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Encouraging Chemistry Learning Through an Augmented Reality Magic Game

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Abstract. Chemistry is often labelled as a difficult subject, which challenges come mostly from topics that require abstract thinking, leading to a negative attitude by the learners. Studies show that augmented reality (AR) is potentially useful for education purposes, particularly in the representation of abstract concepts by depicting them through virtual objects. This paper presents an AR educational mobile game, named “Magic Elements”, targeting children from 9 to 12 years old. The game was designed to promote a positive attitude towards chemistry, teaching children basic concepts while creating climate change awareness. As climate change is having a profound impact on Earth and urgent actions need to be taken, the game also addresses this topic relating chemistry with the real world and promoting sustainable habits among children from an early age. Tangibles and storytelling are explored to engage and sensitize children. Our findings show a positive outcome, as well as a considerable increase in the acquired chemistry knowledge and awareness towards climate change.

Keywords: Mobile game, Chemistry education, Climate change, Learning, Augmented Reality, Tangible interfaces, Storytelling.

1 Introduction

Chemistry topics such as atoms, molecules, and the periodic table itself are the fundamental base for understanding more advanced concepts [19], but students often struggle to comprehend it as it requires abstract thinking [12]. Thus, chemistry is often regarded as a difficult topic, which can demotivate children even before they tackle the subject in school [17].

As climate change is having a profound impact on Earth and urgent actions need to be taken, we decided to address this topic relating chemistry with the real world and contributing to promote sustainable habits among children from an early age.

Nowadays, children have a strong relationship with technology, particularly with mobile devices and digital games, which can be used for entertainment and learning. Augmented reality technology has shown great potential for educational purposes [23], specifically chemistry, since it allows the representation of 3D models, helping to understand abstract concepts, like atoms and molecules, while also building motivation [3, 4, 8, 15, 21]. AR technologies can be combined with physical objects, al-

lowing users to interact with the augmented world, and helping them to visualize and control 3D models in an easier way, improving their visual and spatial skills [9, 10, 13, 15, 19]. Several studies also show that storytelling can be an advantageous tool as it helps to explain complex matters, connect different concepts [5], facilitate engagement and maintain motivation [18, 22].

Therefore, we designed and implemented a mobile serious game targeting children (9 to 12 years old) that combines AR, tangibles and storytelling, aiming to achieve three main goals: (1) foster an attitude change regarding chemistry by generating motivation and demystifying the idea that chemistry is a hard subject (2) promote the retention of some knowledge regarding the topics (chemistry concepts and climate change) addressed in our game (3) sensitize children for climate change and create a desire to implement small environmentally friendly practices in their daily routines.

2 Related Work

AR is defined by Azuma [1] as any system that has the following three characteristics: (1) combines real and virtual (2) is interactive in real time (3) is registered in three dimensions. Recent years have seen significant advances in AR technologies, leading to the proliferation of several studies which have demonstrated great potential of this technology in the education field. In a recent study [8], results suggested that the field with most potential to use AR technology is science education where, specifically in chemistry, 3D demonstrations of chemical bonds and molecules can be developed to envision micro models. Since AR works like a bridge between the real and virtual world [1, 14], this allows its combination with physical objects, improving user's visual and spatial skills [15] and making the control of virtual objects more manageable [10]. Studies also indicate that AR can be used in education to draw users' attention, increasing motivation and academic achievements, allowing students to interact with the learning subjects, unlike traditional approaches that put the learner as a passive element during the learning process [8, 15].

Multiple chemistry games and applications using augmented reality were already created, such as Núñez et al. AR system for teaching Inorganic Chemistry [15] and Chen application to learn amino acids [3], as well as other chemistry applications focused on the topics of atoms and molecules, such as Augmented Chemistry [19], Taçgin et al. application [21], The Table mystery [2] and Periodic Fable [16]. Interestingly, all these applications also incorporate tangible objects, usually used to control the movement of 3D virtual objects that represent chemistry abstract concepts, such as molecules. Most of these applications do not involve a playful component, and do not provide specific goals to the users, allowing them to freely explore the world of atoms and molecules. The Table mystery, although providing specific goals and challenges, requires a lengthy system set-up. Moreover, these applications do not explore the integration of chemistry with climate change.

3 Magic Elements

We created a mobile game to be played by 9 to 12 years old children that seeks to motivate them to learn chemistry and promote their awareness towards climate change. It combines AR techniques, tangible objects and storytelling. The use of the mobile phone as the AR display can be advantageous due to its portability, affordability and simplicity [7]. Touchscreens are also the preferred device of our target group, who can handle them easily [11]. We also explored cards as physical objects, in terms of promoting 3D spatial perception abilities since this can be an advantageous object to be used, given its portability. Besides conveying chemistry concepts, the story behind the game raises users' awareness towards climate change.

The development of the game described in this paper followed a user-centered design methodology, involving an iterative design process with several design, implementation and evaluation cycles that help to improve the system's quality, functionality and interface.

To ensure that the concepts covered in the game were suitable for our target group and well presented, we had the collaboration of a chemistry teacher that analysed our approach and game concept during the preliminary design, which at the time allowed us to identify some concepts that were too advanced and to correct some details that could lead to confusion in understanding the concepts. Also, she validated the final version of the game and, in this later stage, she claimed that the addressed concepts were appropriate for our target group, pointing that the way they were approached in the game allows children to understand them rather than memorize them, while transmitting the message that chemistry can be fun. As a teacher, she stated that she would advise younger students to install the game since she thinks it will encourage them a lot to learn about the subject.

3.1 Game Description

The fictitious premise of Magic Elements happens in Lemuria, a virtual magic world that is suffering with climate change. To fight it, the player has to perform some tasks during a game level and find an exit (that leads to the next game level), leaving the current place in a limited amount of time. To better explain the dynamics of the game, we next describe the main actions that take place during the first game level, showing the corresponding game screens in Figure 1.

The first three magic objects that the player needs to collect in the first game level are the glasses (allowing the player to see abstract models such as atoms, molecules and macromolecules), a magic wand (to manipulate and interact with abstract models) and a multiplier (to multiply a molecule forming a resource, e.g. reproduce a water molecule to create a considerable amount of water). The hypothetical use of magic by the player during the game gives him more freedom to manipulate and interact with abstract models, like atoms and molecules, while it clarifies the idea that that interaction and manipulation is not possible in the real world.

Unlike the glasses and the wand, which are visibly available to be collected by the player, the multiplier can only be collected after the player opens the chest (Figure

1.a) which in turn can only be opened with a key. To earn the key, the player needs to perform an activity by entering a portal that firstly leads to an AR closet, where the player chooses their magic accessories needed to perform the following activity. After choosing the magic accessories, the player performs an AR activity to “build” an atom of a certain element using paper cards. The card allows the player to visualize an animation of the atom electronic cloud. He then needs to stop the electrons of the electronic cloud model (Figure 1.b), which will show the Bohr model visualization. The element card follows an atomic notation, showing the atomic symbol, the mass number and the atomic number of the element, indicating the number of subatomic particles of that element (Figure 1.c). The player can add the subatomic particles (electrons, protons and neutrons) to the Bohr model of the chemical element’s atom by scanning its corresponding card and consequently clicking a button labelled “Add (name of the subatomic particle)” until it reaches the number of each particle depicted in the card (Figure 1.d). When the atom is fully built, the player can visualize it in 3D by moving the card around (Figure 1.e).

Afterwards, he returns to Lemuria main environment and, with the key he won by performing the AR activity, he can now open the chest and collect the multiplier. After collecting all the items pictured in the door (glasses, wand, multiplier) (Figure 1.a - center), the door opens, placing the player closer to the exit. At the other side of the door the player can talk with Carol that assigns him the mission of filling the lake with water. In order to create water, the player needs to collect the water spell, which is visibly available to be collected by the player (only at the other side of the door). The spell shows the atoms needed to compose the water molecule. The atoms can be gathered by splitting greenhouse gases (GHGs) molecules (which are abundant in Lemuria) using the magic wand and consequently collecting the atoms that made up the split molecule (Figure 1.f). To create the water resource, the player goes to the laboratory, uses the water spell and chooses the required atoms in the periodic table shelf (Figure 1.g). Before using the multiplier to reproduce the water molecule and produce a considerable quantity of water, the water molecule can be visualized using AR during its creation process in the lab (Figure 1.h). Finally, after creating water, the player can use the boat to leave the current place and go to the next game level.

The remaining game levels are identical to the first one in terms of actions, however they take place in different Lemuria environments, that must be explored by the player, and comprise different challenges in terms of assigned missions and resources that need to be created. For example, in the second game level the player needs to create dioxygen to open a cave entry.

At the end of each game level, a score for that game level is calculated. Besides the score, a game level is marked with one (low score), two (medium score), or three (high score) stars. This technique has as main purpose to encourage the user to repeat the game levels, reviewing some concepts addressed in that game level, and increasing his score.

Since all game levels have a limited time to be completed, it may happen that the player can’t win a game level at the first try. Therefore, the game level has several checkpoints that save the actions of the player, so he doesn’t lose all of his progress if he wants to retry the game level. However, this will affect his final score in the level.

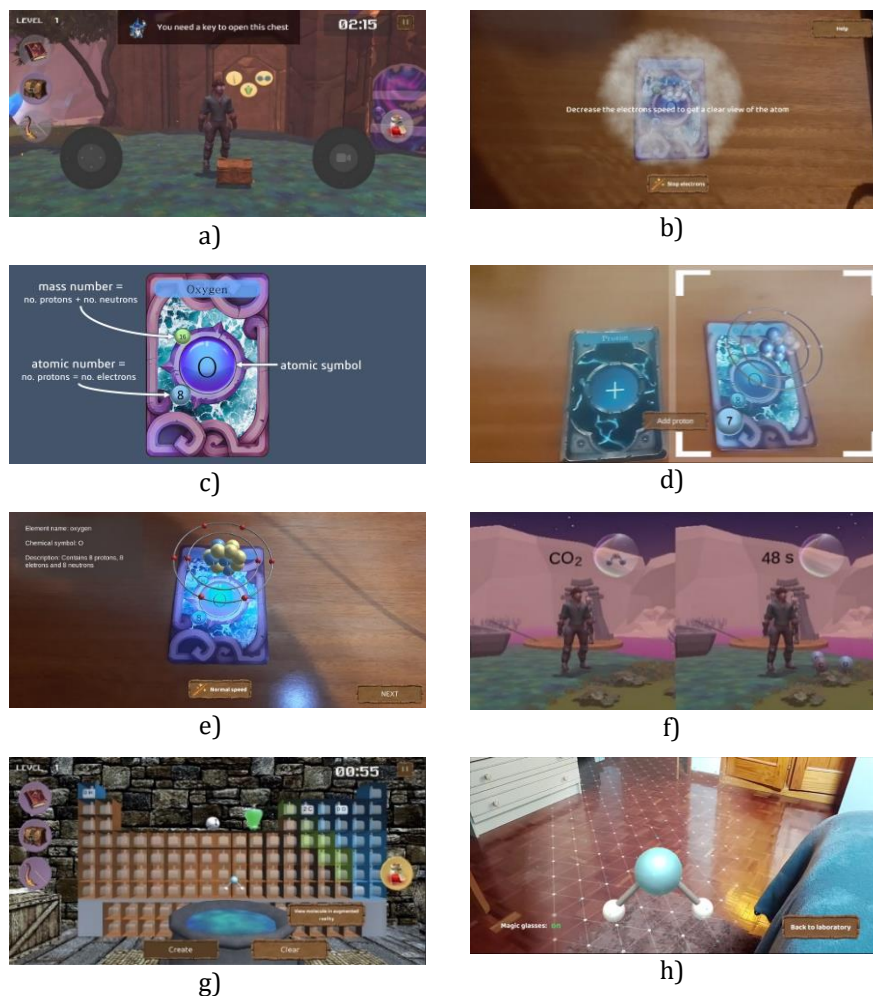


Fig. 1. Magic elements' first level game flow. a) The player needs to open the chest to access and collect the multiplier. b) Oxygen atom electronic cloud. c) Oxygen paper card. d) Subatomic particle (proton) card (left) and Oxygen card (right). e) 3D model of the atom. f) Splitting a CO₂ molecule to further collect its atoms (on the floor). g) Laboratory with periodic table shelf. h) Molecules AR 3D visualization and manipulation.

There are some data (such as game items and missions) that needs to be stored and accessible for the player at any time in the Lemuria place. Figure 2 illustrates the interface elements of our game, showing the main controls, game level information, and data access buttons corresponding to the spells book, the inventory (where the magic objects, atoms, and resources are stored), and the missions list. During the first game level we developed an interactive tutorial which provides the player, at some moments of the game, with guidance text (in the top center of the screen) accompanied by an animation that specifies which control the player should use.

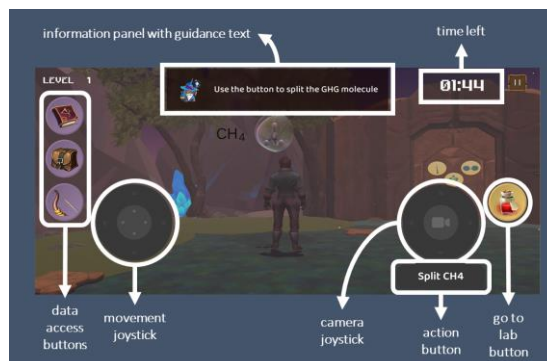


Fig. 2. Scheme of the Lemuria place interface

The character depicted in the information panel (Figure 2 – top center) is Auberon, who guides the player throughout the game, giving him clues and tips. In each game level, the player can talk to two other characters: Carol and Vinicius. Besides attributing missions to the player, Carol also shares her personal stories that aim to sensitize children to climate change using evidences (e.g. climate change impacts with animals and plants, climatic phenomena). Vinicius, a Lemuria activist, shares some tips and small individual practices to soften climate change, to be implemented on Earth, where there is no magic and which can be adopted by children.

The current version of the game contains two fully developed game levels. New content (e.g. more GHG molecules, chemical elements, missions and stories) can be easily added to new game levels.

4 Evaluation

This section describes the last user tests performed on the current game version. Previous informal tests were conducted within each iterative design cycle to inform the design.

In this user studies, we mainly intended to evaluate whether (1) the game motivated the participants, promoting a positive attitude regarding chemistry; (2) the children retained some knowledge regarding chemistry; (3) the game sensitized children for climate change. Before the actual testing phase, the children's guardians were informed about the purpose of the study, data recording procedures and confidentiality and they signed a consent document to allow their children to participate in the study. To compare the results before and after the participants play the game, they had to answer a pre-test and a post-test questionnaire using Google Forms. Both questionnaires included the same questions regarding chemistry and climate change. The pre-test questionnaire also included an initial part focused on the participants' demographic data and the post-test questionnaire a final part concerning the participants' game experience. The questionnaires were carefully created to be suitable for our target group, containing a non-complex language and some instruments from the Fun

Toolkit [20], such as the smileyometer, as well as the 5 Degrees of Happiness [6] (using pictorial representation).

4.1 Participants

Despite our initial idea being to perform tests on a larger scale, given the current pandemic situation, instead of performing the user tests at schools, we had to find individual users that fit our target group, having different profiles (so that the results were as rich as possible), and who were available and willing to test the game. We tested a total of 8 children (5 boys and 3 girls). Four of them were 10 years old (5th grade), two of them were 12 years old (7th grade), one of them was 11 years old (6th grade), and, lastly, one of them was 9 years old (3rd grade). All of them were new to chemistry, as at school none of them had the discipline yet. According to the results, most of the participants (seven - 87.5%) have their own smartphone, which operating system is often (five - 62.5%) Android.

4.2 Results

The game promoted a positive attitude regarding the chemistry topic. We asked the participants whether they considered chemistry a hard topic, using a smileyometer scale where 1 means “Very difficult” and 5 means “Very easy”. In the pre-test we obtained a mean score of 3.12 ($SD \pm 0.99$) that increased to a mean score of 4.50 ($SD \pm 0.76$) in the post-test.

In order to evaluate the educational effectiveness of the game, the pre-test and post-test questionnaires contained the same questions (14 multiple-choice questions in total) focused on chemistry. To quantify the results, a percentage score was attributed to both tests, according to the number of correct answers.

The results, summarized in Table 1, were very positive and showed a substantial improvement between the pre-test and the post-test. The mean score increased from 10.7% ($SD \pm 6.8\%$) to 59.2% ($SD \pm 20.9\%$). Although the pre-test results were more consistent as none of the children had studied the topics at school, all the participants obtained higher grades in the post-test than in the pre-test questionnaire.

To evaluate whether the game promoted climate change awareness, the pre- and post-test questionnaires also included some questions regarding this topic. According to the pre-test answers, only five (62.5%) of the participants could already point out some daily individual practices to soften climate change. However, in the post-test questionnaire, all participants knew what the practices were, reported in Vinicius’s stories, giving 100% of correct answers. Four (50%) of the participants remembered some climate change consequences reported in Carol’s stories.

Table 1. Summary of acquired knowledge (knowledge test scores)

	Mean	SD	Lowest	Highest
Pre-test	10.7%	6.8%	2.4%	24.4%
Post-test	59.2%	20.9%	26.7%	86.7%

Concerning the game experience, participants considered the game fun. When asked how fun was the game, using the 5 Degrees of Happiness scale (where 5 is the most positive answer), a mean of 4.38 ($SD \pm 0.74$) was obtained. All participants deemed the game useful and important. When asked why, they stated the game helps them to learn new things, with 50% specifying that it teaches important subjects, such as chemistry and how to fight the climate change. To conclude the questionnaire, we asked the participants if they wanted to play the game again, using the 5 Degrees of Happiness scale (where 1 means “Yes, a little bit” and 5 means “Yes, a lot!”), obtaining a mean of 4.75 ($SD \pm 0.71$).

During the tests we could notice that the participants were enjoying the game, understanding the concepts, and we could hear some comments such as “Oh, so this is what (some concept) means!”, showing satisfaction for being able to understand it.

All participants stated that they want to install the game, not only for the enjoyable experience, but also because it made them feel like they were learning important concepts in a “non-boring” way. They also stated that, now that they played the game, they think it will be easier for them to understand the concepts when they learn it at school. Finally, we could also notice some interest from the children’s parents, who thought the game was a great initiative mainly because they noticed a positive reaction by their children at the end of the session.

Although some aspects of the game needed to be improved, such as the player movement controls, in general the evaluation results were very positive. Both the questionnaire and the participants’ own reactions and comments show that they enjoyed the game, not only because it made them feel competent for learning new important concepts in such a short time, but also for the fun of the game itself.

5 Conclusions

Even before children approach chemistry as a school subject, the idea that many of them have is that chemistry is a difficult topic. To change their attitude towards chemistry, looking at it as a more pleasant topic and motivating them to learn chemistry, we created “Magic Elements”, an educational mobile game aimed at children from 9 to 12 years old based on AR and tangible objects, containing a unique storyline. We also explored its use to raise awareness towards climate change. Our results reinforce the positive effects of using narrated games, as well as AR technologies and tangible interfaces in promoting children’s motivation, constructing knowledge and developing awareness. According to the results of the user evaluation, the game also promoted a more positive attitude towards chemistry and sensitization regarding climate change. Further testing sessions, as well as a longitudinal study, are needed to better understand its potential, as well as to help to eliminate further design issues.

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