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Augmented Reality in Primary Education: An Active Learning Approach in Mathematics

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Abstract: Active learning, a student-centered approach, engages students in the learning process and requires them to solve problems using educational activities that enhance their learning outcomes. Augmented Reality (AR) has revolutionized the field of education by creating an intuitive environment where real and virtual objects interact, thereby facilitating the understanding of complex concepts. Consequently, this research proposes an application, called "Cooking Math", that utilizes AR to promote active learning in sixth-grade elementary school mathematics. The application comprises various educational games, each presenting a real-life problem, particularly focused on cooking recipes. To evaluate the usability of the proposed AR application, a pilot study was conducted involving three groups: (a) 65 undergraduate philosophy and education students, (b) 74 undergraduate engineering students, and (c) 35 sixth-grade elementary school students. To achieve this, (a) the System Usability Scale (SUS) questionnaire was provided to all participants and (b) semi-structured interviews were organized to gather the participants' perspectives. The SUS results were quite satisfactory. In addition, the interviews' outcomes indicated that the elementary students displayed enthusiasm, the philosophy and education students emphasized the pedagogy value of such technology, while the engineering students suggested that further improvements were necessary to enhance the effectiveness of the learning experience.

Keywords: Augmented Reality; active learning; usability; primary school; mathematics

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1. Introduction

Technology has advanced so rapidly in recent years that it has transformed several domains, including education. One such technology that has gained significant attention is Augmented Reality (AR). AR provides users with an interactive and immersive learning experience by superimposing virtual elements onto the real world [1]. AR also has a lot of potential to improve teaching and learning, especially in primary grades. The basis for a child's future learning and development is laid throughout the crucial primary education stage of their academic career. Primary education has traditionally placed a strong emphasis on conventional methods like textbooks and still images to present educational content to young learners. However, these conventional methods often fail to actively engage students [2], whereas AR consistently promotes active participation [3]. Hence, incorporating AR into primary education can offer an opportunity to overcome these constraints and transform the learning process for students.

Various studies have highlighted the beneficial impacts of AR across educational disciplines like mathematics [4,5], physics [6,7], geography [8,9], and history [10,11]. For example, Cai et al. [7] found that AR tools enhanced student motivation, attention, and knowledge retention over conventional teaching methods. Similarly, Dunleavy et al. [12]

observed an improvement in spatial cognition and problem-solving capabilities among students using AR tools. Furthermore, the incorporation of AR in primary education is aligned with the active learning principles [13], which prompt students to actively participate in significant learning activities and critically evaluate their actions [14]. As noted by Prince [15], active learning fosters student engagement and knowledge retention and refines cognitive skills.

Therefore, although there are some studies that investigate the benefits of incorporating AR and active learning in primary education across various disciplines [16–18], there is little research that targets AR use specifically in mathematics [5]. Moreover, combining AR and active learning in primary mathematics could benefit the learning process in terms of engagement, the simplification of abstract mathematical concepts, interactive learning, immediate feedback, etc., resulting in a potential transformation of the way mathematics are taught in primary school. Considering the aforementioned factors, this paper proposes an AR application, called "Cooking Math", that includes several educational games aimed at teaching mathematical concepts, including but not limited to addition, subtraction, decimal numbers, and fractions, to sixth-grade elementary school students. Additionally, it investigates the usability of the AR application from three distinct groups, and it analyzes their feedback to improve the benefits of the learning experience. By exploring the use of AR as a tool for active learning in primary education, this paper intends to contribute to the research and inform educators and researchers about the transformative potential of this innovative technology in enhancing the teaching and learning experience for young students.

The structure of the paper is outlined as follows: Section 2 presents the integration of AR in primary school mathematics. Section 3 details the AR application and its associated educational games. The pilot study is introduced in Section 4, followed by the results and a discussion of its findings in Sections 5 and 6, respectively. Finally, the conclusions are presented in Section 7, while the limitations and future work are presented in Section 8.

2. Literature Review

Augmented Reality has emerged as a promising technology for enhancing primary education. Numerous research works have explored the integration of AR in primary mathematics education, shedding light on its impact and benefits. The interactive nature of AR technology allows students to visualize and manipulate three-dimensional objects by blending the virtual with the real world (as opposed to, for example, computer games placed in a virtual environment), fostering a deeper understanding of spatial concepts and geometry principles [19,20].

Several studies support students' conceptual understanding, problem-solving skills, and geometry learning outcomes. For instance, Flores-Bascuñana et al. [21] conducted a preliminary exploratory study on the use of AR for learning 3D geometric contents with sixth-grade primary students. The study demonstrated its potential to enhance geometric understanding, indicating that AR positively impacts students' attitudes towards learning mathematics. Cahyono et al. [22] explored the design and implementation of an AR-based learning environment for geometry instruction, highlighting the benefits of AR in enhancing elementary students' spatial reasoning skills and geometric understanding. Yixuan and Qiang [23] focused on the use of AR technology to teach three-dimensional graphics in primary schools. The study investigated the effectiveness of AR-based instruction, providing insights into how AR can be effectively utilized to teach three-dimensional graphics, enhancing students' understanding of spatial concepts, and improving their visualization skills. Sun and Chen [24] examined the effectiveness of using an AR app to learn geometry, specifically in the context of the volumetric measurement of compound bodies, in elementary schools in Taiwan, while Purnama et al. [25] developed a geometry learning tool using AR for elementary school students, both showing positive impacts on learning outcomes and engagement. Additionally, Husniah et al. [26] introduced GemAR, a geometry AR application designed for sixth-grade elementary school students, demonstrating its potential to enhance learning outcomes, engagement, and motivation, while Rossano et al. [27] developed an AR-based learning environment that effectively fosters student engagement, spatial visualization skills, and a conceptual understanding of geometry. Javaheri et al. [28] developed and evaluated the usability of an AR environment aimed at promoting spatial imagination in mathematics education for first- and second-grade elementary school students. Finally, Chen [29] and Arvanitaki and Zaranis [30] investigated the effects of AR on learning performance, motivation, and math anxiety in geometry, where the findings shed light on the potential benefits of using AR to improve learning outcomes and reduce math anxiety.

In addition to geometry, there are research studies that specifically concentrate on the branch of mathematics related to arithmetic. Li et al. [31] explored the utilization of AR in an innovative social learning game designed for elementary school students. The findings emphasized the AR game's positive influence on student engagement, collaborative problem solving, and social interactions, showcasing its potential to enhance learning experiences. Similarly, van der Stappen et al. [32] introduced MathBuilder, a collaborative AR math game for elementary school students, highlighting the benefits of using collaborative AR games in mathematics education. Rebollo et al. [33] focused on the development of an AR game, aiming to create an engaging and interactive learning experience for mathematics. The study evaluated the effectiveness of the AR game in improving students' math learning outcomes and engagement.

Finally, in the context of incorporating AR and active learning into primary school, Demitriadou et al. [5] developed an AR application for teaching geometric solids in primary education, because students frequently struggle with distinguishing between two-dimensional and three-dimensional geometric shapes. The findings revealed that AR not only improved the learning outcomes of students in understanding mathematical concepts but also significantly boosted their engagement and interest.

In summary, the aforementioned research papers collectively highlight the potential of AR in enhancing primary mathematics education. AR-based approaches, such as AR social learning games, geometry learning tools, and collaborative AR math games, have shown positive impacts on student engagement, problem-solving skills, spatial imagination, and geometry understanding. Furthermore, the integration of AR in primary mathematics education addresses the challenges in teaching three-dimensional graphics, promotes visualization skills, and contributes to improved learning outcomes and motivation. Therefore, the above studies provide valuable insights into the use of AR technology in primary school. However, due to the fact that research on the integration of AR and active learning in primary mathematics education remains scarce, the need for further exploration in the field has emerged.

3. AR Application: Cooking Math

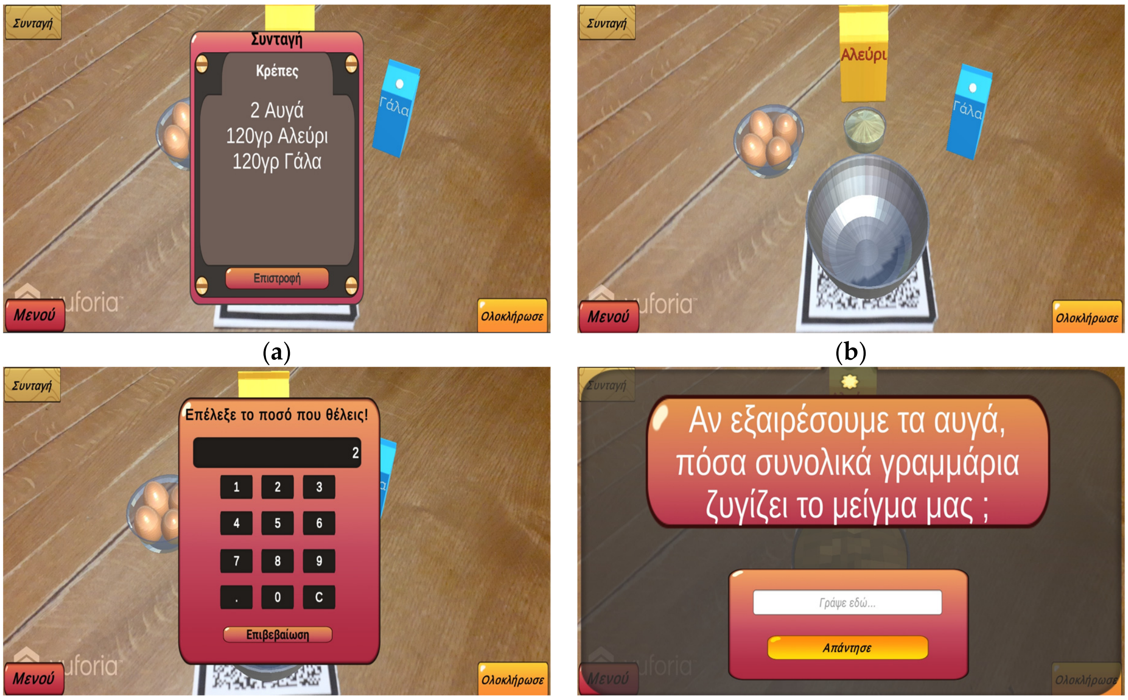
An AR application titled "Cooking Math" (Figure 1a) was developed that employs active learning strategies to facilitate the teaching of mathematics to sixth-grade elementary students. The AR application integrates several educational games, each specifically designed to teach topics such as addition, subtraction, decimal numbers, and fractions. These AR games are ingeniously framed within cooking recipes to ensure active student engagement and participation in the learning process. Specifically, the application features nine educational games (Figure 1b) tailored to the Greek mathematics curriculum for sixth-grade elementary students. Upon selecting a game, the device's camera, whether on a mobile or tablet, is activated, prompting the student to scan the designated QR code corresponding to a particular chapter in their school textbook. Once scanned, the game starts and provides the student with pertinent information for that specific game. The AR application was developed by using the Unity Game Engine and the Vuforia Engine. The current version is available in the Greek language, since it is provided to sixth-grade Greek elementary students, and can be downloaded from https://t.ly/RBu45 (accessed on 8 September 2023) for free (see Supplementary Materials). All nine educational games are described analytically below.

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

Figure 1. (**a**) The introductory interface with the two buttons, "Start" and "Exit". (**b**) The main menu with the 9 educational games.

3.1. Integer Numbers

The first educational game aims to teach *integers* through a basic recipe for making crepes. Firstly, according to the recipe (Figure 2a), the student drags an ingredient into the mixing bowl (Figure 2b) and then the quantity selection interface appears (Figure 2c), where the student has to choose the appropriate quantity for each ingredient. The procedure is iterated for every ingredient and can be conducted in any sequence. Upon adding all the ingredients, a question is presented that features a basic integer addition problem, asking the student to determine the cumulative weight of the mixture by summing up the individual ingredient quantities (Figure 2d).

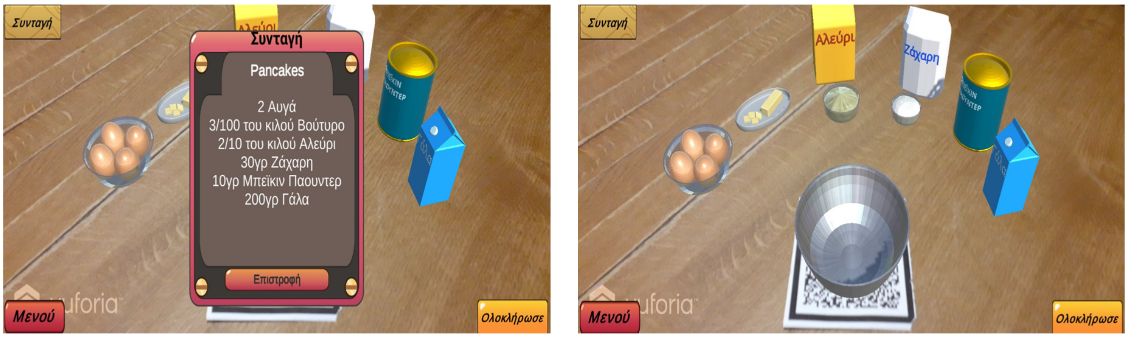


(**a**) (**b**) (**c**) (**d**)

Figure 2. (**a**) The recipe interface using integer numbers. (**b**) The main game interface. (**c**) The ingredient quantity selection interface. (**d**) The concluding question interface.

3.2. Fractional Numbers

The second educational game delves into the concept of *fractional numbers* through a pancake-making recipe. The gameplay mechanics and the logic mirror those of the previous game. Therefore, the student is required to drag an ingredient (Figure 3b) and then determine the appropriate quantity for it based on the recipe provided (Figure 3a). Certain ingredients in this recipe are represented as fractions of a kilogram.

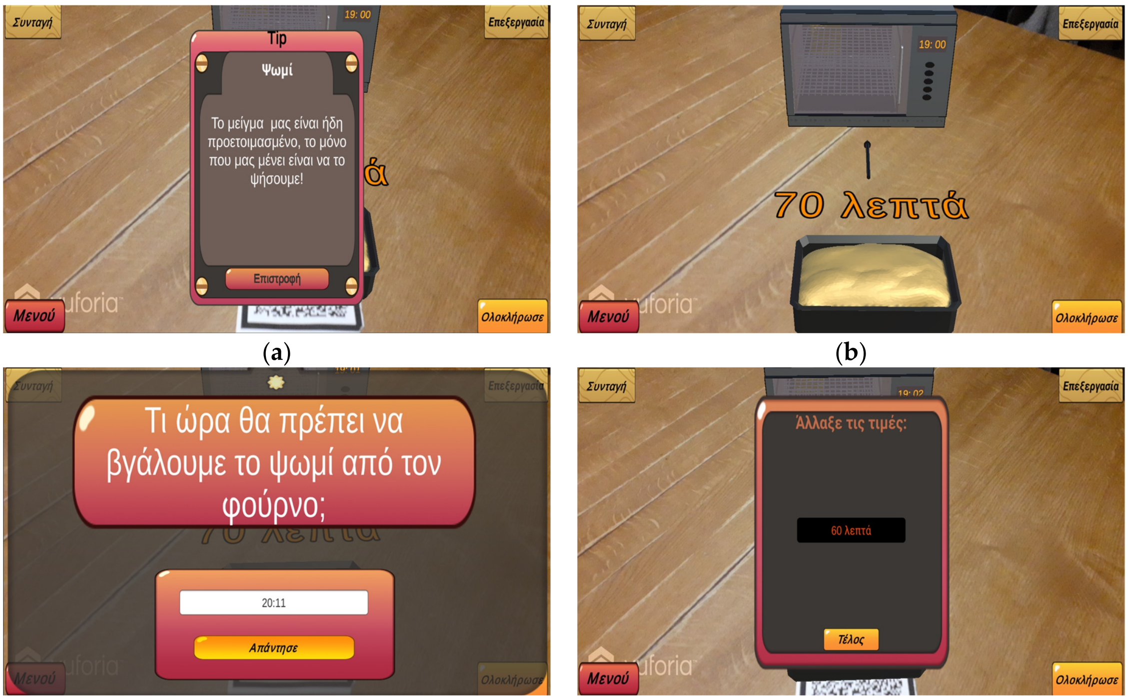


(**a**) (**b**)

Figure 3. (**a**) The recipe interface using fractional numbers. (**b**) The main game interface.

3.3. Mixed Numbers and Time Measurements

The third game is designed to familiarize students with *mixed numbers*, which combines a whole number with a fraction, using time measurements as a context. The objective is to bake the bread accurately. The game initiates by presenting an informational message to the student (Figure 4a), and then the current time and the baking duration for a pre-mixed dough are displayed to the student (Figure 4b). After that, the student is prompted to accurately calculate the appropriate time to remove the bread from the oven (Figure 4c). This game is a time calculation exercise, relying on the present time and a provided fractional time interval. An additional feature allows the teacher to modify the desired baking interval by clicking on the top-right button (Figure 4d).



(**a**) (**b**)
(**c**) (**d**)

Figure 4. (**a**) The informational message; (**b**) the main game interface; (**c**) time calculation interface; (**d**) editing interface.

3.4. Rule of Three

The fourth game introduces students to the *Rule of Three*, which is a method for solving problems centered on proportions. This game comprises two parts: a theoretical one and a practical one. In the theoretical part, the student first receives an informational message (Figure 5a). Then, the student is directed to drag the tea bag into a cup of water (Figure 5b) and subsequently observe a brief animation (Figure 5c).

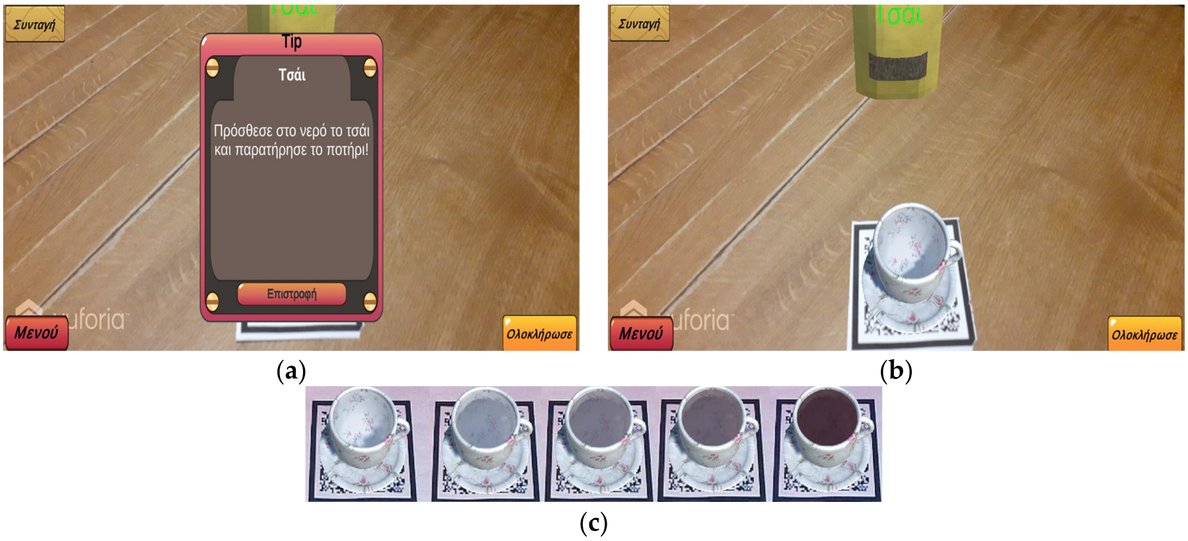
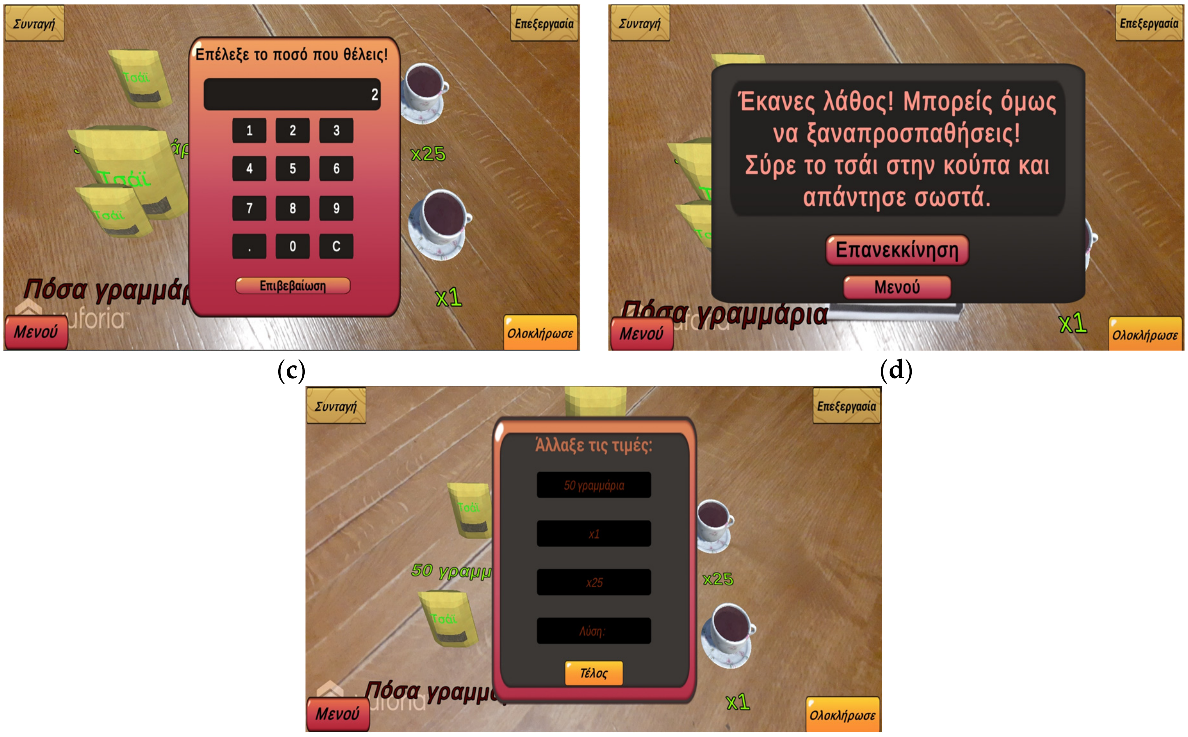


Figure 5. (**a**) The informational message; (**b**) the main game interface; (**c**) the tea animation.

In the practical part, the student engages in an exercise based on the "Rule of Three". This part starts with a concise description of the task, which asks the student to calculate the grams required to prepare a single cup of tea (Figure 6a). The student is first prompted to drag the tea bag (Figure 6b), after which the quantity selection interface appears (Figure 6c). If the student provides the correct quantity and successfully completes the game, they can move on to the next game. Conversely, if the student's response is incorrect, an error prompt emerges, urging the student to attempt the task again (Figure 6d).

Additionally, there is an option (top-right button) to modify the exercise variables to more comprehensively address challenges related to the "Rule of Three" (Figure 6e).

Figure 6. *Cont.*

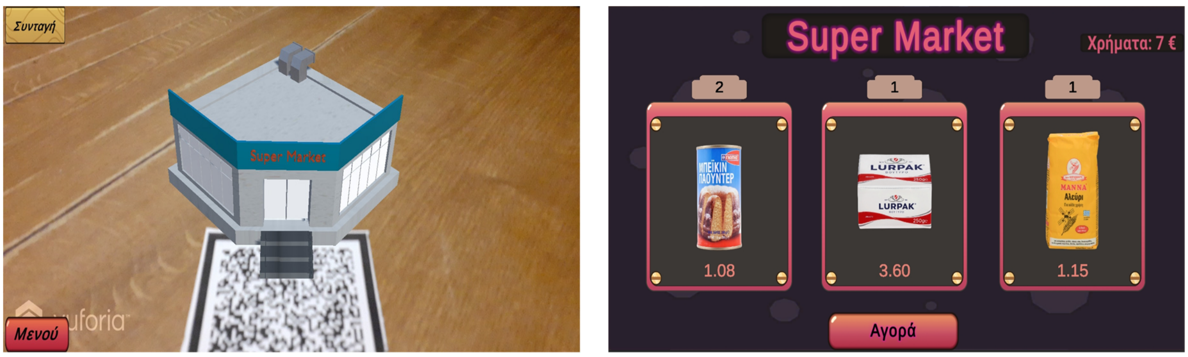


(**c**) (**d**) (**e**)

Figure 6. (**a**) The informational message; (**b**) the main game interface; (**c**) the calculation interface; (**d**) the feedback with the error prompt; (**e**) the editing interface.

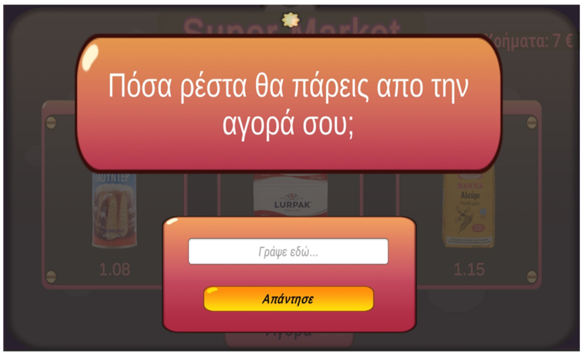
3.5. Decimal Numbers

The fifth game refers to the topic of *decimal numbers*. To illustrate this mathematical concept, a real-world supermarket scenario is employed. The student's goal is to purchase certain products required for subsequent recipes, and then, based on their available funds, determine the remaining balance. Initially, a 3D representation of a supermarket is presented to the student (Figure 7a). By selecting the door, the student gains entry to the supermarket. Subsequently, three products, along with their respective prices, are displayed, and the student, after making the product selection, presses the bottom-middle button (Figure 7b). Following this, the student is tasked with calculating the remaining amount of money that they possess (Figure 7c).



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

Figure 7. *Cont.*

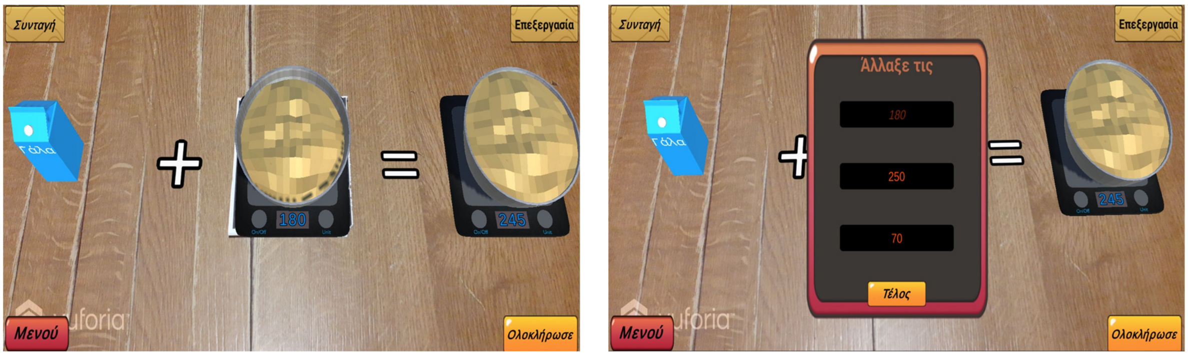


(**c**)

Figure 7. (**a**) The 3D representation of a supermarket. (**b**) The product selection interface. (**c**) The calculation interface.

3.6. Equations

The sixth educational game is centered on *equations*, focusing particularly on simple first-degree equations wherein the unknown "x" is deduced from two known quantities. To model such an equation, a scenario is developed in which the student has a donut dough ready, yet it lacks a specific quantity of milk for completion. The only clues provided are related to the dough's weight and a specified weight limit that it must not surpass (Figure 8a). Therefore, the student has to calculate the exact quantity of milk to solve the problem. Note that similar to other games, this game provides the capability to adjust and modify its parameters through an editing interface (Figure 8b).



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

Figure 8. (**a**) The main game interface. (**b**) The editing interface.

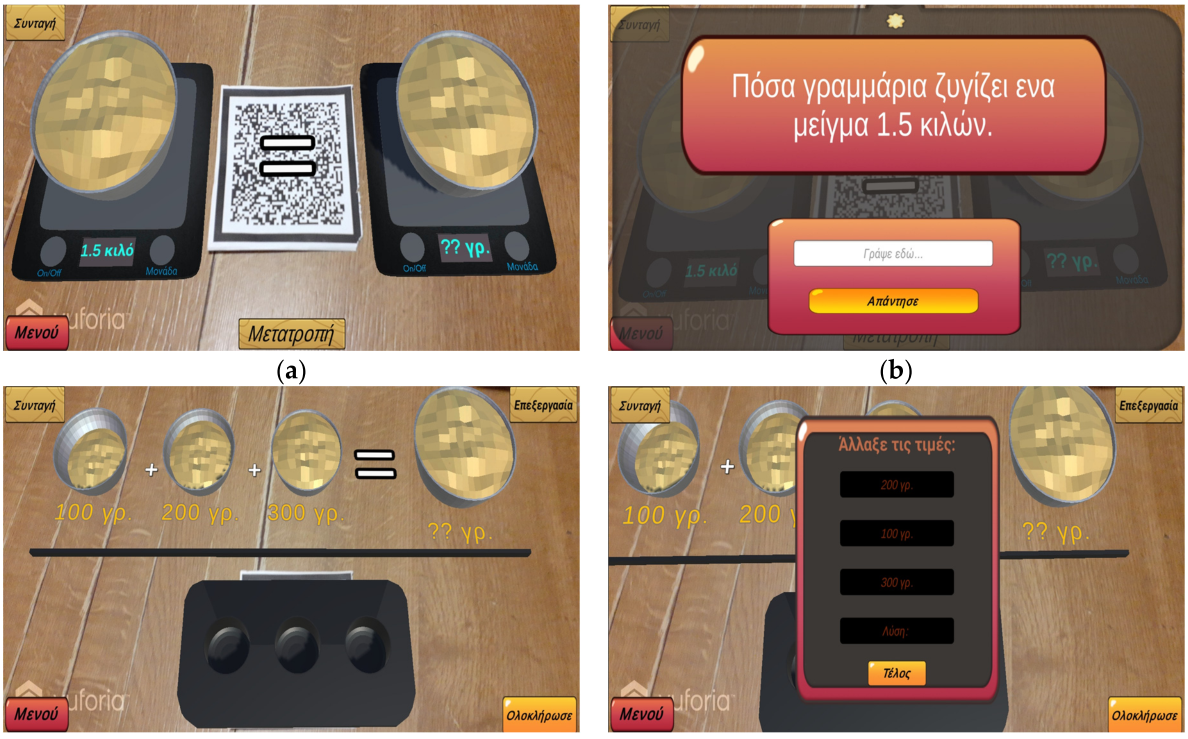
3.7. Ratios and Percentages

The seventh game is designed to instruct students on the concepts of *ratios* and *percentages*. This game comprises three distinct parts, each representing a portion of a walnut pie recipe. Initially, in the first part, the student adheres to a basic recipe, carefully adding specified ingredient quantities to a mixing bowl (Figure 9a). Then, a ratio problem centered on the quantity of eggs and sugar employed in the preceding step is presented to the student (Figure 9b). In the second part, the student has to prepare the syrup (Figure 9c), which is crucial for the walnut pie's final steps. This part mirrors the straightforward nature of the first part, with the student incorporating the appropriate quantities of each ingredient (Figure 9d). The recipe's final segment introduces a percentage-based problem. Here, the student is made aware that the culmination of the walnut pie preparation involves the integration of the previously concocted syrup. However, the syrup's quantity to be incorporated is presented in percentage terms (Figure 9e,f). Furthermore, within this game, teachers have the flexibility to adjust the problem parameters.

Figure 9. (**a**) The walnut pie preparation. (**b**) The ratio exercise. (**c**) The syrup recipe. (**d**) The syrup preparation interface. (**e**) The informational message. (**f**) The percentage exercise.

3.8. Measurements

The eighth game explores the concept of *measurements* and consists of two parts. In the initial part, the emphasis is on weight conversion. By selecting the bottom-middle button (Figure 10a), the student is prompted to transform the mixture's weight from kilograms to grams (Figure 10b). Upon the completion of this part, the student transitions to the subsequent section, which introduces the principle of averages. Here, the student is apprised that there remains a sufficient quantity of the previous mixture to craft additional small cakes. This mixture, however, is partitioned into distinct small bowls. The challenge lies in determining how to equitably distribute the entire mixture across the three designated compartments of the provided baking form (Figure 10c). In a manner consistent with the earlier games, the student provides the solution by dragging the collective mixture towards the baking form before them. Furthermore, an option to adjust the game's parameters is made available (Figure 10d).

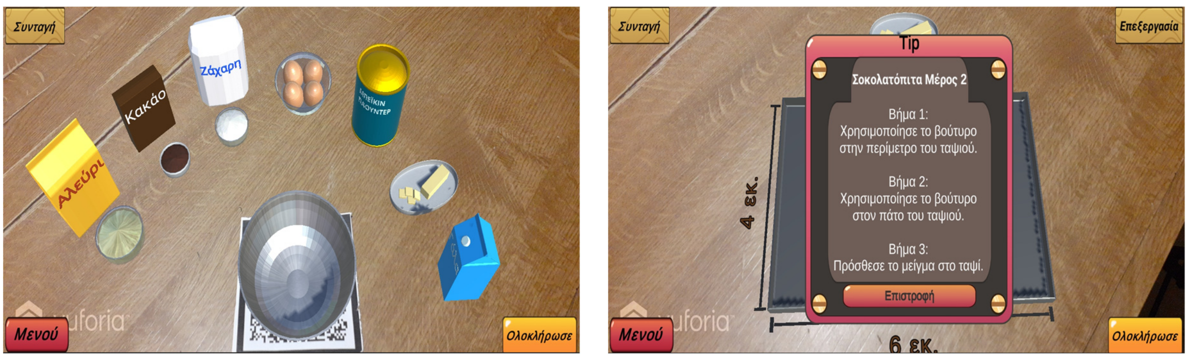


(**a**) (**b**) (**c**) (**d**)

Figure 10. (**a**) The weight measurement interface. (**b**) The calculation interface. (**c**) The average calculation interface. (**d**) The editing interface.

3.9. Geometry

The ninth educational game addresses *geometry*, specifically the concepts of perimeter, area, and volume. The game's aim is to guide students through a chocolate cake recipe, which is segmented into two parts. The initial part involves the preparation of the mixture for the chocolate cake, in which the student, based on the recipe provided, adds the correct quantity of ingredients one by one to the mixing bowl (Figure 11a). Advancing to the recipe's subsequent part, an informational message outlining a three-step process is presented to the student (Figure 11b). A rectangular parallelogram-shaped oven pan is displayed with its side dimensions articulated in meters (Figure 11c). As the student attempts to butter the oven pan, a query arises prompting them to compute the pan's perimeter (Figure 11d), followed by its area (Figure 11e). In the concluding step, the student pours the cake mixture into the oven pan, and the culminating question focuses on the pan's volume (Figure 11f). Notably, this game also offers the flexibility to adjust the parameters.



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

Figure 11. *Cont.*

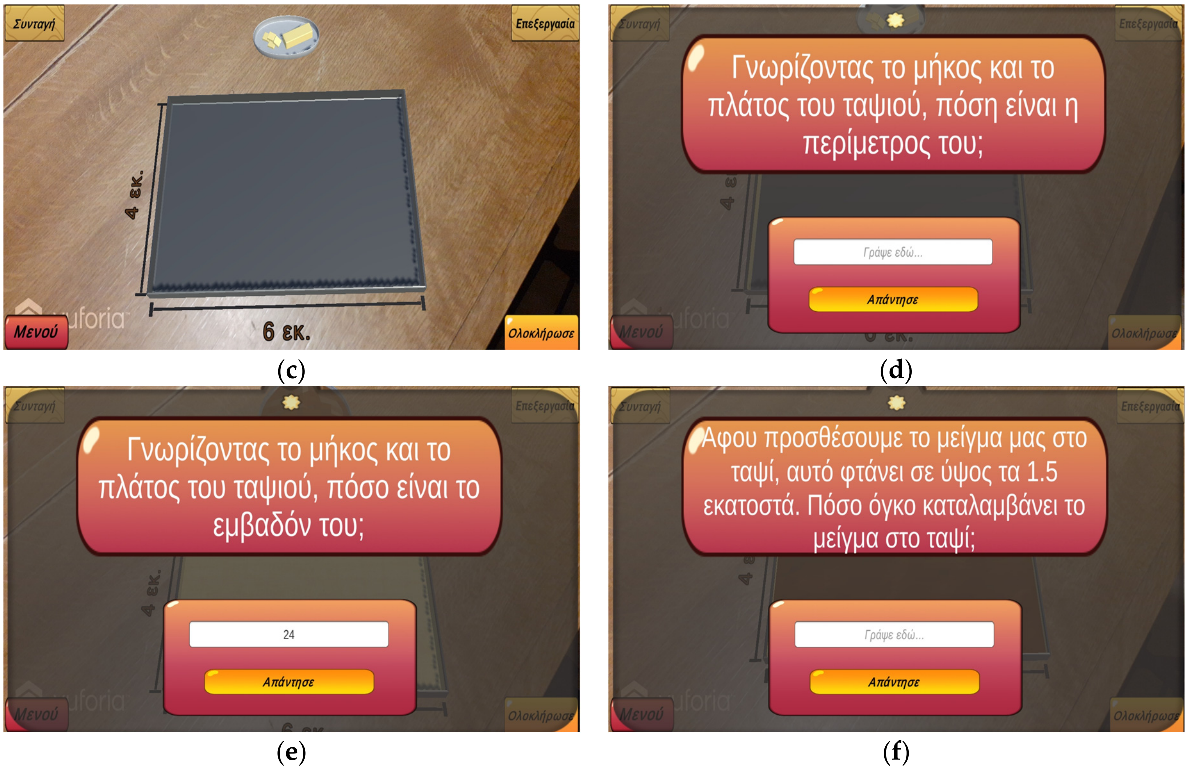


Figure 11. (**a**) The chocolate cake preparation. (**b**) The informational message. (**c**) The main game interface. (**d**) The perimeter calculation interface. (**e**) The area calculation interface. (**f**) The volume calculation interface.

Finally, it worth mentioning that in order to achieve consistency, there are three buttons across all nine games: (a) the top-left button that allows the student to revisit the recipe; (b) the bottom-left button that facilitates the student to return to the main menu; and (c) the bottom-right button that is used to complete the game.

4. Pilot Experiment

4.1. Participants

To evaluate the usability of the AR application, an experiment was conducted involving 174 participants from Greece (see Table 1 and Figure 12), divided into three distinct groups:

1. Undergraduate students of the Department of Philosophy and Education at the Aristotle University of Thessaloniki (AUTH) in the course of Teaching Methods and New Technologies (eighth semester);
2. Undergraduate students of the Department of Information Technology and Electronic Systems Engineering at the International Hellenic University (IHU) in the course of Human Machine Interaction (fifth semester);
3. Sixth-grade students from the third Public Elementary School of Florina in the course of Mathematics.

Table 1. Participants.

	Philosophy and Education Students	Engineering Students	Elementary Students	Total
Participants	65	74	35	174

Figure 12. Participants.

All participants were informed about the experiment and voluntarily participated by giving their consent. In the case of the elementary students, their parents provided the consent.

4.2. Material and Procedure

To evaluate the usability of the AR application, the System Usability Scale (SUS) questionnaire [34] was employed. This questionnaire contains 10 statements, with responses measured on a 5-point Likert scale that ranges from “Strongly Disagree” to “Strongly Agree”. The SUS questionnaire was chosen because it is easy and quick, and it was translated into Greek [35].

The experiment lasted 50 min, and the protocol that was implemented included the following phases:

1. *Introduction to the experiment* (10 min), where the researchers analytically informed the participants about the experiment and the steps that the participants had to follow;
2. *Experiment Execution* (15 min), where a group of two participants played the seventh educational game and followed the steps that are described in Section 3.7;
3. *Usability Questionnaire* (10 min), where each participant completed the SUS questionnaire;
4. *Semi-structured Interview* (15 min), where the participants shared their experiences with the AR application. Specifically, (a) the philosophy and education students were questioned on the educational merits of the technology; (b) the engineering students were asked to provide feedback on the game’s development and design; and (c) the elementary students were asked about their overall experience using the the AR application.

5. Results

5.1. Usability Results

The results of the SUS questionnaire for all groups are presented in Table 2.

Table 2. Usability scores.

	Philosophy and Education Students	Engineering Students	Elementary Students	Total
Participants	76.31	65.24	68.43	70.01

Total refers to the total SUS score when the total sample of the AR application is considered.

Table 3 analytically presents the SUS scores per SUS question and for each group: (a) philosophy and education students; (b) engineering students; and (c) elementary students.

Table 3. SUS scores per question.

Item	English Version of SUS	Score from Philosophy and Education Students	Score from Engineering Students	Score from Elementary Students
Q1	I think that I would like to use this system frequently.	3.692	3.068	3.767
Q2	I found the system unnecessarily complex.	1.846	2.500	1.791
Q3	I thought that the system was easy to use.	4.138	3.338	3.930
Q4	I think that I would need the support of a technical person to be able to use this system.	1.892	1.932	1.744
Q5	I found that the various functions in this system were well integrated.	3.892	3.473	4.140
Q6	I thought that there was too much inconsistency in this system.	1.954	2.311	1.674
Q7	I would imagine that most people would learn to use this system very quickly.	4.185	3.824	4.023
Q8	I found the system very cumbersome to use.	1.800	2.338	1.791
Q9	I felt very confident using the system.	4.046	3.351	3.907
Q10	I needed to learn a lot of things before I could get going with this system.	1.938	1.878	1.791

5.2. Interviews

Interviews were conducted among the participants and the researchers after completing the usability test. From the three distinct groups, a random selection of students took part in the semi-structured interviews, leading to the inclusion of (a) 10 philosophy and education students; (b) 15 engineering students; and (c) 7 elementary students. Regarding the data analysis, the Qualitative Narrative Analysis technique [36] was used to interpret the participants' experiences and perspectives.

Table 4 presents results of the interviews through direct quotes, offering a thorough insight into the participants' experiences.

Table 4. Indicative participants' quotations.

	Quotations
Philosophy and Education Students	Q.1.1 "I'd love to use it in the classroom" Q.1.2 "I believe that AR technology will facilitate the learning process for the students as well as the teaching process for the teachers" Q.1.3 "Students were more engaged with the use of AR as they want to delve deeper into exploring the application and therefore learn more things" Q.1.4 "I believe that AR would have a huge impact on students"
Engineering Students	Q.2.1 "A help button is missing from the application" Q.2.2 "The arithmetic numbers should be shown in the interfaces with questions, as it is demanding for the elementary student to retain this kind of information and do calculations simultaneously" Q.2.3 "There should have been a correlation between the icons in the main menu and the chapters of the textbook (e.g., the icon with the crepes should have the title "integer numbers" underneath)" Q.2.4 ". . .AR is a beneficial technology, and an AR application specially designed for the end-users can enhance the educational process..."
Elementary Students	Q.3.1 "I did not understand that I had to drag the ingredients into the bowl" Q.3.2 "The calculation interface was not very easy to use it" Q.3.3 "The lesson with the use of the application is more interesting than with the use of only the book" Q.3.4 "This is the best day of my life" Q.3.5 "I want to play all the games now!"

6. Discussion

The results of the SUS questionnaire were quite satisfactory for all groups (see Table 2, Section 5). The philosophy and education students rated the AR application with a SUS score of 76.31, the engineering students rated it with a score of 65.24, and the elementary students rated it with a score of 68.43. Finally, the total SUS score for the AR application “Cooking Math” was 70.01, in which as a sample, the total sample of the participants for the AR application was considered. According to Bangor et al. [37], a score above 70 is acceptable, while a score between 50 and 70 is marginally acceptable and needs improvements.

The aforementioned SUS scores are consistent with the results from the interviews. More specifically, the philosophy and education students were very satisfied in general with the AR application in terms of its usability, while during the interviews, they mainly focused on the pedagogical value of such technology. Specifically, they all agreed on their willingness to incorporate such technology into the classroom, since it motivates students to learn and explore new concepts. Additionally, they supported that AR technology has the potential to enhance both the learning and teaching processes, as it simplifies complex concepts, promotes active learning, encourages exploration, and makes learning more interesting. The above are confirmed by quotations Q.1.1–Q.1.4 presented in Table 4 (Section 5).

Conversely, the engineering students were the least satisfied, as they found the application difficult and cumbersome for the sixth-grade elementary students, mentioning that improvements should be made in the design of the AR application to increase its intuitiveness. All engineering students mentioned the absence of a “help button” from the application, which can be a crucial feature to assist students who are unfamiliar with AR interfaces (see Q.2.1 in Table 4, Section 5). Moreover, some feedback was given on the potential cognitive load on students that can be produced by a poorly designed interface (see Q.2.2 and Q.2.3 in Table 4, Section 5). Despite the critical feedback on the application’s design and user interface, the engineering students acknowledged the potential of AR in the educational process. Their overarching sentiment was supportive of AR technology, emphasizing the importance of tailoring AR applications specifically for their intended audience (see Q.2.4 in Table 4, Section 5).

Finally, the elementary students were quite satisfied with the AR application, since some of them found it complex to use and had difficulties in interacting with the interface, highlighting the need to learn some things before using it (see Q.3.1 and Q.3.2 in Table 4, Section 5). Despite the challenges, many elementary students were really excited and found the AR-enhanced lesson to be far more engaging than traditional methods (see Q.3.3, Q.3.4, and Q.3.5 in Table 4, Section 5).

In summary, the above results are in line with the literature review [3,5,7], which concluded that AR can enhance learning and teaching processes, providing a richer experience as it fosters active participation, exploration, and motivation, resulting in better learning outcomes.

7. Conclusions

Leveraging the aforementioned factors, the present work evaluates the usability of an AR application, titled “Cooking Math”, which promotes an active learning approach in sixth-grade elementary students. A usability experiment was conducted on three distinct groups, and the results were quite satisfactory. In conclusion, philosophy and education students, who will likely become the educators of tomorrow, seem to hold a very positive view of the integration of AR into the educational process. Their feedback focuses on the potential to engage, motivate, and deepen students’ understanding. This optimistic perspective indicates a potential shift in future educational methodologies, where AR might play a crucial role in enhancing the learning experience. Regarding engineering students, while they recognized some significant shortcomings in the AR application’s design, they also acknowledged the transformative potential of well-designed AR tools in education. Their feedback highlights the importance of user-centered designs, especially when developing educational tools for younger audiences. Finally, the elementary students' feedback provides a balanced view of the AR application. While there were definite areas of improvement, notably in making the interactions more intuitive, the overall enthusiasm was undeniable. In summary, while the promise and enthusiasm surrounding AR in education are evident, the feedback underscores the imperative of a user-centric design approach. Addressing these usability concerns and achieving a seamless integration with traditional learning resources will be critical in harnessing AR's transformative potential in educational environments.

8. Limitations and Future Work

The proposed AR application has certain limitations that merit attention. Firstly, the current version exclusively supports the Greek language, since it is addressed to sixth-grade students in Greek elementary schools. In addition, the user interface has limitations according to the aforementioned feedback; thus, it would be beneficial to refine the user interface design, ensuring smoother and more intuitive interactions, especially for sixth-grade elementary students. Therefore, in terms of future directions, emphasizing user testing will also be essential to improve the application's usability and instructional clarity. Finally, investigating students' learning outcomes will be also crucial, which can be achieved through comprehensive, long-term studies and large-scale experiments in classroom settings.

Supplementary Materials: The APK for the AR app: https://t.ly/RBu45 (accessed on 8 September 2023).

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