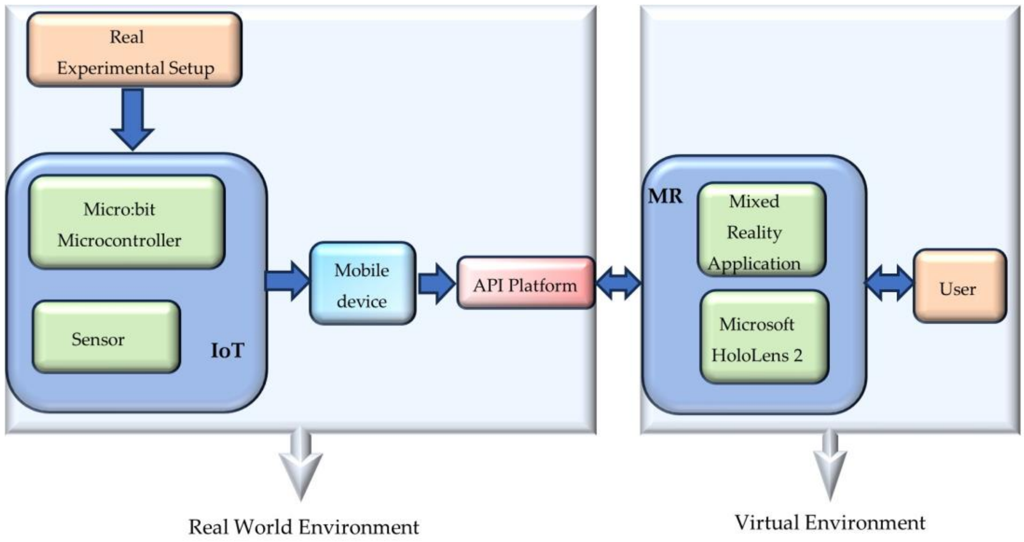


Figure 5. Research setup.

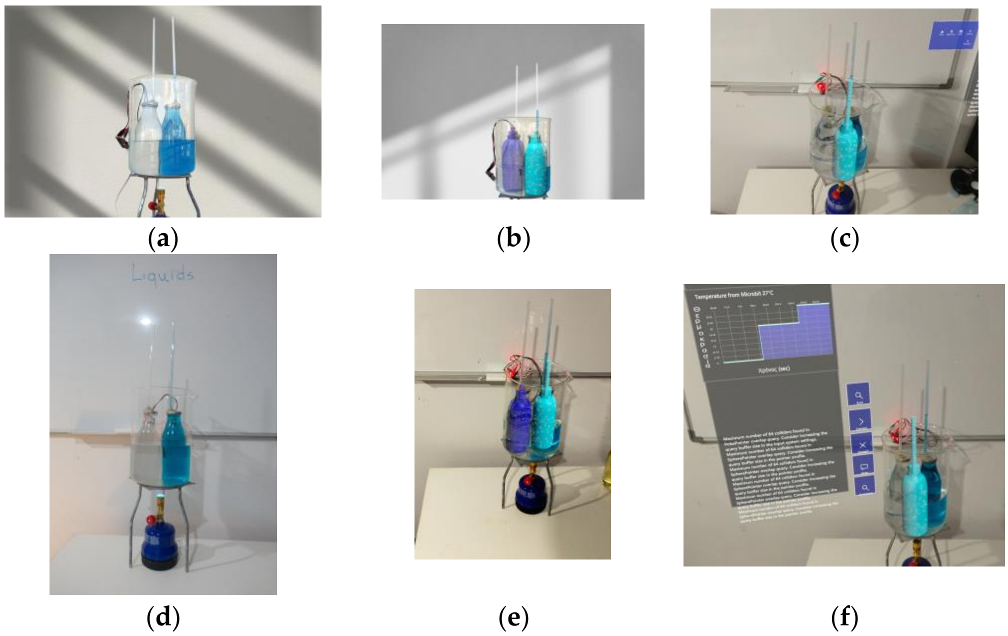
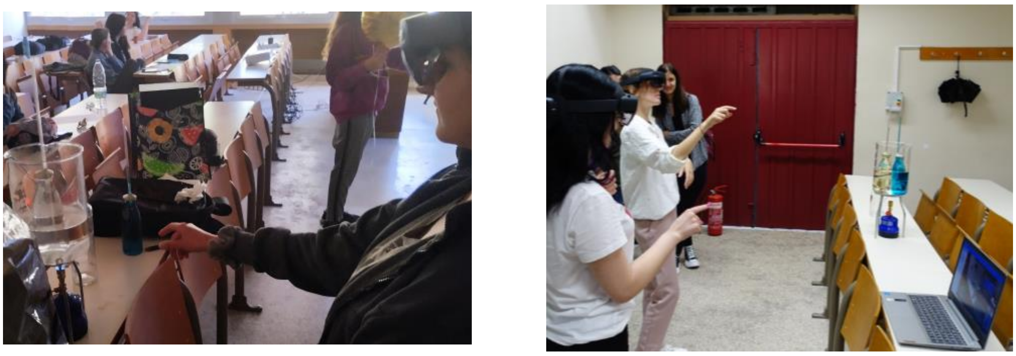


Figure 6. Research setup: (**a**,**d**) experimental setup with real objects; (**b**,**e**) real and virtual worlds mixed; (**c**,**f**) holograms and real objects separated.

The second part of the device is the Internet of Things (IoT), which includes a Micro:Bit microcontroller connected to a TMP36 temperature sensor. With the help of the MIT AppInventor online platform, a mobile application was developed aiming to exchange the temperature data with the Micro:Bit and record its value in the cloud through a simple API interface. For this purpose, the page https://keyvalue.immanuel.co/ (accessed on 10 April 2024) was used, and the temperature was stored as a key/value pair during the course of the experiment in real time. This temperature value is easily accessible online with the help of an API Request and is used in the next level of the arrangement by Microsoft HoloLens to set the required parameters when running the Mixed Reality application.

In the last part of the layout, there is the Mixed Reality application, which was developed in the Unity 3D environment. The design of the application was carried out in C# language, and the research team checked its scientific validity. With the help of Microsoft HoloLens 2, the application displays the digital holograms in the physical environment of the users. These correspond to the real ones used in the real experimental setup and parameterize the visual objects based on the temperature value of the real sensor, which is taken online in real time with an API Request (Figure 7).



(**a**) (**b**)

Figure 7. (**a**,**b**) Implementation in practice.

4. Methodology

4.1. Purpose and Research Questions

All too often, students find it difficult to explain and comprehend the phenomenon of liquid expansion/contraction, for which they display a number of misinterpretations [84]. For instance, they believe that the increase in the volume of the bodies, when these undergo expansion, involves an increase in the quantity and weight of the body. These misinterpretations become more intense as we pass from solids to liquids and from liquids to gaseous bodies [62].

Based on the above, the research aim is to evaluate the effectiveness of Mixed Reality, used as a teaching environment, in improving University learners' (prospective primary education level teachers) performance in the concepts of liquids' expansion/contraction.

The research objectives are to explore the usability of the Mixed Reality environment, the simplicity or ease of its use, the time needed to handle it, the interaction of the users with the environment and learners' cognitive development in the research concepts.

To this end, the research hypotheses are the following:

H1: *The use of a Mixed Reality environment improves the learning results in the concepts of liquid expansion/contraction.*

H0: *The use of a Mixed Reality environment does not improve the learning results in the concepts of liquid expansion/contraction.*

The research questions are as follows:

1. To what extent can the use of a Mixed Reality environment enhance the learners' cognitive level in regards to the study of the liquid expansion/contraction phenomenon?
2. What is the learners' opinion on the usability of the Mixed Reality environment?
3. To what extent is there interaction between the Mixed Reality environment and the user, according to the research participants?

4.2. The Research Sample

The research sample consists of 54 students attending the last year of their studies at the university. Out of the 54 students, 43 (79.6%) were female, and 11 (20.4%) were male. Of the 54 students, 81.5% had humanities courses orientation during their high school studies, 14.8% had majored in science within their high school studies, and 5.5% had focused on economics and informatics while attending high school, and these percentages are not differentiated over the academic years. The above differentiation percentages are due to the fact that students from all directions and knowledge backgrounds in their last year of high school studies—humanities, science, technology—are, by law, entitled to participate in the University exams, and upon successful participation, they may enter the Pedagogical Department, although the majority that choose to study in this department derive from humanities school background and orientation studies.

Even though the research was conducted within the science university courses curricula, for ethical reasons, students were informed of the authors' intention to explore the effectiveness of Mixed Reality through the research experiments. All learners were enthusiastic to participate in the research and explore the combination of the two worlds (real and virtual) for the purposes of their studies. Furthermore, for ethical reasons, it was clarified to the students that their participation was voluntary. It was also clarified to them that their participation would be anonymous and that no reference would be made to their personal data. For the same reasons, the opinions of the participants are referred to in the results section as P1, P2 (Participant 1, Participant 2, etc.).

4.3. The Research Method and Tools

For the purposes of the present research, a mixed-method approach (quantitative and qualitative) was used. In particular, one of the tools concerns a properly designed questionnaire that aims to investigate the level of students' knowledge of specific science concepts and, in particular, of the expansion and contraction of liquids before the intervention.

The same questionnaire was also administered in the post-intervention phase. This questionnaire, used in the pre- and post-intervention processes, consisted of 21 multiple-choice and open-ended (with short justification) questions relating to the basic concepts of temperature, heat, thermal energy, and thermal expansion/contraction. Out of the 21 questions in total, questions 4 to 9, pertaining to the expansion of liquids, and 11 to 15, relating to the contraction of liquids, are multiple-choice questions, given on a Likert-type scale with five possible response values. Value one corresponds to "I completely disagree"; value two corresponds to "I disagree"; value three is "Neither Agree/Neither Disagree"; value four is "I agree"; and value five corresponds to "I strongly agree". There were also short justification answers for the selections made in these questions, which assessed the respondents' comprehension of the phenomena of liquid expansion and contraction. The remaining nine questions were open-ended, with short answer questions also requiring justification. Each short justification answer given by the students was evaluated by the research team, according to its scientific correctness, on a four-value Likert scale with value one denoting "Scientifically Wrong", two as "Partially Scientifically Wrong", three as "Partially Scientifically Correct," four as "Scientifically Correct", and there was an option of "Don't know/don't answer" (Table 1).

Table 1. Pre- and post-phase questionnaire categories.

Categories of Teaching Objectives for Subject Taught	Question	Question Type	Teaching Objective
O1: Basic concepts of thermodynamics	1,2,3	Short answer	To detect learners' ideas concerning the concepts of thermal energy, heat and temperature.
O2: Thermal expansion	4,5,6,7,8,9	Multiple choice and short justification answer	To understand the concepts of the thermal expansion phenomenon
O3: Thermal contraction	11,12,13,14,15,16	Multiple choice and short justification answer	To understand the concepts of the thermal contraction phenomenon
O4: Comparative study of both phenomena	10,17,18,19,20,21	Short answer	To understand the concepts of thermal contraction and expansion after their comparative study.

The questionnaire was checked for content validity and reliability with pilot testing. The questionnaire construct validity was further examined (a) with the help of a group of learners and (b) with interviews with students of the pilot study [85]. The internal consistency of the questionnaire (and, by association, its reliability) was tested by computing Cronbach's α only for the justification and short development questions, which were given more emphasis. The analysis of the result revealed that, in terms of internal consistency and construct validity, Cronbach's α was 0.734.

In order to assess the ease of use of the Mixed Reality environment, the System Usability Scale (SUS) questionnaire was administered to the students. The SUS is an effective tool for assessing the user experience of a new system and investigates three main aspects: the effectiveness, the efficiency and the satisfaction of using this technology [86]. The questionnaire consists of questions answered on a five-point Likert Scale, where value one corresponds to "Fully disagree" and value five to "Fully agree". The Cronbach coefficient of the questionnaire is 0.794.

Other research tools were two focus groups: a group per course consisting of ten randomly selected learners per group, two male and eight female learners—this number was decided in order to keep the population rate per gender. The semi-structured focus group discussions were formed in order to have more analytical and in-depth answers to the research questions, and they were conducted based on the main pillars of the administered questionnaires.

Additionally, a member of the research team had the role of the observer, who recorded all the interactions taking place throughout the intervention and whose notes and opinions were taken into consideration in the evaluation of the whole process.

4.4. The Research Stages and Process

The research phases and their aim are summarized and shown in the following table (Table 2).

Table 2. The research phases.

Research Phases	Process	Aim
1st phase 1 h	Pre-intervention phase, part one: Administration of a questionnaire about the study phenomenon of liquid expansion Pre-intervention phase, part two: Focus group discussion with ten randomly chosen learners out of the 54 that were attending the courses.	To detect learners' ideas about the research concepts and know their justification/explanation, if any. To verify their questionnaire answers and understand their possible misinterpretations and how they perceived the liquid expansion phenomenon before the intervention.
2nd phase 3 h	Intervention phase: Implementation of the research experiment with the use of the Mixed Reality environment.	To explore whether Mixed Reality can be used for educational purposes and the extent to which it can improve the understanding and learning of the phenomenon of liquid expansion.
3rd phase 2 h This phase was implemented a week after the intervention	Post-intervention phase, part one: Administration of the same questionnaire given in the pre-intervention stage. Post-intervention phase, part two: Focus group discussion with ten randomly chosen learners out of the 54 that were attending the courses.	To investigate any changes in the comprehension of the phenomenon of liquid expansion and see whether learners can better and correctly justify their answers at this point. To investigate the opinions of learners and their understanding of the phenomenon as well as their views on the Mixed Reality platform and its usability.
4th phase 1 h	Two months later. Discussion about the expansion–contraction phenomenon and what it is.	The aim was to test learners' metacognitive skills and see how much they understood and remembered after the intervention.

For the research experiment, two Microsoft HoloLens 2 glasses (due to the limited availability), as well as experimental sets of real objects and materials (materials for boiling water, gas, basin, bottles, etc., as shown in Figures 7 and 8), were used. In every course, the students worked in groups, following the inquiry-based approach.

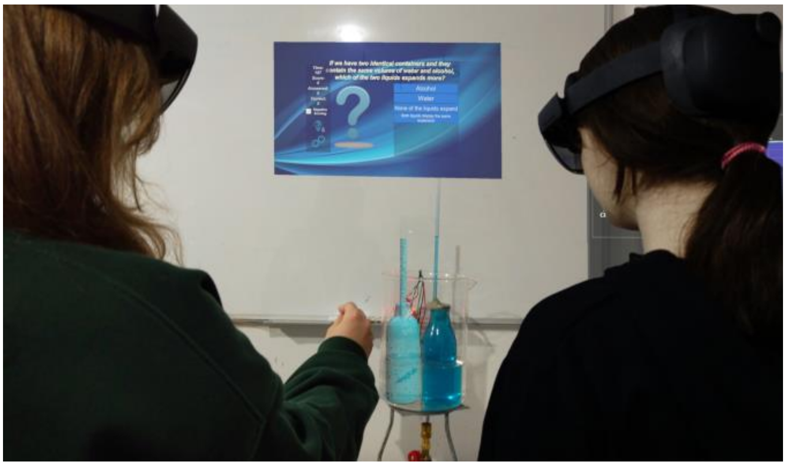


Figure 8. MR knowledge test.

In particular, the HoloLens 2 devices were connected to PCs via their device portal, and through the portal's Mixed Reality Capture ability, students monitored the process at the same time through the computer screens. Everyone in their group took turns in using the device and observing the liquid expansion phenomenon. In the experimental setup, they could move the virtual bottle and place it on the real one to observe the phenomenon process. The students had only two bottles in the basin as the HoloLens cannot hold more than two, e.g., water with oil or water with alcohol. The students wearing HoloLens 2 had access to a 10 min digital scenario based on a guided inquiry process that led them through the experiment, and thus, through the MR environment, they had the possibility to test their knowledge (Figure 8).

As aforementioned, throughout this process and within the groups, other students were observing through the HMDs, others were watching the process on their computer screens, and other learners were recording what was happening, taking measurements or observing the actual experimental setup or the boiling process.

5. Results

5.1. The Data Processing

The quantitative analysis of the questionnaire data was carried out with the help of the statistical package SPSS v27 and Microsoft Excel. Regarding the qualitative data, the students' opinions were recorded during the discussions by the teacher himself and an independent observer of the research team. Then, with the help of the content analysis method, the evaluation and coding of the opinions of the participants were taken in written form by the researchers, and three categories emerged. These were related to (a) the basic concepts of heat/expansion of liquids, (b) the learning benefits of using MR technology, and (c) the usability and potential difficulties of the Mixed Reality environment and HoloLens 2 in practice.

5.2. Quantitative Findings

The utilization of the Mixed Reality environment had a substantial impact on students' alternative conceptions pertaining to the concepts discussed in the field of science.

The overall improvement in terms of the total set of questions is significant (48.94%) (an improvement from 31.63% to 80.57%), and on average, 5 out of 10 students differentiated in depth their alternative ideas towards the scientifically accepted explanation/interpretation of the phenomena (concerning the justification of the occurrence of these phenomena) (Figure 9).

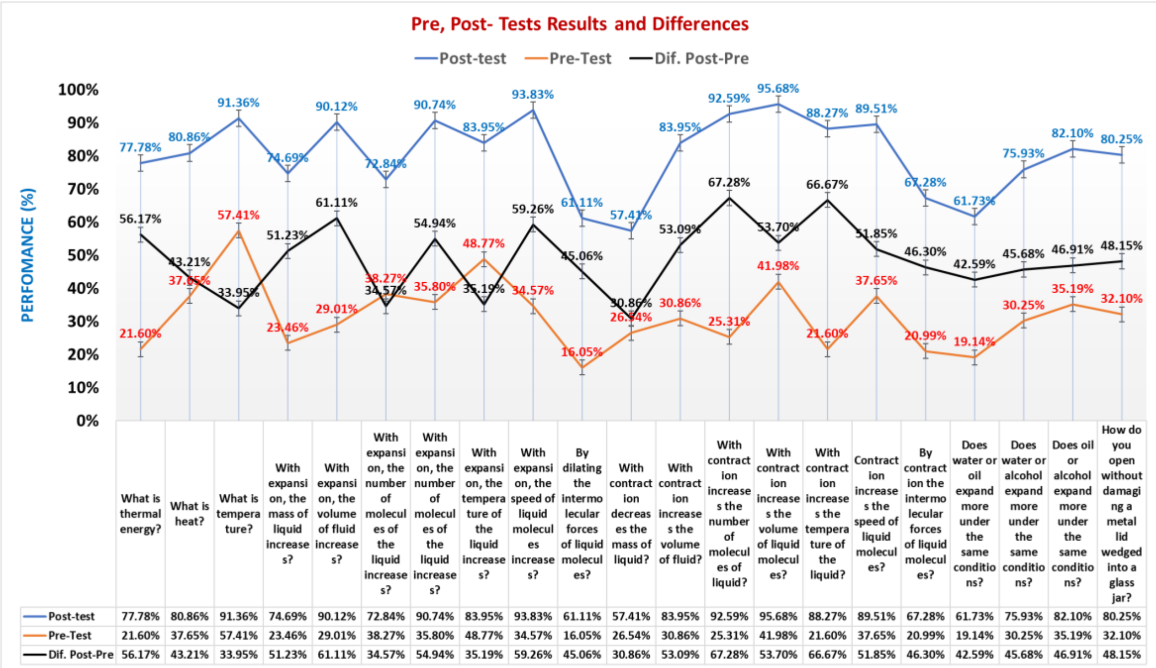


Figure 9. Students' performances in the pre- and post-test process and their mean differences.

In more detail, focusing on the students' performance improvement in the questionnaire items, it is observed that, regarding the concept of contraction and whether it is associated with a reduction in mass, the students' performance improvement to 30.9%, although significant, is still the strongest alternative idea of the student teacher candidates, (almost about 43% of the students still cannot give a scientifically correct interpretation). Similarly, the relationship between the number of molecules and the phenomenon of expansion or contraction is still considered an alternative concept by students despite a notable 34.6% improvement in their understanding of the scientifically accurate interpretation of the phenomenon. Furthermore, a great improvement (45.06%) was shown in the question about the strength of intermolecular forces during the expansion of liquid bodies, which is a particularly difficult concept for students to comprehend, and the percentage of students (61.1%) who answered correctly is considered significant. The corresponding question, regarding the strength of the intermolecular forces during the contraction, also showed a 46.3% improvement and is considered important in terms of understanding the specific concept (67.3% gave explanations of the phenomenon that are scientifically acceptable). Equally important are considered the student teacher candidates' alternative ideas in everyday concepts (6 out of 10 and 4 out of 10, respectively, in the questionnaire items relating to what is heat and what is temperature), analogies which are reduced to a considerable extent after the teaching intervention with the use of the Mixed Reality (2 out of 10 and 1 out of 10, respectively).

It should be pointed out that there was a very wide variation in the students' answers regarding the scientifically accepted point of view in questions concerning the increase or decrease in the molecules of the liquid and the mass of the liquid during expansion or contraction (about 9 out of 10 participants formulated the scientifically acceptable point of view, a fact that was also highlighted during the discussion with the control group, attributing it to the use of the Mixed Reality environment).

The overall improvement in terms of the set of categories of the questionnaire and their teaching objectives is significant (80.91%), with performance ranging in each of the categories from 71.40% to 84.57% (Table 3).

Table 3. Results per teaching subject category (pre–post testing).

Objectives	Pre-Test		Post-Test	
Categories	Mean	SD	Mean	SD
O1: Basic concepts of thermodynamics	38.89	18.79	83.33	18.91
O2: Thermal expansion	40.12	13.16	84.36	10.41
O3: Thermal contraction	32.20	10.97	84.57	10.10
O4: Comparative study of both phenomena	31.58	11.71	71.40	13.32

The above differentiation is also apparent in the corresponding subcategories, as shown in Table 4, and especially in category O4, where the improvement is reflected in the comparative study of the two phenomena with different materials, as recorded by the students' questionnaire answers but also by their comments in the focus group. Based on all the possible comparisons of the pre and post-tests (Table 4), we can conclude that for all categories, O1, O2, O3, O4, the result is statistically significant ($p < 0.001$). The 40% improvement in their initial ideas in the specific subcategory highlights both the metacognitive skills acquired during the specific process and the positive effect of the use of appropriately designed teaching interventions using Mixed Reality environments. The same conclusions can be reached by using a chart (Figure 10) with intervals of confidence at 95% of the means of the students' performances.

Table 4. Paired samples *t*-test results.

Paired Samples Test						
		Paired Differences Mean	SD	t	df	Sig. (2-tailed)
Pair 1	Average explanation O1 (%)_Post test—Average explanation O1 (%)_Pre test	44.44	27.81	11.74	53	<0.001
Pair 2	Average explanation O2 (%)_Post test—Average explanation O2 (%)_Pre test	44.24	16.86	19.29	53	<0.001
Pair 3	Average explanation O3 (%)_Post test—Average explanation O3 (%)_Pre test	52.37	15.77	24.40	53	<0.001
Pair 4	Average explanation O4 (%)_Post test—Average explanation O4 (%)_Pre test	39.81	18.34	15.95	53	<0.001

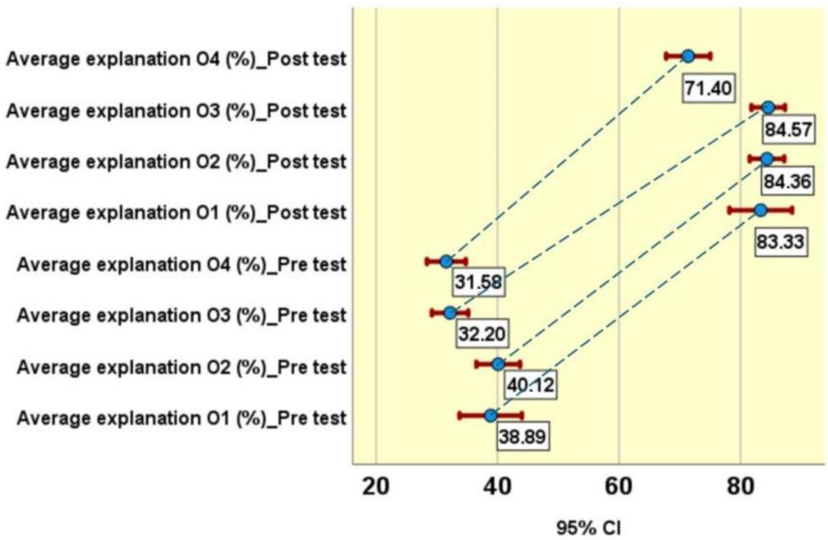


Figure 10. Error chart for the 4 main categories (O1, O2, O3, O4) in the pre–post testing process.

The same conclusions, in terms of statistical significance, can be drawn from Figure 11, where students' overall performance and performance of short answers, in terms of scientific correctness in the pre- and post-phases, are depicted.

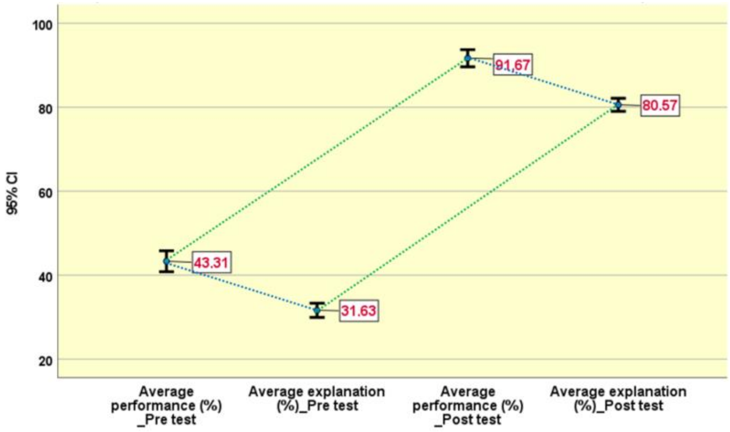


Figure 11. Error chart for the students' overall performance and performance of short answers, based on their scientific correctness.

The analysis of the questionnaire data regarding the usability of the Mixed Reality environment is depicted in Figure 12. After calculating the SUS score, by using the formula SUS score = (X + Y) $\times$ 2.5, where X equals the sum of the points for all odd-numbered minus 5 (X = sum(odd number question points) $-$ 5) and Y equals 25 minus the sum of the points for all even-numbered questions (Y = 25 $-$ sum(even number question points)) [86] there was an acceptability score of 84.4 (with 100 the highest score possible). According to the Usability Scale, the MR environment can be characterized as close to excellent.

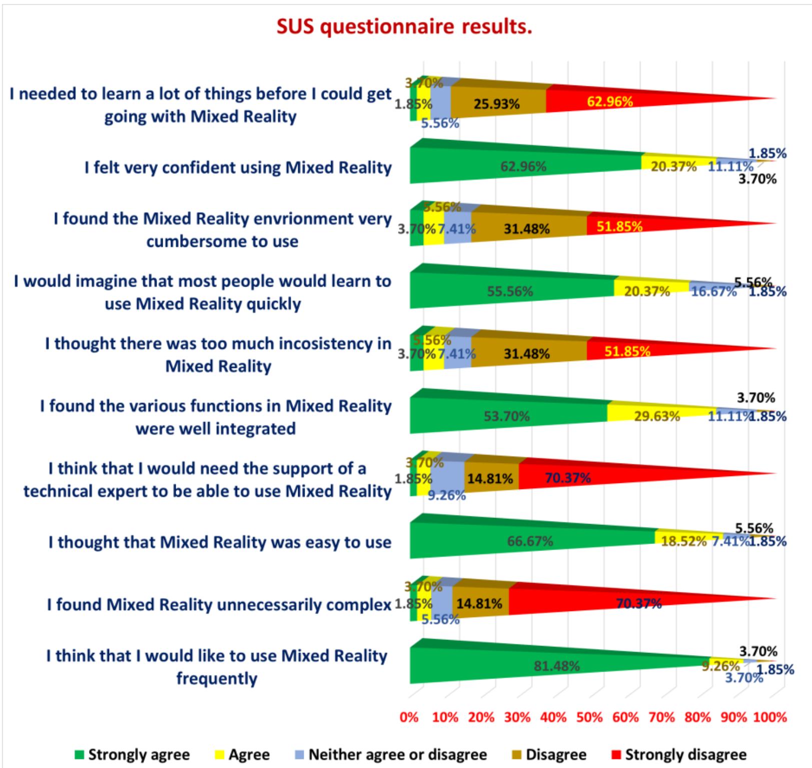


Figure 12. SUS questionnaire results.

The above results concur with the qualitative analysis results in this research, which are presented below.

5.3. Qualitative Findings

5.3.1. Students' Views on the MR Experiment

The qualitative results support the findings deriving from the quantitative data analysis in this research. Students' curiosity for the new tool was a strong motive to actively engage with it and the experiment. According to the learners, on the one hand, the tactile sense they had during their interaction with the virtual and real worlds was a pleasant experience for them. On the other hand, the simultaneous feeling of the macrocosm and microcosm seemed to be a challenge for them and facilitated the understanding of the phenomena under study. As the learners admitted, and after the first pleasant "shock", as they described it, they found the exploration of the phenomena observed in the real and visual world very interesting to know, like, for instance, what water molecules "look like" and how they constantly move.

In particular, and based on the results of the qualitative analysis, there was a significant improvement in the connection of thermal energy and thermal expansion with molecular mobility. The comparison of different kinds of liquids during the experimental process allowed the learners to perceive more factors that affect the expansion of liquids, such as the molecule types and the intermolecular forces. The views of the students listed below are typical of their understanding of the phenomenon and satisfaction with the MR experimental use:

> *"While I was watching the thermometer and the temperature was rising, I could see at the same time the molecules were moving faster and when the temperature in the thermometer was getting lower, the molecules were moving slower."*
>
> P2
>
> *"I could understand how important is the strength of the forces among the molecular as I was watching the different expansion of the liquids in the experiment."*
>
> P6
>
> *"As the liquids were heating up, I saw the molecules going faster and faster. The bottles had molecules inside the straws which were collected on top of each other. These molecules come from the fluid that was originally present in the bottle. The more we heated it, the faster the molecules 'ran' and tried to escape towards the straw. As the liquids cool down the molecules move slower and slower and return back to the bottle. It was very clear that their size does not change."*
>
> P3
>
> *"The molecules of each liquid are different. Those of the water are smaller, the molecules of the oil are bigger but they move faster, while those of the alcohol move faster than all of them. That is, the higher the temperature, the faster the molecules move, the lower the temperature the slower they move. but of course, this also depends on the type of liquid we have and how strong the force between these molecules is. As I saw through the device, As I saw through the glasses (HoloLens 2) the molecules of each liquid remain the same in size during the experiment."*
>
> P5
>
> *"I was able to understand what was happening because I could see the molecules through the device. Each liquid's mass remains unchanged but the change in temperature makes the molecules move faster resulting in the increase of the in-between them distances which leads to the change in the volume of the liquid."*
>
> P1
>
> *"…the more we heat the molecules, they don't grow [dimensions], they do not change in number, they just move faster, they bump into one another more and more and are forced to move away from each other… They get the energy because we heat the water in the container…"*

P2

"I can say that the Mixed Reality helped me understand the concepts we studied in class, about the contraction and the expansion of the liquids I mean..."

P8

"The hotter the liquid gets, the faster the molecules move and move away from each other. In this way their distance increases and the volume of the liquid changes. The mass of the liquid remains the same and the dimensions of the molecules remain constant."

P4

"...I saw all molecules clearly. When the water finally cools down it is clear that the molecules move more slowly and are forced to come closer so again the liquid returns to the original volume..."

P7

"Oil has larger molecules than water, this is clearly visible. Then something else definitely happens and they move faster...Probably something keeps the water molecules more bound together and doesn't let them move easily. Maybe there is a stronger force between them."

P6

"Alcohol's molecules move faster than the molecules of the other liquids. But water's molecules are the smallest but also the slowest ones. Something must stop them move faster and away from each other...The forces between them must be greater than those in the alcohol and they cannot move as easily."

P2

5.3.2. Students' Views on the MR Environment's Learning Benefits

Regarding the interactivity between users and the MR environment, it was seen that it was intense, aroused their interest and facilitated their understanding to a great extent, allowing them to acquire a better visual and tactile perception of the phenomenon under study. Typical examples of the learners' views are the following:

"With the help of Mixed Reality you can see things that are not perceptible with the eye. The picture you see with the molecules helps you better understand what exactly happens inside a liquid when you heat it. It was very impressive to see the real objects and the microcosm."

P6

"...I was impressed by the handling of the 'digital' bottles and how they were connected to the real experiment..."

P3

"Real experiments are essential for Physics. The extra information that the device gives you makes you see the classic experiments with a different perspective and draws your interest to observe what exactly happens inside the matter...with this arrangement with which we measure the actual temperature, neither of the two worlds is degraded. They just complement one another."

P1

"The best thing of all was the fact that I could see both worlds (Virtual and Real) simultaneously. If I could see only the Virtual world without having to observe the experimental one, I wouldn't know which phenomena we are studying. But by having both worlds at hand I am fully aware of the object of our study and also the reasons of the results we recorded."

P5

"If the virtual world was the only one shown and I observed only what happened there, without seeing the real bottles and the experiment, I could easily describe the changes in the molecules I observe but I wouldn't know why I see this, and which experiment I am studying. The connection to the reality would be missing. But now that I saw the fluids and I observed them in the real bottles, I was aware that they expand when the temperature rises (through the thermometer) and contract as temperature decreases, whereas, through the Mixed Reality glasses, I was also able to understand why this happens, observing the molecules and how they move."

P9

"As the volume of the liquid in the glass bottle grew, so did the volume in the virtual bottle according to the liquid, and I could see the molecules, as though being real inside the bottles."

P1

Most students agreed that implementing MR at school would be a great innovation. In particular, learners argued the following:

"The implementation of such a technology in the school will greatly upgrade the teaching of the Physics lesson in the Elementary School. I believe that it will keep the interest of the students undiminished and make the lesson more successful..."

P8

"...I believe that students participate more actively in the experiment because they will be able to interact with the microcosm by simply observing and recording their observations."

P5

"If there were something like this in my school, I would definitely use it for the lesson...The children would definitely explore these objects more easily and with less risk..."

P4

"It was easy to operate and I had no trouble at all observing what was happening during the experiment..."

P2

"Having the worksheet in front of you, like a window, can help learners conduct the experiment more easily. The knowledge quiz and the fact that, the rest of the students can see what the user sees, are great features of the environment. So, all students together can cooperate in order to conduct the experiment or answer the quiz answers."

P6

However, there were students who stated that the application of MR in a school classroom would have some limitations, especially due to the cost of the device. These learners explained the following:

"...This device could give another dimension to the lesson, but I believe there would be obstacles in its application in the classroom. Mainly because the costs are high and the money in the schools for equipment is limited."

P7

"The application of such technology in the classroom can be pedagogically integrated into the teaching of Physics. The difficulty that will exist will be mainly due to the applications that can work in such a Mixed Reality tool because you need a little more specialized knowledge to make such programs..."

P8

"...You will definitely need a good internet connection which even now many schools lack..."

P4

5.3.3. Students' Views on the MR Environment and Device Usability

Regarding the Microsoft HoloLens 2 device, the students argued that they particularly enjoyed the Mixed Reality environment, which they found "very easy to use", "innovative", "important for clarification purposes", "what all learners should be able to see", "a tool of a contemporary lesson", "a significant step to science concepts comprehension", and many more. A large percentage of the participants emphasized its high degree of ease of use. The students described the operation of the device as "not complicating at all" and the time needed to get used to it as "brief" and "apparent". Additionally, a large number of students emphasized its relatively small size and portability. The tactile manipulation of the holograms with gestures in the air (air tap) was considered easy by most participants since they emphasized that they were able to move and rotate the projected virtual objects in a very short time and with no difficulty at all. Its operating system, in general, and the application environment, in particular, did not cause any unpleasant feeling or feeling of disorientation as they constantly had a full perception of the physical space in which they were. However, some learners pointed out a difficulty in operating the HoloLens 2 that related to the relatively narrow field of view (FoV) which, nevertheless, they quickly adapted to. Typical examples of their views are presented below:

> *"The HoloLens was easy to use. It didn't take me long to adjust. . .I liked that everything was in front of me without the surrounding environment being hidden and that the virtual objects were visible from all sides just like when I was looking at the real bottles."*
>
> P4

> *"It was clearly a very good experience. . .Objects went where I wanted and I could even manipulate them remotely. I didn't feel weird in any way since I could see where I was and walk around with easiness and without feeling dizzy. . ."*
>
> P1

> *"The device was light and I could move around very easily. It was not difficult to operate it and I had no trouble at all observing what was happening in the experiment. If I looked slightly to the side the objects were lost (narrow field of view). I didn't like that, but it didn't bother me either."*
>
> P6

> *"At first when I put the HoloLens on I felt weird but that feeling went quickly away because I could see my hands and the surroundings in front of me and in that way I didn't' have any disorientation problems. I knew exactly where I was standing (inside the classroom)."*
>
> P3

> *"I had tried Virtual Reality (VR) glasses before. It was a completely different experience and it took me a long time to adjust. With HoloLens 2 I adapted in the MR Environment straight away without any problems."*
>
> P9

In general, and according to the teacher and observer researcher notes it appeared that the students were particularly active during the implementation of the experiment, showing great interest and enthusiasm about the whole procedure. According to the researchers' recordings and notes, everyone participated in all the experimental steps, showing that they really enjoyed the combination of the two different environments (real and virtual). After the intervention, the students were asked to re-answer the same questions that had been administered to them for diagnostic reasons before the experiment. Based on the learners' replies, it was seen then that the majority of them gave scientifically correct answers. Again, a very prominent comment among the many was the fact that learners were able to "see" the molecules of the liquids with their own eyes. This interesting fact also applied to their understanding of which liquid had the highest or lowest expansion, and this was something that, as they claimed, they could never forget because they were able to "see". Therefore, and based on the findings, it can be argued that the students managed to connect the mobility of liquid molecules with the expansion, and therefore, they were able to comprehend the phenomenon.

Equally interesting seems to be the fact that two months after the research intervention, the same students were asked about the expansion phenomenon within the framework of their Spring Semester science classes. Their answers this time were given directly and without hesitation or much thought and were scientifically correct. When asked by their instructor/researcher how they managed to be so immediate with their answers, the students admitted that they simply remembered everything from the Virtual Reality experiment, repeating again that it was difficult to forget something they "had seen" or "had observed" with their own eyes and had fully comprehended.

Table 5 below summarizes some of the participants' indicative comments on the research issues:

Table 5. Students' indicative comments and answers.

Research Questions	Students' Summarized Indicative Comments and Answers
Question one: Cognitive improvement	"While I was watching the thermometer and the temperature was rising, I could see at the same time the molecules were moving faster and when the temperature in the thermometer was getting lower, the molecules were moving slower." P2 "As the liquids were heating up, I saw the molecules going faster and faster." P3 "Each liquid's mass remains unchanged but the change in temperature makes the molecules move faster." P1 "Oil has larger molecules than water, this is clearly visible." P6 "I was aware that they expand when the temperature rises (through the thermometer)." P9 "It was very clear that their size [the molecules] does not change." P3
Question two: Usability of the MR platform	"It was easy to operate and I had no trouble at all observing what was happening." P2 "The HoloLens was easy to use. It didn't take me long to adjust." P4 "The device was light and I could move around very easily." P6 "With HoloLens 2 I adapted in the MR Environment straight away." P9 "I didn't' have any disorientation problems. I knew exactly where I was standing (inside the classroom)." P3
Question three: Interactivity between user and MR tool	"With the help of Mixed Reality you can see things that are not perceptible with the eye" P6 I was impressed by the handling of the 'digital' bottles and how they were connected to the real experiment. . ." P3 "The best thing of all was the fact that I could see both worlds (Virtual and Real) simultaneously." P5

6. Discussion

The purpose of this research paper was to investigate the degree of applicability of Mixed Reality in the educational process and the extent to which it enhances the learning results when using such an MR environment in the study of the phenomenon of expansion and contraction of fluids.

Regarding the first research question, the use of the Mixed Reality environment significantly improved the cognitive level of the participants regarding the thermal expansion and contraction of liquids. The students had the opportunity to investigate the concepts under study through an exploratory approach and the integration of a Mixed Reality environment by experimentally examining the thermal expansion and contraction of different types of fluids. The participants recorded and interpreted the results derived from their own observations using real materials such as heating devices and bottles with different kinds of liquids in combination with the technological equipment.

Based on the results of the pre- and post-questionnaires as well as the focus group discussions, it was observed that, before the teaching intervention, although the students were able to provide correct answers to some questions about the concepts of the cognitive subject, they had difficulty in reasoning their opinions or gave scientifically correct answers [51,52,55]. Several students had difficulty interpreting the basic concepts of thermal energy or of heat and temperature, while a large number did not understand the meaning of the terms "contraction" and "expansion" [56,57]. A large percentage of students held the belief that the expansion of all liquids is identical. Additionally, some students expressed their lack of knowledge regarding this subject, and some simply gave an answer by chance, while a percentage of 2% of the students expressed the belief that expansion/contraction does not occur, giving the water to steam conversion as an example. A small number of students mentioned intermolecular forces as a factor that can affect the expansion of liquids. In general, students considered contraction and expansion as the same phenomenon and were not able to justify why and how expansion/contraction happens or which liquid undergoes greater expansion and which less.

After the intervention process, the students were able to describe the change in the kinetic state of the molecules and its effect on the expansion and contraction of liquids more accurately, while they observed and recognized ambiguities and contradictions in their original assumptions about the sizes of the molecules and the kinetics energy. During the experimental process, with successive comparisons between oil and alcohol, alcohol–water and oil–water, they observed, through the Mixed Reality environment, that water molecules, although smaller in size, show the smallest change in their kinetic energy. Through this combined investigation, with the use of the two environments, as well as through extensive discussion, the students realized the simultaneous role of intermolecular forces in the expansion phenomenon. This understanding reinforced the importance of the different behavior of molecules, depending on the liquid and the interaction in their environment, offering students a more comprehensive and scientific realization of the processes studied. Overall, after the intervention, there was a great improvement in the understanding of the phenomena and in students' performance on answering the administered questionnaire, with quantitative scores averaging higher than 80% in each question [50].

The metacognitive value of the intervention was demonstrated when, after the intervention, learners were asked to measure their body temperature and notice what would happen. Upon the completion of the experiment, students were able to determine why the thermometer index rose. When asked why and how this had happened, the participant students explained that the human body has a higher temperature (37 °C), so the heat is transferred from the body to the thermometer, it heats the alcohol or mercury, and it undergoes the expansion which is displayed by the index in the tube, as it rises. In other words, learners were now able to interpret the phenomenon, i.e., understand the energy of the molecules, something that they were unable to do before the intervention. Therefore, it can be said that the expansion phenomenon was fully understood.

Regarding the second research question, and according to the learners' opinions, the MR Environment was characterized as a modern educational tool, easy to use, with a short time needed for familiarization, that allows deeper immersion in the study of physical phenomena through the interactive and integrated experience it provides [47]. The students expressed their positive attitude towards the Mixed Reality environment, characterizing it as a user-friendly, innovative and necessary tool to enhance their understanding of scientific concepts. The immediate adaptation to the Mixed Reality environment and the high quality of interaction with the virtual objects led to an approach to the learning content that enables exploration and experimentation. Students also stressed the fact that the minimum need for technical knowledge to learn the environment functions and the absence of feelings of disorientation and discomfort led to the ease of observing the experimental evolution of the phenomena under study.

Concerning the third research question, and based on the research participants' opinions, a critical factor in the educational approach was the possibility for students to interact simultaneously with the real and the virtual environment. By using the Mixed Reality glasses, students were able to observe the volume expansion of different liquids (water, alcohol and oil) using a thermometer at the same time, with alcohol showing the greatest expansion. The simulation in the virtual environment allowed them to have the feeling of 'touching' the holograms of the molecules, whose mobility was linked directly and in real time to the temperature of the liquids, and recognize them in the real liquids. At the same time, they could observe the changes in the straw with the increase or decrease in the liquid volume, which was happening simultaneously. The significant degree of interconnection between environments facilitated the observation, documentation, and explanation of the phenomenon. The importance of having the two environments simultaneously, contextually related and mutually interacting with each other to a great extent was stressed by the students [87]. According to the learners, this was the main reason the experimental setup helped them describe the phenomena in detail and use the MR environment to explain the reasons for the occurrences of these phenomena in everyday life.

In general, and based on the results, the interaction within a hybrid reality created a more lively and playful experience, enhancing student understanding and engagement. The method of digital scenario presentation and knowledge test evaluation, in conjunction with synchronous observation of the experimental environment, was regarded as a way to greatly facilitate the experimental process progression. The simultaneous monitoring of the phenomenon evolution in the real field as well as the simulations in the virtual field, both by the users and by the other members of the groups, through a shared computer, leads to collective observation and teamwork that encourages the scientific processes [55]. This can result in a deep understanding of the target phenomena, with the learners being able to give scientific interpretations of the process and implement it as accurately as possible [54]. Additionally, throughout the educational procedure, the importance of using Mixed Reality and the HoloLens 2 device was particularly highlighted. The ability to clarify complex scientific concepts through MR in a tangible way was also stressed by the students [53]. In addition, the need for such environments to be accessible to all (students and in-service teachers) was underlined, as they offer a modern method of exploring and understanding scientific concepts that could increase the effectiveness of teaching and change their attitudes towards learning science [48,49].

7. Conclusions

The present study explored the usability and effectiveness of the MR environment in teaching and learning science concepts. The results of the research highlight both the potential and the challenges of using MR in the educational process.

As aforementioned, and based on previous research, a trend of the co-existence of real and virtual environments and the exploitation of their advantages for teaching purposes is observed in the educational practice. Today, their interconnection can be realized using sensors and IoT technology, transferring information and data from one world to the other. However, the co-existence of the two environments must be realized in attunement and within a common conceptual and methodological framework so that the two worlds function in a mutually complementary way. This is because learners receive stimuli from the two sources simultaneously. Therefore, it is of particular significance that the information learners receive from both worlds is equally important, and neither world is downgraded at the expense of the other or causes any confusion in the understanding of the phenomena under study and dealing with their alternative ideas. This way, learners are able to explore and discover the cause–effect relationship (increase in the temperature, change in the kinetic state of the molecules, change in the volume of the liquid) without a large information load increase.

Thus, the simultaneous appearance of the two worlds in the users' field of view may lead to the enhancement of the perception of the phenomena under study. Through the co-existence of real and virtual objects, users can interact with their environment in ways that were previously impossible, revealing new aspects of the studied concepts and increasing their interest and creativity. The equivalent interaction and the transfer of information from the real environment to the virtual one and vice-versa can provide a deeper experience to the users by creating such vivid images that they are not easily forgotten. Therefore, learners are smoothly led to a conceptual change and the acquisition of new knowledge. This way, the combined depiction of phenomena in a hybrid environment can affect and change users' mental representations by offering information that will maintain their interest and increase their active involvement in the educational practice, improving, at the same time, the learning results.

Additionally, the use of Mixed Reality enhances kinesthetic learning through tactile feedback and improves the educational material, as it is framed with multimedia (digital script, access to online videos, assessment tests) based on students' choice. All in all, the creation of a hybrid learning environment, which enhances inquiry, allows learners to control their learning to a great extent, supporting at the same time metacognition, strengthening their self-confidence and leading them to a more extensive change in their attitudes and beliefs towards science.

The limitations of this study relate to the fact that this is contemporary technology that is used in educational practice; it is in a stage of development, and there are not much data on it so far. It is hoped that researchers and our research team, through constant research, will be able to contribute to its further development in the future. As a further and future step, this research aims to compare this technology with other technologies and integrate it in more cognitive subjects or use it with different age groups of learners and test its efficacy.

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Institutional Review Board Statement: These interventions are part of the teaching routine practices which are a usual process for the research team in the University and for which there is no need to acquire an approval from the Ethics Committee as they are part of activities for teaching purposes. Relevant information can be found here: https://www.edu-sw.upatras.gr/en/faculty/hatsihour/ (accessed on 3 July 2024), https://www.edu-sw.upatras.gr/en/courses-outline/ (accessed on 3 July 2024).

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Conflicts of Interest: The authors declare no conflicts of interest.

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