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Developing Physics Experiments Using Augmented Reality Game-Based Learning Approach: A Pilot Study in Primary School

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Abstract: The augmented reality game-based learning (ARGBL) approach is an advantageous pathway for the development and enhancement of teaching and learning processes. To this end, this paper presents the design and development of an ARGBL application for the implementation of physics experiments in the fifth grade of a Greek primary school. The purpose of the ARGBL system is twofold: to educate and entertain. For this reason, a treasure hunt game was implemented, which allows students to interact with a digital world and to manipulate virtual objects with the use of an augmented reality (AR) device. Then, according to the instructions, students have to collect all the materials to conduct the AR educational experiment. Overall, the evaluation of the system's usability by 17 users (both students and teachers) was very promising, indicating that the ARGBL application has the potential to be an easy-to-use educational tool for improving not only the teaching of physics experiments in primary school but also the learning process, by positively affecting the students' motivation and engagement.

Keywords: augmented reality; game-based learning; usability; primary school; physics

1. Introduction

Azuma [1] defined augmented reality (AR) as a technology by which users can integrate 3D virtual objects in real time into their real-world environment. AR is a popular technology that is used in many aspects of our lives [2,3]. The basic reason for its popularity is that it has no special equipment requirements as in virtual reality. A smart device (tablet or smartphone) is enough. Moreover, recently, large companies in the field of information technology, such as Google and Apple, have delivered suitable frameworks and APIs to programmers, in order to develop a high quality of augmented reality applications, such as ARCore [4], ARKIT [5] and libraries for Unity [6].

For the last decade, augmented reality has been used in research to improve the educational process at all levels of education from primary education to university [7]. A remarkable number of augmented reality applications have been created, which basically augment the content of a schoolbook mainly using text, pictures and video [8,9]. Field experiments using AR application in education have shown that the education process was improved by increasing the fun, enjoyment, interest and engagement of students [7]. Furthermore, another interesting approach that has gained attention in education science is augmented reality game-based learning (ARGBL), which can transform the learning experience and influence students' motivation, skill development and knowledge [10]. Apart from the learning process, AR and ARGBL technology can additionally benefit the teaching process. Teachers who integrate such innovative approaches into the teaching process can introduce and explain to students complex and/or abstract concepts through a multisensory way, encouraging social interaction and improving collaboration [7,11]. All in all, AR and ARGBL can be successfully used in educational environments, positively

affecting both the teaching and the learning process, since (a) the cost of materials for the experiment disappears (sometimes a big problem for the education procedure [11]), (b) the experiment can be repeated as many times as the educational process requires (without the thought of wasting materials) and, most importantly, (c) the student can repeat the experiment when studying the course at home.

In this paper, an ARGBL approach was introduced for teaching the experimental part of a lesson of physics in the fifth grade of a Greek primary school. In particular, an application is presented that is based on ARGBL for the development of all the experiments for the unit of physics in the fifth grade of a Greek primary school. The contribution of this research is multifaceted. The case study focuses on lab/practical experiments in a unit such as physics, by adopting a game-based approach, which, according to the literature review, has found limited implementation in primary schools. All the experiments can be executed using an ordinary smart device such as a smartphone or a tablet. Additionally, the applications were designed to be interactive. This was conducted using game-based learning, where students are invited with a treasure hunt game to discover the materials of the experiment in one place. Thus, they are "forced" to pay attention to the materials used for the experiment. Then, after "accomplishing the mission" of finding all the materials, they can "run" the experiment as many times as they want until all the questions regarding the experiment and the physics topic are answered. We used the ARGBL application to perform a pilot experiment in a primary school, where the results were very satisfactory and showed that this approach greatly improves the educational process as it increases the fun, enjoyment, engagement and interest in the course.

This paper is organized as follows. In Section 2, AR and ARGBL are introduced. In Section 3, a short review is presented regarding the use of AR and ARGBL in physical science in both primary and secondary school. Next, in Section 4, the description of the suite of applications is analyzed, and in Section 5, the pilot experiment and its results are presented. In Section 6, the discussion of the research work is analyzed, and finally, in Section 7, the conclusions as well as future work are presented.

2. Augmented Reality Game-Based Learning

AR is an emerging technology, which has great potential. Although the first AR applications appeared in the late 1960s [12], it has become more pervasive and affordable in recent years due to the widespread use of mobile devices [13]. AR essentially blends virtual worlds into real ones, by allowing the user to explore, manipulate and interact in a seamless way with both digital and natural objects in real time [14,15]. Additionally, it allows them to envision objects in different situations and receive immediate visual feedback about their actions in a totally safe environment [12]. Therefore, AR improves learners' ability to understand abstract and complex concepts [16], since it can provide enriched experiential and in situ learning experiences [12].

Another learning approach that takes advantage of experiential learning theory is game-based learning (GBL), which uses specially designed games to improve the learning process [17]. One of the advantages of GBL is that through games, users construct their own knowledge and develop the ability to transfer it to other contexts, rather than passively absorbing a new concept, a pillar that the traditional educational process supports [18]. Therefore, of particular relevance to the education sector are the two aforementioned pedagogical approaches which both enhance the learning experience and learners' effectiveness by actively engaging them.

The term ARGBL, which is basically the integration of AR into GBL, is gaining more and more pace nowadays. According to Pellas et al.'s [19] systematic review, some of the most popular domains of ARGBL use in primary and secondary school education are formal science [20–23], natural science [24–27], physical science [15,28–31] and social science [32–34]. Additionally, problem solving, performance, motivation, satisfaction, creativity and collaboration [33] are, among others, benefits of ARGBL in the learning experience.

3. Review

Several previous studies have been conducted to explore the use, benefits and limitations or challenges of AR and ARGBL at all levels of education in the domain of physical science (such as physics, astronomy and chemistry). More specifically, Enyedy et al. [15] developed an AR environment to teach Newtonian force and motion to young children, 6–8 years old. During the activity, children had to predict how the forces would influence the motion of an object (e.g., ball). The results showed that children made significant progress in learning the content and improved their performance, since they engaged, explored and reconstructed their conceptual knowledge through fruitful confrontation and discussion. Additionally, Cai et al. [28] conducted a convex imaging experiment using AR technology, in which the eighth graders explored basic concepts of physics (such as image distance and focal distance) as well as abstract ones (such as what will happen when the object moves closer to the lens). The findings revealed that the AR tool attracted their attention, stimulated their interest and enhanced their learning. A few years later, Cai et al. [29] implemented a system that integrates AR with natural interaction technology by using Kinect, in teaching magnetic fields to students in grade 8. Students could trigger the magnetic field in real time with a wave of their hand in front of the depth camera. The experimental results stated that the system encouraged participants to learn more extensively through a more intuitive way, by activating their motivation and interest in learning.

Regarding astronomy, Zhang et al. [30] designed an AR-based mobile digital armillary sphere for astronomy. An intervention was organized for fifth grade elementary school students, and the purpose was to examine if they could properly identify the constellations through astronomical observation. The analysis indicated that the observation tool, which is based on kinesthetic-style strategies, positively affected participants' motivation and engagement as well as improving their learning experience and observation skills.

Finally, Cai et al. [31] proposed an AR simulation system in which students could control particles in micro-worlds and compose substances. This study was conducted in a junior high school for the chemistry course. Through data analysis, the authors concluded that the AR tool improved the learning outcome and helped students to develop different skills such as problem solving and inquiry-based exploration skills.

Leveraging the aforementioned studies, AR and ARGBL have proved to be advantageous in enhancing performance and learning experiences, developing skills (e.g., problem solving, inquiry-based exploration, observation) and fostering motivation, engagement, attention and interest. Moreover, through AR, students can learn and interact with virtual and real objects in a more intuitive way. Therefore, teachers should integrate such innovative applications which place emphasis on the design of more natural and realistic representations of complicated problems of everyday life into the educational process. However, AR and ARGBL pose some limitations and challenges. Due to the technologies' novelty, proper training and guidance should be provided to both students and teachers [29]. In addition, according to Tobar-Muñoz et al. [35], sometimes there is a gap between designers and teachers in conceiving learning. It is thus important to involve both designers and teachers in the design and development of such AR tools, in order to create a proper learning experience in the classroom that would be only beneficial.

4. Application Description

An ARGBL application for the physics course of the fifth grade in a primary school was developed and evaluated in the present paper. The application follows the new technological developments of smart mobile devices and introduces the concept of AR to the students. Since the purpose of the ARGBL application is both to educate and entertain, a treasure hunt game was implemented, which allows students to interact with a digital world and to manipulate virtual objects with the use of an AR device. They have to discover all the materials in order to conduct the AR experiment, according to the instructions that correspond to each experiment.

4.1. System Overview

In this section, the system overview of the ARGBL application is presented. The system consists of the following components: (a) a smartphone device (hardware), and (b) the Unity platform (software), as shown in Figure 1. More analytically, the ARGBL application was implemented using the free version of the Unity game engine and C# as the programming language. The Unity platform was chosen because Unity software is powerful, easy to use and free [36]. Vuforia SDK was also used to ensure a better AR experience. At first, Unity sends the virtual content to the ARGBL application. Then, the input device, which is the camera of the smartphone, scans the QR code of the textbook and sends the real content to the ARGBL application. Subsequently, the ARGBL application processes the virtual and the real contents and finally displays the augmented content through the smartphone screen, which is the display device.
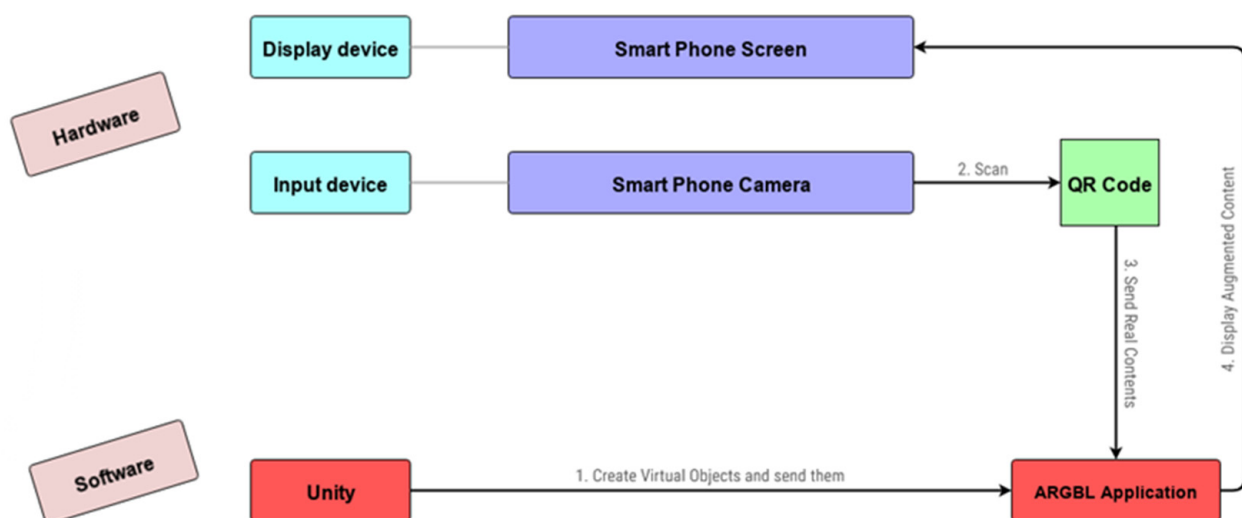

Figure 1. Application components.

In Unity, there is a set of elements which together form a game. These elements play a major role in making the game interactive as well as adding features that can vividly express the objective of the game. The proposed ARGBL application includes the following elements: 41 scenes, 88 scripts, 17 packages, hundreds of assets and thousands of 3D gameobjects and prefabs.

4.2. Suite of Applications

The suite of applications is a collection of six experiments, where each experiment corresponds to one of the six chapters of the fifth grade textbook. According to the curriculum of the 2019–2020 school year, the chapters are: (a) material bodies, (b) energy, (c) digestive system, (d) heat, (e) electricity and (f) light. More analytically, on the start screen (Scene 1), there are six buttons which correspond to the chapters of the book (Figure 2). By selecting a chapter, the application sends the user to the next scene (Scene 2), which is composed of the available experiment.
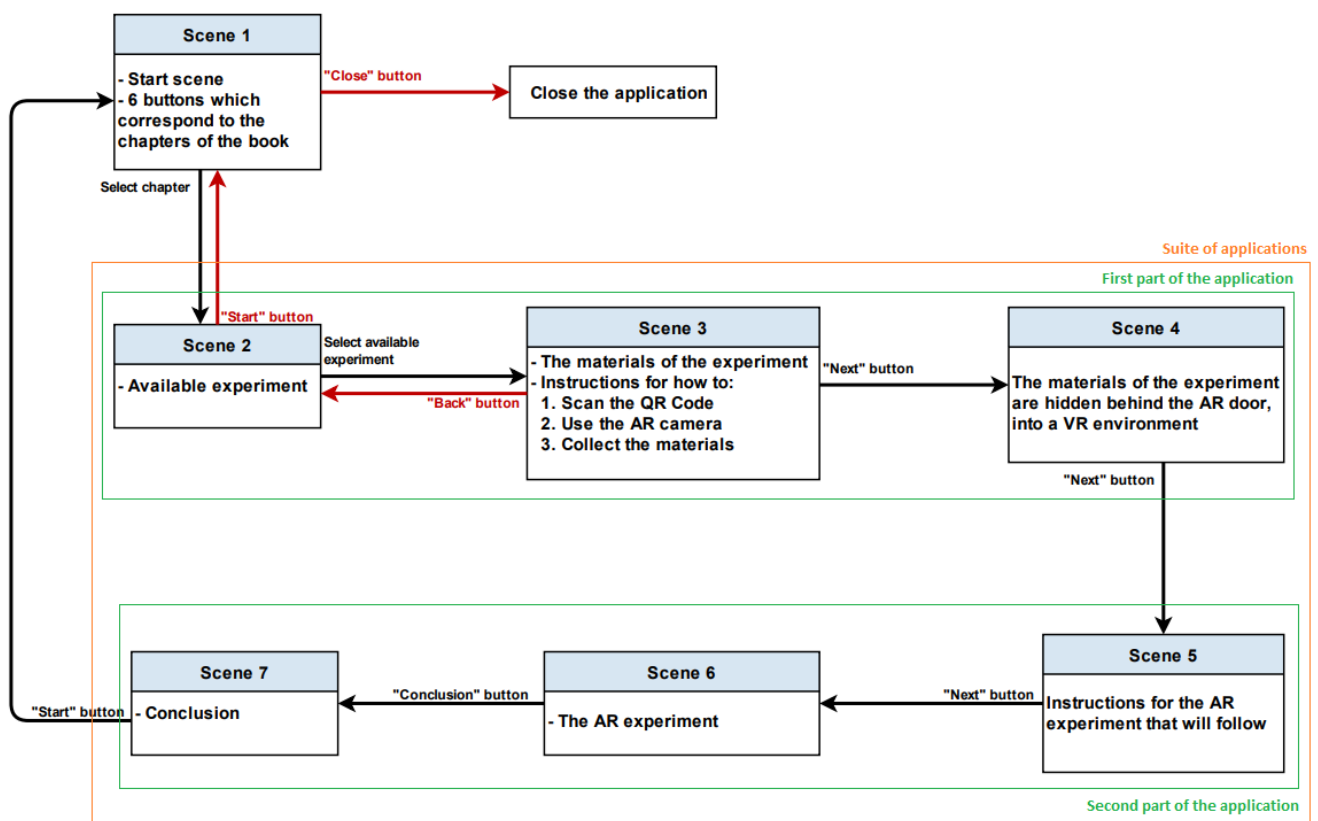
Figure 2. Application sub-components.

According to the student's choice, instructions are displayed (Scene 3) about how the experiment will be performed using the AR technology. In the next scene (Scene 4), the camera of the user's device is activated, and by scanning the QR code of the textbook page where the experiment is located, an AR door appears. Entering the door, the user is immersed into a VR environment. There are hidden virtual objects that must be collected in order for the educational experiment to be implemented, by using AR. At the bottom of the screen, there is a list with all the materials of the experiment which are hidden behind the AR door. In order for the user to proceed with the experiment, they must first collect all the materials by clicking on them in the VR world. Then, the materials are automatically checked in the list. It is basically a treasure hunt game, representing the first part of the ARGBL application which is for entertainment purposes.

Once the student has collected all the necessary materials for the experiment, instructions for the experiment that will be followed are displayed (Scene 5). After scanning the QR code of the textbook page for the selected chapter again, the available experiment is displayed (Scene 6). The available experiments are performed differently by the user, meaning that each experiment has a different process, instructions and learning outcomes. Moreover, with the teacher's guidance, a fruitful discussion takes place in order for students to draw a conclusion. At the bottom of the screen, there is the "conclusion" button which leads the student to the next and the last screen (Scene 7), which consists of the conclusion. This represents the second part of the application which is for educational purposes.

4.2.1. Experiments

As already mentioned, six (6) experiments were formulated, and each one consists of Scenes 2–7 (Figure 2). Scenes 2, 3, 5 and 7 are almost the same in all experiments, with minor changes in their content. The scenes that differ are Scene 4 and Scene 6. Table 1 analytically describes the process of each experiment.

Table 1. Process of each experiment.
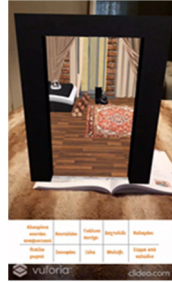
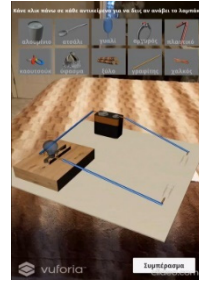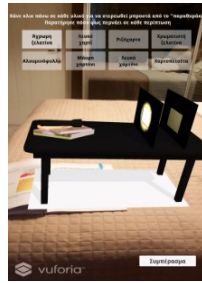| Scene \ No	#1 Section: Material Bodies—Mass	#2 Section: Energy	#3 Section: Digestive System—The Food Journey	#4 Section: Heat—Temperature and Heat	#5 Section: Electricity—Conductors and Insulators	#6 Section: Light—Transparent, Semi-Transparent and Non-Transparent Bodies
Scene 4: QR Code	AR door and VR room representing a patisserie shop	AR door and VR room that is a warehouse	AR door and VR room that looks like a living room	AR door and VR room that is a living room	AR door and VR room that represents a bedroom	AR door and VR room that looks like a corporate office
Scene 6, step 1: AR experiment	(a) AR table with all the products; (b) 8 buttons corresponding to the 8 product combinations; and (c) "conclusion" button	(a) AR circuit; (b) 2 buttons corresponding to the two modes (Connect/Disconnect); and (c) "conclusion" button	(a) AR table with all the products is displayed; (b) once the experiment is completed, the "conclusion" button appears	(a) AR electric stove with a water pot and a thermometer; (b) start button (5 min count starts); (c) "conclusion" button (appears after 5 min)	(a) AR circuit; (b) 10 buttons corresponding to the 10 materials; (c) "conclusion" button	(a) AR table with a torch emitting light and a cardboard window; (b) 8 buttons corresponding to the 8 materials that must be placed in the cardboard window; (c) "conclusion" button

Table 1. *Cont.*

Scene \ No		#1 Section: Material Bodies—Mass	#2 Section: Energy	#3 Section: Digestive System—The Food Journey	#4 Section: Heat—Temperature and Heat	#5 Section: Electricity— Conductors and Insulators	#6 Section: Light— Transparent, Semi-Transparent and Non-Transparent Bodies
Scene 6, step 2: Interaction		Find 3 of the 8 combinations with which the scale is balanced	Interact with the AR circuit and observe the light bulb in both situations	Click on the materials in the correct order to perform the experiment	Measure the temperature every minute for 5 min	Select each one of the materials and observe the behavior of the light (if the light is on or not)	Click on any material, put it between the torch and the cardboard window and notice how much light passes through
Scene 6, step 3: Conclusion		*"Mass is a characteristic property of all bodies. When the masses on the scale are equal, then the scale is balanced."*	*"The light does not illuminate when the battery is disconnected from the circuit."*	*"Liquid dish soap dissolves oil, as saliva helps break down food starch and bile dissolves fats during digestion."*	*"Part of the energy is released when the gas burns. This part of the energy is absorbed by the water. Therefore, the water temperature rises."*	*"The materials are classified into conductors (if the light is on) and insulators (if the light is off)."*	*"Material bodies are characterized as transparent, semi-transparent and non-transparent, depending on the amount of light they allow to penetrate."*

Two Indicative Examples

In this section, two indicative examples of the experiments are presented. Firstly, the example of the "Electricity" experiment which belongs to the section of "Conductors and Insulators" is described. This section begins with an introductory stimulus and is followed by an experimental approach. More analytically, the introductory stimulus is presented through a school textbook comic, where "Lampakis" and "Volfraimios" (Tungsten) are the main characters. The following information is provided to the students: the material of which the wire in incandescent bulbs is made is called tungsten. Then, the students are asked to read the dialogues in the comic, in order to describe the problem that Lampakis and Volfraimios are faced with. The problem is that the light bulb of the circuit they made by using a rope instead of a cable does not light up. At the end of the introductory stimulus, the teacher helps the students to make assumptions about possible materials that can be used in a closed electrical circuit, in order to light the bulb.

The experimental approach that follows helps students find out that while some materials allow electricity to flow, others do not. The materials of the experiment appear through some virtual objects, as shown in Table 2.

Table 2. Objects and the materials they are made of for the "Electricity" experiment.

Object	Material
Aluminum refreshment can	Aluminum
Spoon	Steel
Glass	Glass
Ring	Silver
Straw	Plastic
Baby's dummy	Rubber
Beanie	Cloth
Wood	Wood
Pencil	Graphite
Wires	Copper

The AR experiment is carried out with the guidance of the book and the teacher. At first, an electrical circuit is displayed above the QR code of the textbook, using the technology of AR. In addition, at the top of the screen, there are ten buttons that correspond to the ten materials/objects of the experiment. By selecting each button, the corresponding object is placed between the connectors of the electrical circuit. The student, after observing the behavior of the light, notes down the materials with which the light can be turned on or not in the provided table of the textbook. The teacher leads a discussion in the class, through which the students will formulate the conclusion. The teacher also introduces the terms of "conductor" and "insulator" and explains them to the students. The teacher then urges them to classify the materials studied in the above experiment into conductors and insulators. Finally, the following conclusion is drawn in the school textbook:

- Conductors: aluminum foil, steel, silver, graphite and copper.
- Insulators: glass, plastic, rubber, cloth and wood.

At the bottom of the screen, there is a "conclusion" button, which leads to the next screen which consists of the conclusion of the experiment, for the students to check the correctness of their answers. After completing the above experiment, the learning objectives that are desired to be achieved by the students are to experimentally establish the existence of conducting and non-conducting materials and to understand the concepts of conductors and insulators.

Another indicative example, which is the experiment of the "Digestive system" experiment which belongs to the section of "The food journey", is presented. Similar to the previous example, it includes two parts, the stimulus and the experiment. In the introductory stimulus, the students are asked to chew bread. Then, it is explained by the teacher that bread contains a substance called starch, and it is stated that saliva breaks down food

starch. The following experiment helps the students to understand the above introductory stimulus, by drawing a parallel between saliva (which breaks down starch) and liquid dish soap (which breaks down oil).

At first, a table in which all the materials of the experiment are placed is displayed above the QR code of the textbook, using the technology of AR. The goal of the experiment is that the student, after carefully reading the instructions provided by the textbook, has to "click" on the materials placed in the AR table in the correct order. At the top of the screen, there is a text prompting the student to "Click on the materials in the correct order to perform the experiment". The correct order, according to the presentation of the textbook, is: water, oil, straw, liquid dish soap and straw. The experiment consists of the steps shown in Table 3. At first, a glass is filled halfway with water, and then a few drops of oil are added. The students have to mix the solution well with the straw. They should also notice that the oil does not dissolve in the water, but floats on it. In the second phase of the experiment, a small amount of liquid soap is poured into the glass with water and oil, and after mixing well with the straw, it should be observed by the students that after adding the dishwashing liquid, the oil dissolves and mixes with the water. Finally, the students learn the usefulness of saliva for the dissolution of food starch and the usefulness of bile in the function of digestion.

Table 3. The experiment for "Digestive system" step by step.

No. of Step	Click on	Action
#1	Water bottle	Put water into the glass
#2	Oil	Put oil into the glass
#3	Straw	Stir the mixture
#4	Dish soap	Put liquid into the glass
#5	Straw	Stir the mixture

The conclusion is established with appropriate questions and discussion in class. Students should be aware that the effect of liquid dish soap on oil is the same as the effect of bile on food fats. Finally, students are asked to formulate the following conclusion: "Liquid dish soap dissolves oil, as saliva helps break down food starch and bile dissolves fats during digestion". Once step 5 is completed, the "conclusion" button appears at the bottom of the screen, which leads to the screen with the final conclusion. Moreover, students can check if their answers are correct.

All the experiments are available online (Part 1: https://www.youtube.com/watch?v=0ST0fkDIFEY, accessed 6 August 2021 and Part 2: https://www.youtube.com/watch?v=8jnbmKPim5U, accessed 6 August 2021).

5. Pilot Experiment

The pilot experiment was conducted through a combination of qualitative and quantitative methods. An unstructured interview along with participant observation was carried out to gather qualitative data. This combination of methods aimed to gain insight about the experience of both students and teachers. Regarding the quantitative method, a questionnaire was administered to all participants aiming to evaluate the system's usability. For the system's usability, we used the system usability scale (SUS) which was developed by Brooke [37] as a quick and dirty survey to evaluate the usability of a given system. The SUS test was used because (a) it provides a single score, (b) it is technology-independent and this makes it quite flexible for the system we had to evaluate, (c) it is easy to handle, (d) the questionnaire is nonproprietary and this makes it cost-effective, (e) it is highly effective in terms of reliability [38] and validity [39], (f) it is translated in Greek [40] and (g) it provides reliable results even with a small sample size [39].

5.1. Participants

The study took place at an Elementary School of, Thessaloniki, Greece, during the winter period (January 2021). Fourteen (14) students and three (3) teachers participated in the study. The average age of the students was 10 years. The three teachers who took part in the experiment process had extensive teaching experience (more than 10 years).

All students and teachers volunteered to participate in the activity as part of their everyday school activities. Before the experiment took place, there was a training session with the teachers of the classroom about the implementation of the experiment. The experiment was part of the current school curriculum so that the flow of the school curriculum would not be disturbed, and it was performed within the class hour (duration of 45 min). The students were randomly assigned to work in dyads, forming seven (7) student groups in total, while teachers participated as instructors.

5.2. Setting

Experiments were conducted in classrooms that were offered by schools for this purpose. The classrooms were adequately arranged so that the system was accessible for all students. The system was projected on the whiteboard of the classroom, by the instructor, to be visible to everyone. Additionally, the system was provided to each student group through a smart mobile device.

5.3. Material and Procedure

Students, their parents and teachers were informed about the pilot study one week before the experiment. The lesson was started with an introductory stimulus related to the experiment by the teacher/instructor. Then, the instructor provided instructions and guidelines to the students on how to use the system. The execution steps of the experiment were displayed simultaneously on both the whiteboard of the classroom through the projector, and the screen of the mobile of each dyad of students.

Data were collected through an unstructured interview, participant observation and a questionnaire. Specifically, during the experiment, participants were observed regarding how they react and behave. At the end of the experiment, questionnaires were distributed to both students and teachers in printed form and were answered individually. The completion of the questionnaires was conducted in the same classroom, always in visual contact with the system. After that, an unstructured interview was carried out with the three (3) teachers.

The collected data from questionnaires were organized in Microsoft Excel 2019 and were analyzed using IBM SPSS Statistics v23.0. The system usability scale (SUS) test was translated in Greek and was administered to the students in printed form after the interaction with the system.

6. Results and Discussion

6.1. Evaluation of Quantitative Method

The data collected from the questionnaires in the pilot, along with the mean values and standard deviations for the students and teachers in each question, are presented in Table 4. The overall SUS score was 84.642 (sd 5.773) for the students, while the score for the teachers was 78.333 (sd 10.735). In both cases, the score is quite satisfactory and shows that the system was quite usable for both students and teachers.

Table 4. Mean values and standard deviations of students' and teachers' responses.

Item	English Version of SUS	Student Responses Mean (Std)	Teacher Responses Mean (Std)
Q1	I think that I would like to use this system frequently	4.071 (0.997)	4.6667 (0.577)
Q2	I found the system unnecessarily complex	1.285 (0.611)	1.6667 (0.577)
Q3	I thought the system was easy to use	4.5 (0.854)	4.0000 (0.000)
Q4	I think that I would need the support of a technical person to be able to use this system	1.785 (1.050)	2.3333 (1.527)
Q5	I found the various functions in this system were well integrated	4.571 (0.646)	4.0000 (0.000)
Q6	I thought there was too much inconsistency in this system	1.785 (1.050)	2.3333 (0.577)
Q7	I would imagine that most people would learn to use this system very quickly	4.714 (0.468)	4.3333 (0.577)
Q8	I found the system very cumbersome to use	1.357 (0.497)	1.6667 (0.577)
Q9	I felt very confident using the system.	4.428 (0.755)	4.0000 (1.000)
Q10	I needed to learn a lot of things before I could get going with this system.	2.214 (1.476)	2.3333 (0.577)

More analytically, the average SUS score of the ARGBL application is acceptable for teachers (over 75), while the score for students is relatively high (84.642). This could be explained by the fact that the system worked properly. Although the experiment was successful for both students and teachers, there was a concern about how the students would manage to use the system to conduct the physics experiment. The fact that students are familiar with such devices along with the daily usage of them made it easier for them to handle the device and successfully complete the experiment. However, this led the students to ask questions about the process of the experiment, e.g., how to collect the experiments' materials from the VR room. Although there were written instructions on the screen, students were overwhelmed by the virtual world and, as a result, did not read them. A possible solution to this could be the use of tablets, since the instructions on bigger screens might easily be "caught by the eye".

6.2. Evaluation of Qualitative Method

Based on the observation data, we noticed that most of the students had the curiosity to try new activities, including conducting experiments using the AR technology through smart devices. Therefore, teachers should try innovative instructional methods, tailored to new requirements relating to the ARGBL application. It is worth mentioning that teachers should conduct a training session for students about how to use the system and how to interact with the QR code, before the experiment takes place. In addition, the performance of QR code recognition is mainly based on lighting conditions. The virtual objects formed under weak light conditions may twinkle at times. As a result, teachers are required to adapt the classroom properly in terms of lighting.

According to the unstructured interview with the teachers about their experience, they supported that the group of two students rather than larger groups is more preferable. It was also mentioned that small groups (two or three students) work better than larger groups, not only in the collaboration between the team members but also in the time that the system is used by each member, a fact that positively triggers students' motivation, engagement and teamwork. Nonetheless, groups of two students would require a lot of equipment (number of smart devices), in the case of a larger sample. Last but not least, the teachers agreed on the fact that the ARGBL application is more advantageous, since it can run offline, without the need of an internet connection. This makes it a lot easier to be used in areas of limited WiFi or data connectivity, such as schools. The students can use the ARGBL application instantly without any delays or internet difficulties. On the

other hand, applications that work offline do not provide the functionality of interaction to users. In the ARGBL application, the interaction between users is conducted face to face in a classroom. This means that a discussion between the students as well as between the teacher and the students is necessary to evolve the learning process.

7. Conclusions and Future Work

Leveraging the aforementioned findings, an ARGBL application was proposed for the implementation of physics experiments in the fifth grade of a Greek primary school. The application is both educational and entertaining, since the students have to conduct a physics experiment by playing an AR treasure hunt game. A pilot experiment was conducted, and a questionnaire was administered to all participants, both students and teachers, in order to investigate the usability of the system. Moreover, this study explored the opinions and the preferences of the participants by the process of unstructured interviews and observations. The results of the pilot experiment are very promising, since the system's usability was satisfactory, revealing that the proposed ARGBL application can provide added value to the educational community. More specifically, what we learned, which is in accordance with the literature review, is that students had a positive attitude towards using the system for their learning process since they fully engaged with it [15,28,30]. In addition, both teachers and students supported that the use of the ARGBL application can attract students' attention and increase their learning motivation [10,29,30,33] in the physics course. Finally, a well-structured experiment should be followed by the teachers, including a training session of how students can use the system, how they can interact with the QR code and what the process of the experiment is.

However, the proposed system has some limitations that merit further consideration in future work. Firstly, although our analysis is robust in small samples, a larger-scale experiment is necessary. In the midst of the COVID-19 pandemic, it was hard to have an adequate sample size, due to fact that the Greek schools, most of the school year, were closed. Secondly, the ARGBL application refers to a specific subject, namely, physics experiments in the fifth grade of a Greek primary school; therefore, the research results cannot be generalized to other learning topics and to other age groups. Therefore, our future plans are to extend the learning content of our proposed ARGBL application to other age groups by adding more exercises and experiments. Additionally, a long-term experiment would be necessary to further investigate the usability of the system and to extract valuable results about the learning outcomes of the students.

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