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Augmented Reality mobile application for chemistry learning: the case of ARElements

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Abstract

In recent years, augmented reality (AR) has emerged as a promising technology with significant potential in the field of education. This paper presents a mobile application that utilized AR technology to revolutionize chemistry education. The application combines 3D models with the real world, enabling users to explore the periodic table, its elements, and basic molecules in an immersive augmented reality environment. Users can access comprehensive information through written and audio formats and assess their knowledge with interactive quizzes. Additionally, the application introduces a unique feature that allows users to create molecules by aligning atoms. An initial experiment on the use of the proposed application was conducted in a Greek high school and shedding light on the application's effectiveness and the broader implications of augmented reality technology in chemistry education.

Keywords: Augmented Reality, Chemistry Learning, Educational Technology, Mobile Learning

Introduction

Research in pedagogy (Murodjon, 2022) has revealed that students who are introduced to chemistry for the first time often encounter difficulties in comprehending fundamental concepts and principles within the subject. This challenge arises due to the complex nature of understanding and reasoning about molecular-level phenomena, which involve unfamiliar and non-intuitive concepts (Herron, 1975). Harle and Towns (2011) have concluded that students face difficulties with understanding, interpreting, and translating molecular representations. In addition, Tuckey, Selvaratnam, and Bradley's (1991) research, many students struggle with three-dimensional thinking, even at the university level. Cai et al. (2014) indicated that students' limited imagination further hinders their comprehension of theoretical concepts in chemistry.

Over the last years Augmented reality's rapid expansion has led to widespread use of the technology across various fields of study (Pellas et al., 2019). AR technology has been applied for chemistry education with positive results. It is useful in situations in which a phenomenon cannot be replicated in real life, as well as in situations in which doing genuine experiments may be hazardous. It can also be applied, to allow students independently experiment with various phenomena.

AR in education

The use of augmented reality applications has benefited many fields of education such as anatomy, mathematics, geography, etc. There has been an increase in student interest and motivation. The use of such applications can be done by teachers without cost and has positive results such as higher academic achievement with lower cognitive load (Küçük et al., 2016).

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A study by Yılmaz, R. M., & Göktaş, Y. (2018) reviews the literature on augmented reality (AR) technology, which dates back to the 1950s and can be used in computers, laptops, mobile devices and smartphones. It is revealed that there are two main categories of AR, those based on pointers or not, and two types of applications, image-based or location-based. AR is used in various fields such as entertainment, defense, medicine, engineering, psychology, marketing and education, and is particularly beneficial for teaching invisible objects and situations, providing a sense of authenticity, visualizing complex relationships, providing experiences that cannot be had in real life, and helping to concretize intangible concepts. It provides instructors with a constructive learning environment and is shown to increase attention, make learning more effective and interesting, provide motivation and rich interaction.)

Integrating AR into science education can be particularly useful to help students better understand abstract concepts. By providing visual images of phenomena that are difficult to explore in the classroom, science lessons become more engaging, leading to increased student interest in the subject matter and better understanding of the material (Rehmat & Bailey, 2014). By allowing 3D representation of invisible and difficult-to-visualize events, AR technology facilitates understanding of concepts that typically struggle students (Wu et al., 2013).

Related work

This section presents a short literature review on the use of AR technology for chemistry learning. In addition, it provides a comparative list of AR mobile apps about chemistry along with their features.

Iordache et al. (2012) used a chemistry teaching platform where students can put colored symbols on the periodic table and learn the structure of chemical elements and molecules. It was found that students gained better understanding by constructing molecules and freely controlling the process. In another research (Wojciechowski et al. 2013) an AR environment was implemented, where students performed chemistry experiments such as base and acid reactions in pairs. The results showed that students actively participated in the hands-on process and this had a positive impact on how enjoyable it was, as well as increased motivation to learn chemistry.

Chen et al. (2020) concluded that hands-on learning activities using AR allowed students to improve their conceptual knowledge in chemistry and at the same time stimulated greater interest in science. The research also showed that this practice had a long-term effect on students' interest in science and more specifically in chemistry.

Cai et al. (2014) indicated that students' limited imagination further hinders their comprehension of theoretical concepts in chemistry. Another research by Cai et al., (2014) found that the implementation of an AR tool significantly improved the performance of high school students, particularly benefiting those with lower academic achievement. The AR software utilized in the study simulated atoms and molecules through markers; however, it was not specifically designed for mobile devices. The abovementioned results highlight the positive impact and potential of AR technology in enhancing students' understanding and engagement in chemistry education.

Many applications are available for chemistry learning. For example Arloon Chemistry (Arloon Chemistry – Apps on Google Play, n.d.) is an interactive application that allows high school students to explore atoms, create chemical compounds, and gain a deeper understanding of the periodic table through various exercises, providing limited information about each element and offering 3D models of molecules using markers, though it has minimal utilization of AR technology.

ModelAR Organic Chemistry (ModelAR Organic Chemistry – Apps on Google Play, n.d.) is a user-friendly 3D modelling tool for constructing and viewing chemical structures using AR technology, offering a convenient camera-free environment. It serves as a valuable supplement for organic chemistry lessons and a practical practice tool, featuring a simple interface and interactive features that enhance understanding through real space exploration and engaging rhythms and sounds.

Chemistry AR provides (Chemistry AR (BETA) – Apps on Google Play, n.d.) an AR environment where the user can put together 3D models of chemical elements, causing chemical reactions and creating molecules. More detailed information about each chemical structure is also given.

AR VR Molecules Editor (AR VR Molecules Editor – Apps on Google Play, n.d.) is designed for high school chemistry students, providing them with the ability to construct and modify 3D models of organic and inorganic molecules in both virtual reality and augmented reality environments, with an emphasis on VR technology and support for various types of chemical bonds.

MoleculAR (Coster, 2021) is an augmented reality application for mobile devices that enables visualization and interaction with molecules. By pointing the camera at the appropriate image, an interactive, three-dimensional representation of that molecule appears. Table 1. provides a comparative presentation on the mobile apps features along with the features of the proposed application ARElements.

Table 1. Comparative presentation of AR mobile apps for Chemistry

Applications/ Features	**Arloon Chemistry**	**ModelAR Organic Chemistry**	**Chemistry AR**	**AR VR Molecules Editor**	**Molecul AR**	**ARElements**
Augmentation method	Markers	Markers	Markers	Images	Images	Images
Augmentation Types	3D models	3D models	3D models /2D info	3D models	3D models	3D models /2D info/audio
Molecule creation	✓	✓	✓	✓	---	✓
Interactive periodic table	---	---	---	---	---	✓
Interactive augmentations	✓	✓	---	✓	✓	✓
Detailed descriptions	✓	---	✓	---	---	✓
AR quiz	✓	---	---	---	---	✓
Free	---	✓	✓	✓	✓	✓

It is obvious that AR is a valuable tool in the field of education as long as it is used in the right way. If some difficulties can be overcome, such as the lack of expertise of some teachers or the difficulty of acquiring and using the necessary devices, the results can only be positive. The use of AR in education can facilitate the understanding of complex theoretical concepts and thus further stimulate the interest of students which often develops into a long-term interest in the subject matter.

The design of the proposed AR mobile app was based on the outcomes of Table 1. It is clear that most applications do not support some form of assessment in AR environment, for this reason the proposed application was chosen to have AR Quiz. Most applications have the capability of creating molecules by combining atoms. This feature was considered important and has been implemented in the proposed application, by approaching the appropriate cards by the user, the corresponding molecules are generated in an AR environment. Most applications only have 3D models in the augmentations, whereas the proposed application includes 2D information as well as audio. Another feature that other applications do not have is the interactive periodic table in AR environment where the user can select freely from the table's elements. Last but not least, there is no similar AR application in the Greek educational community.

This paper explores the integration of the AR mobile app ARElements in chemistry education, investigating its potential impact from both students' and teachers' perspectives. By examining the app's effectiveness in enhancing learning experiences and facilitating student engagement, valuable insights are gained into the positive outcomes that can be achieved through the adoption of this innovative educational tool.

ARElements

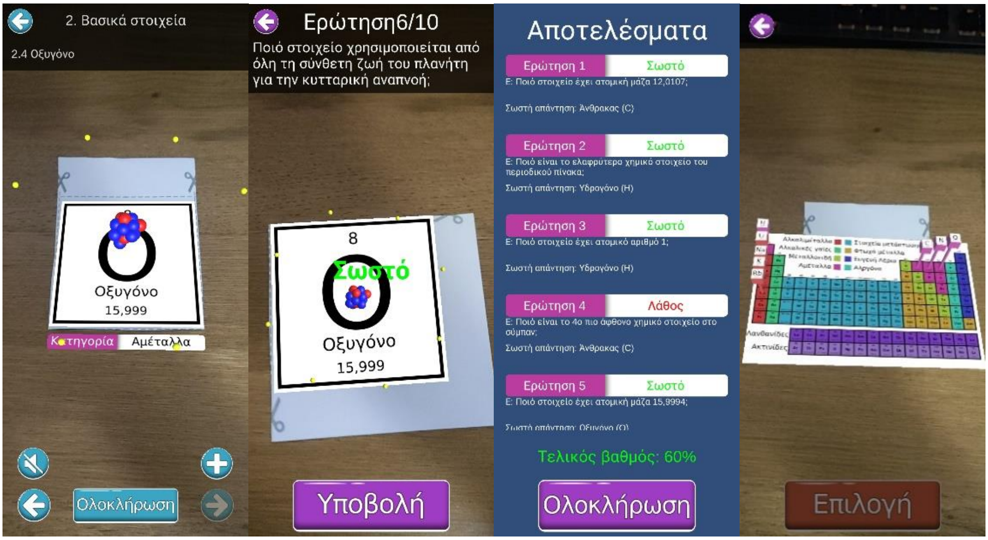
The main aim of the ARElements mobile app was to help students of the 3rd grade high school on chemistry learning. Its content was based on the official Greek chemistry textbook (Chapter 2) and includes the periodic table of elements and some basic chemical compounds. The application is available on AR compatible Android devices and the school textbook is not necessary for its use.

The design of the application based on the following criteria: a) Be easy to use and accessible for every student and teacher, b) provide enough guidance through the available material and c) the provided educational content should be compatible with official curriculum of the third grade high school. More specifically, the student should be able to name the groups of elements in the periodic table and their basic properties. Also, to know the basic information about each element and its properties while being able to identify them by their symbol and atomic number. Finally, students will know the composition of some basic chemical compounds, such as water, learn their properties and be able to relate them to everyday objects.

To accomplish these objectives, the application provides three interactive activities. The first activity is about the theory, where after scanning an image, the student is presented with information about elements or molecules in the form of 3D models, text and audio, all in an AR environment (Figure 1a). They can cycle through them and move on to next chapters.

After they feel comfortable with their knowledge, they can move on to the quiz activity. This activity provides questions to which the answer is always an element or a molecule. To answer the question in the AR environment they have to bring the correct card in front of the camera and hit the submit button when the 3D model appears (Figure 1b). After every chapter there is a screen showing the results with all the questions and their correct answers (Figure 1c). If a score of 50% or more is achieved the next chapter of the quiz is unlocked.

Lastly, there is an interactive AR periodic table where the user can select a specific element and view in AR its information (Figure 1d). This is useful when they want to know something about a specific element and not have to go through the whole theory chapter.



a) Theory activity b) AR Quiz c) Quiz Results d) AR periodic table

Figure 1. ARElement interactive activities

Even though there are free and general-purpose tools to create AR experiences such as ARTutor (Terzopoulos et al, 2021), the requirements of the proposed system make it necessary to develop it from scratch based on Unity.

Research Methodology

The main objective of the research was to examine the potential positive impact of the application on students' learning experience and to awareness among educators regarding the potential contributions of AR technology to chemistry education.

The research aimed to address the following research questions (RQ):

RQ1: What is the students' prior experience with AR technology?

RQ2: Do the students find useful and ease of use the application for chemistry instruction?

RQ3: Is the application feasible within a classroom setting and does it possess the potential for integration into educational practices?

RQ4. What is the impact of the application on students' educational experience?

In order to acquire the appropriate information, a three-part questionnaire, with 21 questions, was used. The first part contained demographic questions about the previous experience of the students with AR technology. The following two parts, contained 5-point Likert scale type questions. The participants were asked to specify the extent of their agreement or disagreement using this scale. The scale ranged from "strongly agree" (1) to "strongly disagree" (5). At the second part of the questionnaire participants were asked about perceived usefulness, perceived ease of use, their satisfaction, user attitudes and intention to use. The third part of the questionnaire, was about the student attitudes over the use of the mobile app. The final part was about the student's overall experience and any comments they had to provide on what they liked or disliked to the application along with their suggestions for improvements.

The sample was junior high school students along with their teachers. The students were provided with the AR mobile application and the necessary printed material. They were invited to try all the functions of the application such as theory and exercises in 45 minutes. After the end of the experimentation with the mobile app, they were asked to answer in 10 minutes the research questionnaire.

Implementation

The research was conducted at May 2023 in a typical Greek junior high school and the participants were 50 students of the second and third grade. The students were asked to use all the functions of the application and then answer a questionnaire. First, they explored the first two chapters of the theory and the interactive AR periodic table. After that they were asked to do the first two AR quizzes. The ones who were finished were encouraged to explore the rest of the chapters and finish all the available quizzes. In the last 10 minutes the questionnaire was given to the students to answer it voluntarily.

After the end of the experiment teachers had a discussion with the researcher about the app.

Due to the fact that the use of the app requires the use of a mobile phone, which is prohibited in schools, it was not easy to test on a large scale. Also, the app is not supported on iOS devices and also not supported on some older Android devices. These problems were addressed by having some students work in groups of 2 or 3.

Results

The application was tested by 3 teachers and 50 children. Of these, 38 responded voluntarily to a questionnaire. Overall, the evaluation results showed significant success in the acceptance of the app. In particular, teachers highlighted the app as an excellent educational tool for teaching such topics, while students expressed their enthusiasm for the app and described it as easy to use and original. Many of the students expressed interest in using the app after the trial at school.

According to the answers of the questionnaire, 66% of the students (3,76) had no experience with AR applications or games. The data also shows that there is significant interest among students in integrating this technology into chemistry (4.63) or other disciplines (4.89) as a learning tool. Students find the ARElements app easy to use (4.41). They confirmed that they liked this kind of instruction using the mobile app (4.81) and the majority of them indicated that they could concentrate on the use of the app. It is worth noting that, according to the students' observation during the experiment, while using the application, they were fully engaged and focused on what they were learning at that time.

Regarding the use of the ARElements students found the ARElements easy (4.52) and simple to use (4.65), with clear guidance (4.65). It was practical (4.5) for the reason they wanted it, and enjoyed using it (4.65). Finally, more than 90% found it fully functional.

From the student responses on the open text question, it seems that they had a very positive experience as many of them asked to include more material to it. They also expressed their wish to use a similar application in more courses and mentioned that they haven't seen something similar till then on the school. They liked the innovative way of studying chemistry.

From the observation of students' actions in the classroom it comes that the 50% correct answer threshold set as a requirement for the user to be able to move on to the next chapter acted as an incentive, for students who did not achieve it, to go back to the theory and try the exercises again. The immediate feedback of the grade and the possibility of improving it led many students to try to achieve better grades, resulting in them going back to the theory section or even looking for the answer to the question in external sources, thus increasing the motivation for learning about the subject.

Discussion & Conclusion

The research aimed to highlight the application's positive impact on the students' learning experience and raise awareness among educators about the potential of new technologies in modern education. By involving students and collecting questionnaire responses, the study demonstrated significant success and acceptance of the application among teachers and students, emphasizing its value as an effective and engaging educational tool.

The results revealed that even the majority of students had not any experience with AR technology, they found easy to use the ARElements application. In addition, they believe that is useful both for chemistry and other disciplines instruction. The perceived ease of use and usefulness shows an intention to use the mobile app according to technology acceptance model (TAM) as it was proposed by Davis (1989). The results were also positive regarding the RQ3 since they confirmed that AR mobile apps are feasible withing classroom settings and have the potential for integration to educational practices.

These findings underscore the importance of integrating augmented reality applications into various subjects, motivating students to actively participate in their learning process and showcasing the potential for further advancements in educational technology.

This study acknowledges several limitations that need to be taken into consideration. Firstly, the survey conducted in this research had a relatively small sample size, which may limit the generalizability of the findings to a broader population. Furthermore, the experiment was conducted in a single specific school, potentially restricting the applicability of the results to a wider educational context. Another notable limitation of this study is the absence of a comparative study between a group of students that work with the AR mobile application and a traditional instruction group. By having only one experiment group of students, the study lacks a direct comparison with a control group, making it difficult to determine the specific impact of the AR mobile application on learning outcomes.

To address these limitations and ensure more robust and reliable outcomes, future research should aim to conduct experiments involving a larger and more diverse participant pool from various schools, and consider incorporating a comparative study design, including a control group receiving traditional instruction, to better assess the effectiveness and benefits of the AR mobile application in comparison to conventional teaching methods. This would provide a more comprehensive understanding of the unique contributions and advantages offered by the AR technology in chemistry education.

In conclusion, this study offers valuable insights into the educational potential of the AR mobile applications as an innovative tool in chemistry education. While the findings demonstrate positive outcomes and improvements in students' learning experience, it is important to acknowledge the limitations of the research and make efforts to address these gaps. Nevertheless, this study contributes to the existing body of knowledge, providing insights into the potential benefits of AR applications in enhancing learning process for chemistry education.

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