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Learn Chemistry with Augmented Reality

Camelia Macariu[a], Adrian Iftene[a]*, Daniela Gîfu[a,b]*

[a]*Faculty of Computer Science, "Alexandru Ioan Cuza" University, General Berthelot, 16, 700483, Iasi, Romania*
[b]*Institute of Computer Science, Romanian Academy - Iasi branch, Bulevardul Carol I, 8, 700505, Romania*

Abstract

Augmented Reality (AR) has been accepted as an effective learning method which means that it becomes complementary to traditional learning, especially in chemistry. In fact, AR is an interactive experience of a real-world environment. Before recent releases of cheap and affordable smart devices, AR large-scale applications in education were almost impossible. After a brief analysis of current trends in the use of AR, we propose a new system, named ARChemistry Learning, to support the Romanian educational system. In this study, we propose a modern AR tool in the chemistry education used to support children or anyone who wants to learn chemistry, to develop logic, and to explore the world seen only on a smart device. The purpose of this research is to demonstrate how effective these AR applications are, even that in Romania they are still in a pioneering phase.

Keywords: Augmented reality; chemistry learning; instructional design; human computer interaction;

1. Introduction

It is well known that every child learns more easily new concepts, calculus, sorts of chemistry, etc. when he/she can put them into practice such as experimentation and testing. These can often be thought of as games in which they actively participate and learn new things. It is well known that 65% of the population is represented by visual persons

* Corresponding author. Tel.: +40 232 201091.
E-mail address: adiftene@info.uaic.ro
* Corresponding author. Tel.: +40 232 201771.
E-mail address: daniela.gifu@info.uaic.ro

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and that 80% of what they experience is much better memorized [1]. In our days, augmented reality (AR) in education serves a number of purposes (e.g. students easily acquire, understand, and remember the information). By exploiting the various channels as visual, AR makes learning itself more engaging and friendly [2]. In fact, AR-based learning generates a multimodal human-computer interaction space which is very attractive to users. The legitimate research questions of this paper intend to answer: *How many times did you have trouble in understanding a new chemistry concept at school*? *Have you tried to find a way for you needed answers, taking into account that teachers are extremely busy outside class hours*?

Our research intends to draw the basic knowledge level over which research intended to decipher all these needs in the educational process, especially in chemistry. Chemistry domain is very offered for Natural Language Processing (NLP) technologies, having a lot of applications. For instance, Chemical and biomedical named entity recognition (NER) is an essential step in order to recognize drugs and chemical entities in text. The final objective is to develop a formative measurement model using a Chemistry learning scenario. By integrating chemical scenarios and the power of NLP, we consider that the ARChemistry Learning an interactive educational tool based on AR that give promising answers [3]. It could respond to your curiosity and to anyone who wants to learn chemistry, to develop logic, and to explore the world seen only on a smart device (e.g. mobile). The application can be expanded. A community will be created where the students can share their scores or chat, the teacher will create some tests online and he will have the possibility to let them some comments. Also, it can be created new applications for other courses (physics, biology, geography, etc.). The application stimulates the interest in the educational sphere, combining learning and fun with the help of augmented reality.

The paper is structured as follow: Section 2 presents a short overview of AR applications in the educational process in order to clarify the role of them and what can we do to develop a complex tool quite necessary in Romanian educational system, while Section 3 describes a few applications of AR in a number of fields of learning. Section 4 refers to the architecture and the instructional design of this new AR system, named ARChemistry Learning. Section 5 briefly discusses the evaluation of this AR system before drawing some conclusions in the last section.

2. Related Work - Augmented Reality in the Chemistry Learning

Since 1994, real preoccupation for virtual reality (VR) notion is increasing the interest of scientists [4]. It acquires new and new dimensions, for instance, it is presented as a virtual reality continuum [5], where AR is a part of the general realm of combined reality. Basically, VR and AR replace the real with virtual. Still, AR as being separated by VR [6]. Previous studies about trends in the educational process [7] showed that the AR has a huge potential to provide a useful context for education, allowing learning and discovery experiences connected to real-world information [8]. In fact, we are witnessing an explosion of AR technologies in education, useful in various branches of activity (e.g. surgical assistance) [9]. It is equal with "technology to add virtual objects to real scenes, by adding missing information to real-life" [10]. Mixed realities have been used in education for a long time [11]. For instance, the pioneering activity of Caudell and Mizel in Boeing's augmented reality was designed to teach workers how to assemble complex components into aircraft [12]. The information transmitted by virtual objects can help a user to perform specific tasks. A computer became a very useful tool to make easily a human being's life [13]. The most important areas of intensive use have been described for the first time in [14], and later in [15]. According to what an educational process aims like teaching anatomy is, it requires a considerable amount of effort, expertise, and temporal resources and AR can be used effectively to provide additional information [16].

Another favorable aspect of AR, in terms of learning, is that it offers a student-oriented space. Opportunities for it are everywhere, according to the place where the student is. In fact, students can become critics and co-creators, leaving behind a record of their learning the specific artifact or the place they have met [17]. *But, no worry*! AR will not replace the existing learning paradigm with a new world based on high tech. The TPACK model highlights the dynamic interaction between understanding content, learning, and AR in the educational field [18].

In this paper, we will present six AR applications developed for different types of users: (1) kindergarten children, (2) middle-aged children, (3) high school children, (4) students, and (4) postgraduates. Our main goal is to see how AR applications are received by teachers and students and what impact they have on the educational process. In next section, we briefly describe the application of AR in a number of fields of learning including medicine (Insight

Heart), architecture (ARki Application), Solar System (AugThat!), chemistry (Elements 4D), biology (ARBio) Geography (GeoAR), and so on. These can be used on any iOS / Android mobile device.

3. Based learning systems

3.1. INSIGHT Heart Application

INSIGHT heart (https://download.cnet.com/INSIGHT-HEART/3000-2129_4-78277590.html) supports students, physicians, patients, etc. to explore the human body at any time and enjoy information that is visually explained (Figure 1 left). This AR application is with a particular focus on the pharmaceutical, medical and biotechnological sectors.

Fig. 1. Insight heart application (left), ARki application (right)

The main goal is to make medical education fascinating and explorable anywhere and anytime [19]. That we are in the classroom, lecture hall, or living room, medical lessons can be accumulated interactively, based on real-life medical specifications. INSIGHT Heart becomes a necessary novelty, it offers the first step in order to help one's understanding of the cardiac cycle and general cardiac anatomy so important for internal medicine, cardiology residents, and even medical training in general.

3.2. ARki Application

ARki (https://arki-a-r-architecture.soft112.com/) is an application for real-time visualization of architectural models, incorporating AR technology. The rapid development of these technologies presents a significant opportunity for designers and architects to provide creative solutions for adaptive buildings [20]. By visualizing 3D models, this AR platform responds to both design and presentation purposes. 3D models are superimposed on an existing 2D space (Figure 1 right). The architectural design process is becoming more attractive and friendly. The application offers a few features, including real-time shadow analysis and material selection. Users can record a screenshot in both video and 3-D format and share their content via email or social media with a few clicks.

3.3. AugThat! Application

AugThat! (http://augthat.com/?reqp=1&reqr=nzcdYaEvLaE5pv5jLab=) is an application that infuses AR into real world learning designed for elementary schools. The children can learn about how to create a cosmic universe anywhere and anytime with the help of a smart phone or glasses. In addition, she/he has the possibility to exploit the planets and to watch video materials, facilitating the process of assimilating the information through the interaction with a universe that seems real (Figure 2 left). The goal of AugThat! is to create a learning adventure that will expand a child's thought process. According with this, AugThat! offers 3-D models, 360-degree virtual environments, and activity sheets with animated lessons using different kind of smart devices [21].

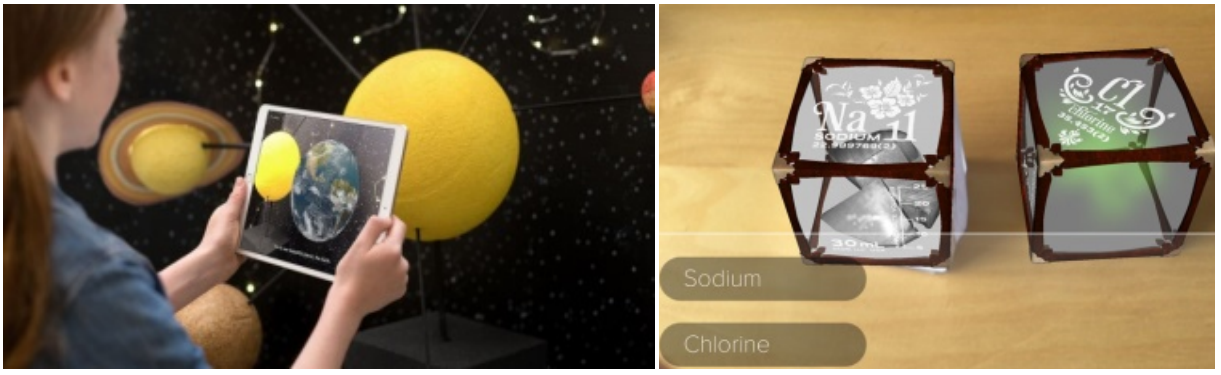

Fig. 2. AugThat! Application (left), Elements 4D Application (right)

3.4. Elements 4D Application

Elements 4D (https://lecbi.bouesha.pw/softwarezute/elements-4d-app-download70.php) is an AR application that allows the user to view substances and information about them, through using cubes. Moreover, it is possible to combine several elements and view the result of the combination. The substances are in their natural state, liquid, solid, or gaseous (Figure 2 right). Elements 4D provides an innovative way to learn real-life chemistry. Furthermore, in order to respond for different curricular needs a collection of lesson plans (from elementary to high school levels) are included. The product contains an educational app and a set of 6 paper blocks consisting of 36 naturally occurring elements of the Periodic Table [22]. One of the interesting features of it is that each face of a paper block depicts a specific chemical symbol, representing one element of the periodic table.

3.5. ARBio Application

ARBio (https://apkpure.com/arbio/com.maisonduweb.app.arbio) is an AR application that respond to the curiosities of children in primary school or any other user to enrich the reality of the images of animals with their 3-D representation [23]. The novelty of this application consists in the fact that it uses markers with animals to activate a preview of them. It also provides the sounds that each animal makes. These markers are consisting of square templates. Each marker, pre-trained in the application, corresponds to a virtual model so that whenever a marker appears in the camera view, the reality will be augmented by adding the appropriate animal. The markers are made up of a black border and the inside of the marker is a suggestive image of the animal with which the marker is correlated (Figure 3 left). In addition, the user is also able to browse the list of animals and find information about each one (from Wikipedia).

Fig. 3. ARBio application (left), GeoAR – the Information View is based on the Marker (right)

3.6. GeoAR Application

GeoAR (https://apkpure.com/geoar/org.n52.geoar) is an AR client for high-dimensional geospatial data that helps children in secondary school to learn the geography of Europe (countries, capitals, flags, and neighbors). Being open-source, GeoAR provides a flexible plug-in mechanism to integrate new data sources and visualizations (Figure 3 right). GeoAR offers the opportunity to test and learn new geospatial knowledge in the form of a game of various questions. Many questions have response variants that are meant to mislead if one is not very familiar with all the details. For more information about a specific country, the user is guided to the Wikipedia page. All printed maps included in this software contains only the contours for each country. When we look at the maps through its phone and video camera, we see them filled in with the name of the country, along with other useful information (flag, capital, and neighbors). It has an extra feature that permits to produce a printed map photo and the country name flag positioned above [24]. Using AR applications in the classroom can turn an ordinary lesson into an engaging and interactive experience, which is significantly reflected in the students' notes. In this study, we develop a new ARChemistry Learning application to support both children in secondary school to learn chemistry and the Romanian educational system to expand their teaching methods.

4. ARChemistry Learning

This application has been built for educational purposes and aims to help anyone who wants to learn chemistry. From the age of 14, children have chemistry classes, and some concepts seem difficult to understand. Thus, the application is based on multicolored and explanatory visual elements that help and aim to improve the learning process. The AR Chemistry Learning application can be downloaded to your phone or tablet and is easy and intuitive to use. Augmented reality underlies the main components of this application. Augmented reality (AR) represents the foundation of this application, along with the E-learning concept. AR allows the interaction with virtual objects, which in this case, are represented by molecules with specific color and volume. They can be seen with the help of the markers, which represent a piece of paper with educational information that can be tracked by the camera. As technologies, it was used by Unity and Vuforia. The application has various components. One of them is text recognition with whom the user can place his phone on any word from a chemistry book and it will be received information from Wikipedia. Another concept is representing by learning and testing. The user can learn to obtain chemical compounds and if he doesn't know the answer, the application provides interactive help. In the end, he can test his knowledge and gain points. The last part of the application is dedicated to the admin user. He has the possibility to add or to delete chemical compounds. This role can be played by a teacher who can help the students to learn faster and better.

4.1. Architecture & Functionalities of ARChemistry Learning

Below (Figure 4) we briefly describe the main modules in order to examine four functionalities of our application: *Learn with the manual*, *Learn with the cards*, *Test your knowledge*, *Add a substance*.

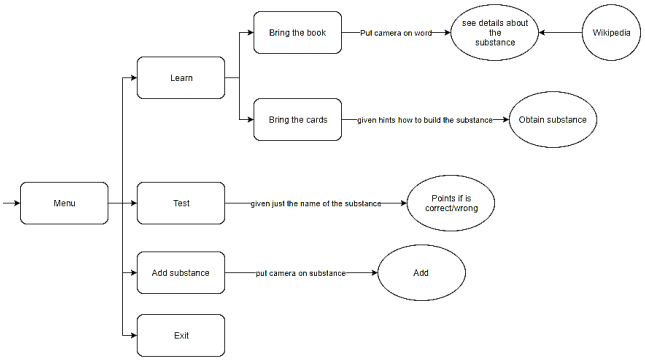

Fig. 4. The general architecture of AR Chemistry Learning application

Learn with the manual

This module is based on text recognition. Thus, for certain words that represent the names of substances, the desired information is displayed (Figure 5). Being several unfamiliar and difficult words in a textbook, an AR approach become a very friendly and faster way of learning. It can be read from anywhere, manually, a simple sheet, directly from the phone or from a computer monitor (Figure 5 left).

If a student wants to find out about *methane*, they must position the phone's camera on the word and the compound will appear above it in 3D. If the word appears several times in the frame, the 3D form will be displayed for each compound. The second step in this module is to press the 3D substance. A window will pop up where information is dynamically brought from www.Wikipedia.com if there is an Internet connection (Figure 5 right).

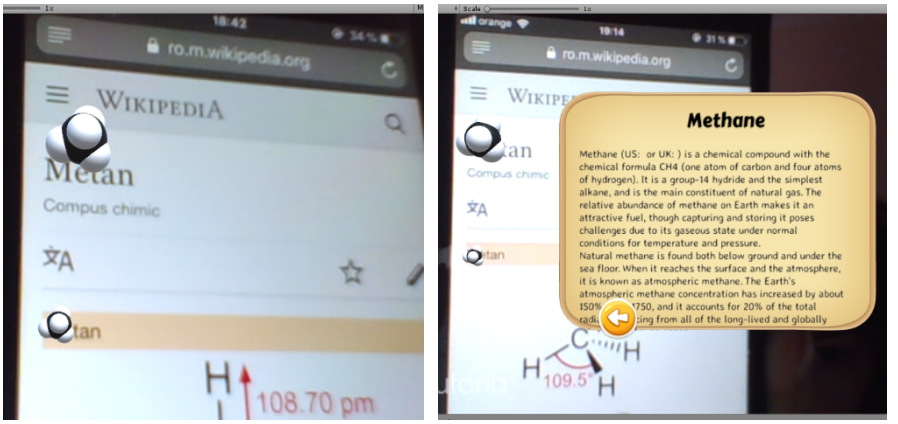

Fig. 5. Text recognition (methane) (left), Additional information when pressing the 3D substance (right)

Learn with the cards

This module focuses on specific learner's behaviour in the educational process. There are some cards made in Adobe Illustrator (e.g. Image Target). A card contains the full name of the substance, the chemical formula, and the periodic table of Mendeleev, being coloured the specific element (Figure 6). These Image Targets are then recognized in Vuforia component. For that, we created a database named "ArLearn", where each card with the corresponding name was registered as an Image Target. Also, Vuforia can recognize the cards and provide the behaviour we build in Unity.

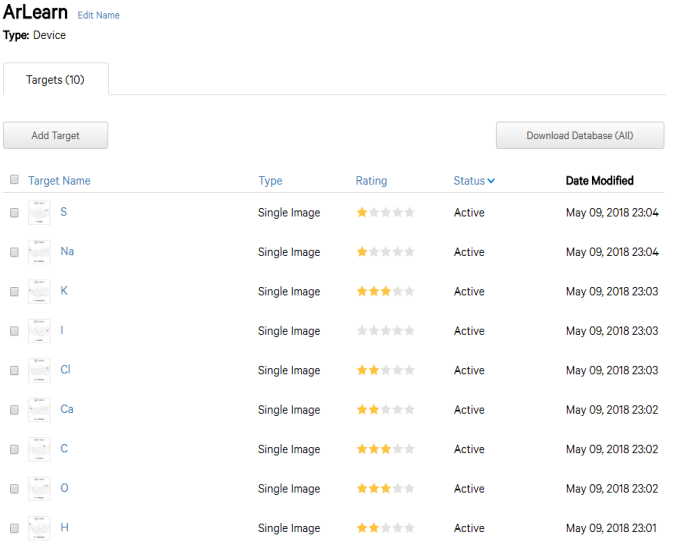

Fig. 6. Database from Vuforia with Image Targets

The main purpose of this module is to help the user to form certain compounds. Cards must be brought one by one within the room until they can be combined. In case the wrong cards are brought, indications are given regarding the correct substances. When the Learn - Bring the cards menu is opened, the room will open in the middle of which there are explanations regarding the notations in the periodic table of the elements (Figure 7 left). This option can be opened later by pressing the button on the bottom left.

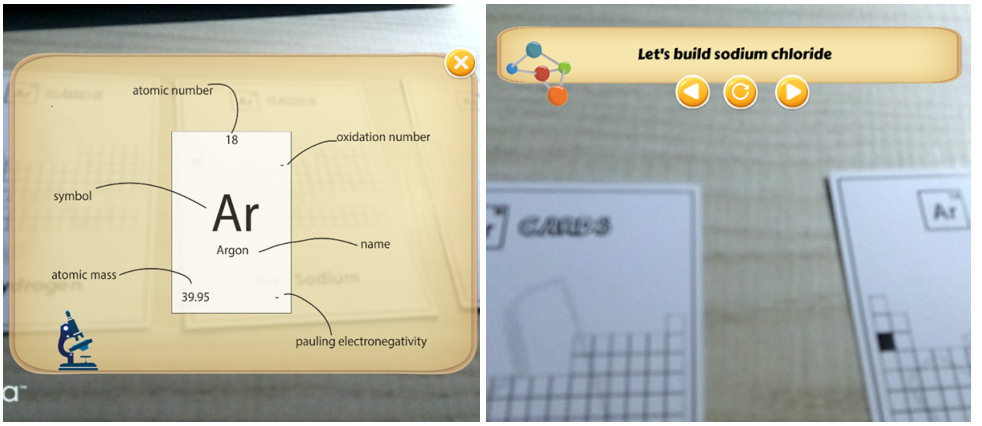

Fig. 7. Cardboard explanations (left), Approaching two cards (right)

After closing the explanatory frame, at the top appear three-button guidance that represents back, resume, and forward (Fig. 7 right). The first indication is to form “sodium chloride”, for which a cardboard “Cl” (chlorine) and “Na” (sodium) is needed. When placing the camera on a card, the molecule will have a specific colour and size and the text with the specific information from the periodic table (Figure 8 left). If it is not the right card or the compound is not fully composed, there will be indications about which card should be brought to the frame. If all the elements necessary to form the compound have been brought into the frame, a message “You can combine the elements” will appear (Figure 8 middle). When combining the elements, a force of attraction is applied to the molecules, the writing on the cardboard becomes specific to the compound and a green edge is applied if the compound is correctly formed (Figure 8 right) or red if it is wrong. After closing the explanatory frame, at the top appear three-button guidance that represents back, resume, and forward (Fig. 7 right). The first indication is to form “sodium chloride”, for which a cardboard “Cl” (chlorine) and “Na” (sodium) is needed.

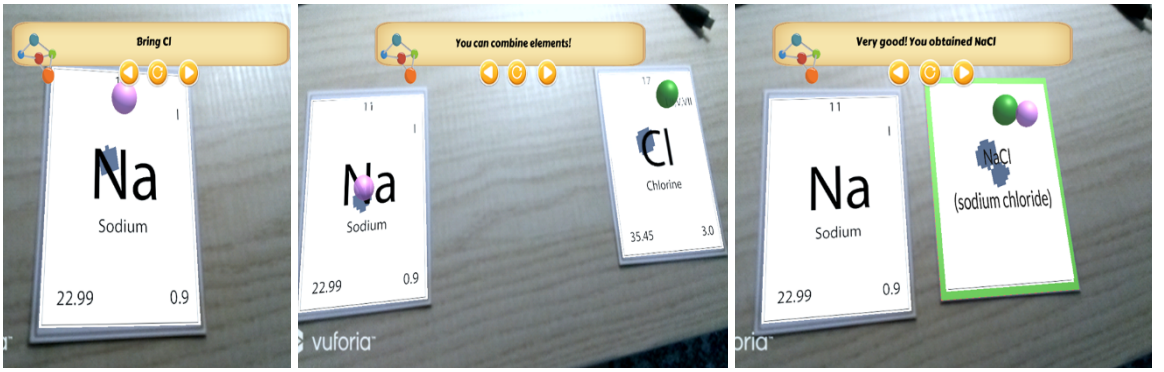

Fig. 8. Details of the substance Sodium (Na) (left), option to combine elements (middle and right)

Test your knowledge

This module focuses on testing knowledge of building a part randomly selected. At the top, it is specified what needs to be built, without giving further guidance on the cards to be brought, and next to it is the “Next” button (Figure 9). In the lower-left part, the scoring record is kept, whether they are right or wrong.

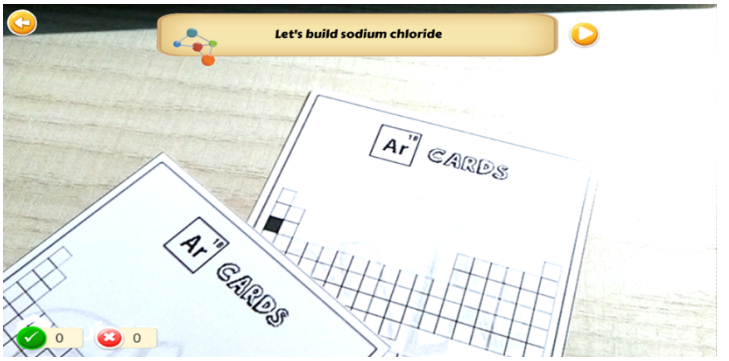

Fig. 9. Test module

The first combination of items is scored, so if the first attempt was wrong, it is added to the score, and if then the correct elements are combined, the score does not change. The edge of the card has a specific color if it has answered correctly or incorrectly. If the user presses the "Next" button without combining any card, it is scored as wrong. In the end, the score obtained is displayed, with the possibility to restart the game.

Add a substance

This module allows the user to enter a compound created by him into the application. When you open the "Add a substance" menu, you can see at the bottom a text that guides the user to use the application correctly. Once the elements you want to combine have been brought into the frame, press the button on the bottom right. The details on the card on the left are missing because the name of the substance has not yet been given, to be written after the "Ok" button is pressed. A box with information about the chemical formula, automatically filled in and the name of the formula added at that time by the user, is displayed, in this case, it was called "my-substance" for easier recognition. After the user presses the "Add" button, a confirmation box appears that the substance has been successfully added to the application. Once the substance has been introduced into the application, it is considered as the others. For example, if the user immediately enters the Learn menu, he may notice that the newly created substance is created "my-substance". The compound also appears in the Test menu.

In order to share the same information, a class was created in which the basic substances were initially added. In this class, the Singleton design pattern was implemented so as not to create multiple instances of the class and thus keep all the substances added in the application.

5. Evaluation

In order to improve ARChemistry Learning, several usability tests were conducted. Then, we collected end-users opinions.

Methodology: A usability test contains tasks, a short interview, and a post-test questionnaire, which are briefly explained in the introduction. All participants were instructed how to make the task series (approx. 5 minutes for one), which had to be announced orally. By using the QUIS (The Questionnaire for User Interaction Satisfaction) scale, we succeeded to gather their experience evaluations. The main problem of this experiment was the execution of the steps by some of the participants, neglecting the initial instruction.

5.1 Professors opinion

The ARChemistry Learning was first shown and tested by professors, was first shown to teachers following the same steps described above.

Participants: For this phase, which lasted 3 consecutive days, we collaborated with 70 professors (40 women and 30 men) who teach the students we involved in. They were selected randomly, with or without AR experience.

Results: We noticed the ease with which the professors solved the tasks, even if the execution was not so fast. They assessed their experience with a note from 1 to 9, where 1 stands for confusing/frustrating experience, and 9 for clear/pleasant experience. We collected their responses to the post-test questionnaire that showed the "overall look and feel experience" is most appreciated by participants (9.5 in average), followed by options "Bring the cards" and "Test" (both with scores around 9.1) and by options "Bring the book" and "Add substance" (both with scores around 8.0).

5.2 Students opinion

After the interaction with professors, the ARChemistry Learning was shown and tested by their students, respecting the same conditions.

Participants: For this phase, we collaborated with 200 students (119 girls and 81 boys), from middle school classes to high school classes, randomly selected. In their case, the experience with games from tablets or smartphones was obvious. In their case, the experiment lasted only 1 day.

Results: We noticed the ease with which the students are performing the tasks after previously observing someone else doing the tasks. The ease with which they passed from one exercise to other shows that they, accustomed to network play, entered the competition with each other. We collected their responses to the post-test questionnaire using the same notes scale. The "overall look and feel experience" is most appreciated by participants (around 9.7 in average), followed by the other options (with scores between 8.5 and 9.5).

5.3 Remarks

As we expected, students did not follow very strictly the steps of the tasks, finding shortcuts to finish fast all of them. That means, they blocked more often the applications. In general, students were impressed by ARChemistry Learning, even they did not obtain impressive results at beginning. They became very vocal and pleased to solve together tasks. The main observations from recording analysis reveals the following:

- the user interface based on AR look was appreciated positive both types of participants;
- explanations and given examples were clarifying in solving the tasks, even if at the beginning their behaviour was restrictive;
- when smart devices are used fast, minor performance and stability issues can occur;
- it is very important the light in the room where the electronic devices are used, especially when are not kept at an angle that allows the recognition of the cards;
- it is notable the interaction between participants, especially for students and visual effects, molecule dynamics are challenging by both groups;
- ARChemistry in the learning process increases attractiveness for students and helps professors in presenting new lessons;
- students' stress is visibly reduced and they become more cooperative with the professor.

6. Conclusions

Today, AR is booming, with huge potential to revolutionize learning in many areas. In order to support individual learning styles, we describe the importance of the visual channel in the chemistry learning process. ARChemistry Learning responds to the curiosity of children, students, and develops logic to learn chemistry in an interactive way. The visual mode, the interaction of the user with the virtual elements becomes captivating, and the information is assimilated without feeling that extra effort that is felt when the student tries to remember something new. The application wants to arouse interest in the educational field, hoping to increase the interest in introducing such learning modes, preferred by little ones.

Following discussions with professors and students, we conclude that AR applications attract more students in the class, supporting traditional teaching methods. In fact, the visual level is very important in learning, students are retaining more easily new information. Tests based on AR can reduce students' stress. This application improves the interaction between students and professors. In order to add voice recognition to take answers from students, we intend to use a component-based on Alexa from Amazon to evaluate students that use ARChemistry Learning. We

are convinced that the results during the evaluation process will be much improved.

Acknowledgments

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