AR Lab: Augmented Reality App for Chemistry Education

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ABSTRACT

Technology has been advancing and becoming increasingly present in education, where it has brought huge changes, allowing students to read books online, do their research on the Internet and even do schoolwork on computers and smartphones. One of the technologies that has been gaining ground in recent years is Augmented Reality, which allows to insert virtual objects into a real-world view using a device's camera and screen. This form of interaction associated with education can improve teaching in schools, especially in more difficult subjects such as chemistry. Our project created an application that assists chemistry students during their learning of chemistry glassware, using the Augmented Reality technique. The app was developed in Unity with Vuforia SDK. It shows 3D models of lab glassware with important description about each flask and its application and also features a quiz mode where users can test what they learned and share results with their teacher. The app was evaluated by 80 students, divided in two groups, against a traditional class in a chemistry lab. Data analysis found, statistically, no difference between the means achieved by the two students groups, which implies the app is at least as good as a regular class. The outcome of a qualitative inquire showed students praised the app, the realism of the flasks and the completeness of the available library of flasks, remarking it could be used to review the subject later. Finally, results support the use of AR apps in schools for teaching glassware particularly in schools that don't have the available funding for a chemistry lab.

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KEYWORDS

Augmented Reality; AR Education; Augmented Reality in Chemistry

1 INTRODUCTION

Important advances in the last decade on the cell phone industry supported a novel class of applications that mix the real environment with virtual information created by software. Augmented reality applications can be used as a way to motivate students to learn abstract concepts such as chemical elements, substances and reactions.

Developing countries are witnessing a growing trend in cell phone adoption. More than 74% of the high school students use smartphones [14]. Frequent use of cell phone can hinder students' attention and lower academic performance [11], however it's also possible to use these mobile devices to leverage new strategies for active learning [8]. One of the strategies is the Augmented Reality (AR), technology capable of inserting virtual objects into a real-world view using a device's camera and screen.

Abstract concepts sometimes are hard to convey in an ordinary classroom blackboard and therefore students are taken to a chemistry laboratory. Despite that some drawbacks include: risks associated with students in an environment with chemical substances, cost of construction and maintenance of a chemical lab, and availability's to students throughout the course. These issues affect peculiarly developing countries like Brazil where up to only 44% of the schools have a science lab [7].

According to Lopes and Chaves [12], it is noted that the teaching of chemistry is constantly resumed to memorization of formulas, nomenclatures and mathematical calculations, causing the devaluation of chemistry learning concepts by most students [16]. Also, learning only through books and the blackboard has been shown inefficient because lacking of attention by the students [16], particularly when mobile phones are allowed in classroom [5].

The main purpose of this project is develop a software, focused on students, which help them to assimilate the equipments used in a chemistry lab and their respective functions.

Several applications have already been developed with the intent of helping students learn, using resources like as Augmented Reality [19]. The main advantage offered by AR technology is their interactive user interface that enables simulations and visualization of 3D material and chemical reactions, that was available only as 2D, flat figures, on the books before [16].

In this paper we introduce AR Lab, an augmented reality mobile app for learning of chemistry glassware aimed at High School technical students. AR Lab uses realistic 3D models of chemistry glassware, both volumetric and graduated, teaching important concepts like correct measurement and glassware application in chemical reaction in laboratory. Students may review the concepts, answering a quiz, and then are presented with a summary that can be shared with their teacher, for follow up action.

2 THEORETICAL FOUNDATION

This section will cover the main concepts proposed in this project, beginning with the use of technology in education scope and proceed to the Augmented Reality and its applications. Will also be presented works related to the proposed application.

Technology in Education

In the last 25 years, the world experienced a rapid technological advance, process that brought great impacts upon how we forge our reality. Soon, being so significant, the technological development couldn't stop influencing a sector quite relevant of our reality: the Education [17].

Thus, the smartphones stand out in education area for being accessible for most young people [6]. We can highlight beyond versatility and accessibility, other features which favors the use of the mobile devices, such as: document reproduction in multiple platforms, the speed of obtaining any information, the interactivity and ease of use [9].

The generation of content in educational area can decrease obstacles to obtain information and simplify its correct understanding. Tavares et al. [18] evaluated a five applications for chemistry education and reported that up to 67% of the users felt the apps were more effective than traditional exercises. The same research also remarks the importance of gamification (featuring a quiz, for example), as incentive for cognition [18].

Augmented Reality

Augmented Reality (AR), is a strand of Virtual Reality (VR). While the purpose of VR is to completely immerse the user in a synthetic environment, in AR, the purpose is to complement the reality, adding virtual information together with the real world. In other words, in Augmented Reality, the real world elements prevail, but the perception of the user is increased by virtual data [3].

An Augmented Reality interaction system consist in the recognition, when the software captures landmarks and, in the tracking, while the desired media is overlapped on the real world, digitally. According to [2] it is possible to divide this system into:

AR system based on markers: the camera recognize physical landmarks (images, bodies or spaces), so that the device can estimate the position, orientation and movement of the virtual object. Usually these systems have a higher accuracy than marker less algorithms for environment registration.

One example of AR app for education, using markers, introduced by Young et al. [20], is an app with a game about mathematics that uses a green marker for tracking, representing the virtual/simulated world. The game is shown on Figure 1, left .

AR system without markers: the system use a combination of features to determine the geographic position and the orientation of the device and allow information to be presented according to the proposed program.

One of the most successful applications of Augmented Reality without markers is Pokemon Go. The game consists in search on the real environment for virtual animals (Pokemon). When the player shoots the world with his camera phone a Pokemon may appear and, in this case, can be captured. Since it's release, in 2016, the game has earned more than 2 billions of dollars leading to research about its effects on players [13].

Software tracking environment without markers usually seek a recurring pattern for surface estimation and commonly are not as precise as systems with markers. See Figure 1 on the right for an example of augmented reality system without markers.

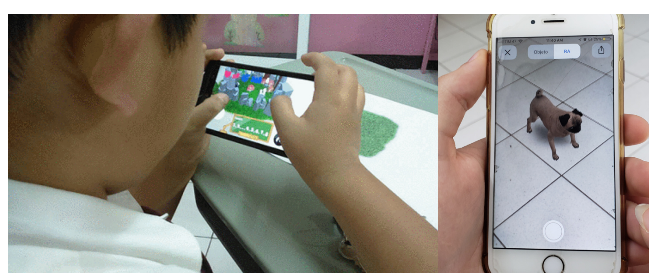

Figure 1: Left: Augmented reality game with marker - AR-Matika [20]. On the right: Google Search render results as 3D models without marker.

3 RELATED WORKS

Many areas of learning have benefited from AR apps for example: geography, anatomy, math, engineering and others. Users note an improvement in motivation and interest in lessons, and feel AR can be a complimentary tool for instruction, helping students in short and long term, as a reviewing platform [10].

The work of Williams and Pence [19] presented some advantages that AR applications could have on teaching chemistry concepts for students and also reported initial initiatives, mainly on universities. Nevertheless it is important to understand some differences in trends experienced by teenagers, particularly in developing countries, where both teachers and students are still learning the benefits of using mobile devices in classrooms [15].

According to Cai et al. [4], students' imagination are limited and sometimes it's difficult for them abstracting theoretical concepts of chemistry such as how reactions happen. Their research proposed an AR supplemental software for chemical reactions with substances. The software used different markers to track and to simulate atoms and molecules. The software was tested in an experiment with 29 students from high school and demonstrated improvements on scores of those that experienced AR software. However the research method did not include a control group and the software was not mobile.

Akçayır et al. [1] developed a similar application of AR but with the goal of teaching laboratory skills for students. A five weeks experiment, with 76 freshman students, showed significant development of skills among those on the group that used AR. The research also gathered how users perceived the AR technology with many praising shorter time to complete tasks, ease as support for learning. The software developed was a mobile app, however the subject was general lab apparatus and not specifically glassware.

In addition to academic research we report mainstream apps for mobile devices, related with this proposal.

Figure 2: On the left: Chemist. On the right: QuimicAR. (https://play.google.com/store/apps/details?id=air.thix.sciencesense.chemist) (https://play.google.com/store/apps/details?id=com.Scota.QuimicAR)

Chemist

The application of Figure 2, left, simulate a chemistry lab virtually. The software is paid and available only for Android devices. Chemist uses 3D models allowing carrying out chemical experiences and observe it's reactions, exercising several tools and reagents. However, mostly of its features are available only as in-app purchase, which makes it limited. Yet, to use this app you must have a prior knowledge of chemistry. It offers both glassware and elements, but there is no guide or script of how to correctly employ them.

QuimicAR

The app of Figure 2, right, is similar to the proposed software but for a structural point of view of substances, for educational purpose. It's available only for Android devices, made in Unity and using Vuforia SDK. It offers a booklet with seven basic chemistry practice lessons guides. This scripts provide a walk through of the practice lesson, along with a marker, which is used for visualization of molecular structures and glassware by the application. Also offers a mode for people with color blindness. Some drawbacks are no testing mode and the library of glassware which is limited.

4 SYSTEM IMPLEMENTATION

AR Lab mobile app can be divided in two parts: learning about different types of glassware and usage and, knowledge assessment with a questionnaire mode. The two main use cases with included functionality are described on the UML diagram presented on Figure 3.

The first part shows each glassware with its textual description and application on the screen. Users can rotate and move the phone closer for minute details inspection. It's possible to browse forward or backward. The app library currently contains fifteen glassware: beaker, round-bottom flask, volumetric flask, burette, Erlenmeyer flask, Büchner funnel, filter funnel, Büchner flask, dropper, graduated pipette, volumetric pipette, Petri dish, graduated cylinder, test tube and, a crucible. Figure 4 presents a few of the glassware featured on the app.

The second part of the application consists of a questionnaire about glassware. Ten questions are presented to users who are asked to point, tapping on the screen, and confirm, which glassware should be chosen given a specific scenario. After each question users receive right/wrong answer and, after the test is completed, a summary is presented. Students

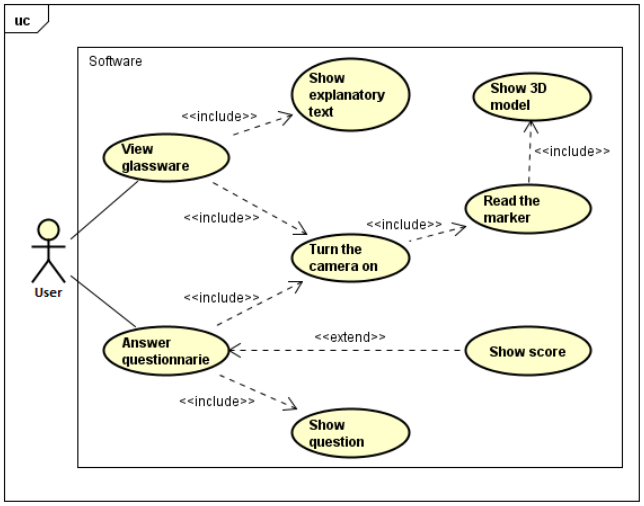

Figure 3: Use case diagram of AR Lab.

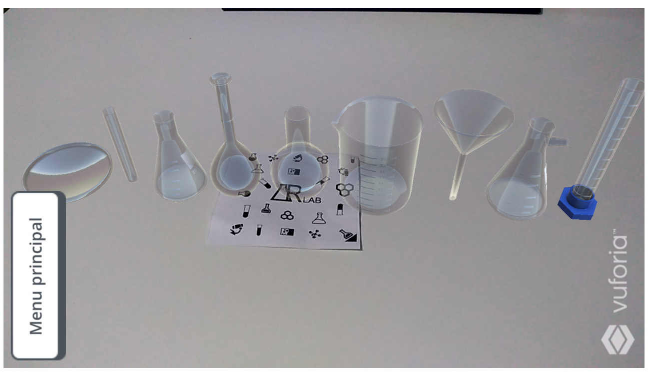

Figure 4: Nine glasswares featured on ARLab. From left to right: Petri dish, test tube, Erlenmeyer flask, volumetric flask, round-bottom flask, beaker, filter funnel, Büchner flask and, graduated cylinder.

can then opt to share that final summary with their teacher, for later review in class.

The app was developed using Vuforia[1] with with Unity[2]. Vuforia is an SDK that provides real time tracking of the physical marker, with mobile's camera, that then render the virtual model objects on the screen taking into account orientation and position. The necessary coding for interaction was programmed in C#. All the glassware was modeled after real flasks, using the 3D modeling software Blender[3]. Prototypes of the application were assessed by chemistry teachers for accuracy regarding the shape, markings and information description given to the user. Figure 5 shows some of the main screen views of AR Lab.

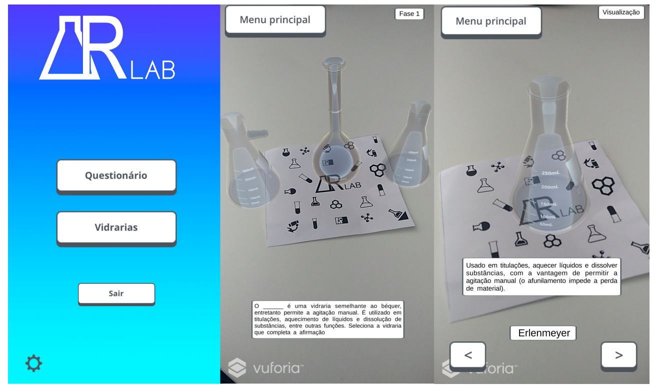

Figure 5: On the left: main menu of ARLab. On the center: knowledge test mode. On the right: glassware library description and inspection mode.

5 EXPERIMENT DESIGN

We designed our experiment to understand the effectiveness of AR Lab as a teaching tool and possible replacement of a traditional class in a chemistry laboratory. The first goal of our experiment was to measure and compare grades of students that received instruction only with AR Lab against those that had access to a chemistry lab with real glassware. Also we collected information about usability and users' satisfaction and overall critics and suggestions for application improvement.

Participants

A total of 80 technical students of high school courses participated on the experiment, 43 from Informatics and 37 from Chemistry. Ages varied between 15 and 17 years old, they all had mobile phones however a few had to borrow from classmates due to the software only being available for Android OS.

Procedure

First of all, to avoid any bias, we ensured participants that scores assigned during the experiment would not count for their grade on the subject and, that all students would be granted access to the lab and to an app, which we would evaluate.

Students who agreed to take part were divided, randomly, into two groups A and B. Those on A were given instruction with AR Lab in a common classroom (see Figure 6) while students on group B were taken for a regular class in the lab (show in Figure 7), as a control group for the experiment.

[1]https://developer.vuforia.com/
[2]https://unity.com/
[3]https://www.blender.org/

Figure 6: On the left: teacher explaining glassware with AR Lab and, on the right: a student inspecting an AR round-bottom flask.

When the instruction was completed, a standard test was applied for both groups. The exam was comprised of 10 multiple choice objective response questions, of 1 point each.

After the exam, groups switched: group A was presented to the real glassware in the lab and group B to the app.

Finally, all participants answered to a questionnaire about how they perceived AR Lab. Each item presented a proposition that participants had to rate using a Likert scale, with values ranking from 1 (strongly disagree) to 5 (strongly agree).

Figure 7: Teacher presenting a round-bottom flask in the lab.

6 RESULTS

A statistical analysis was applied to the results students attained on the exam followed by a qualitative review based on perception of AR Lab, gathered with the questionnaire, at the end of the experiment.

Both groups had an almost identical means of 8 points in 10 questions (see Table 1 for a detailed summary). Even so, grades were processed for statistical analysis across the means of groups A (AR Lab) and B (control). Independent two sample t-test did not show significant difference between the means of both groups for $p < .05$ (t-value: 0.06, p-value 0.47), which indicates that both methods provided a similar outcome on the exam.

Qualitative

Users' perception were mostly favourably to the application. Users acknowledged the completeness of the library of glassware with 62% strongly agreeing that AR Lab has the main

Table 1: Summary of the exam results.

	N	Mean	Std Dev	Max	Min
Group A (AR Lab)	38	8.00	1.77	10	5
Group B (Control)	42	7.98	1.69	10	4

laboratory glassware (Figure 8) and about 60% recognizing the realism of the 3D glassware displayed on the application (Figure 9).

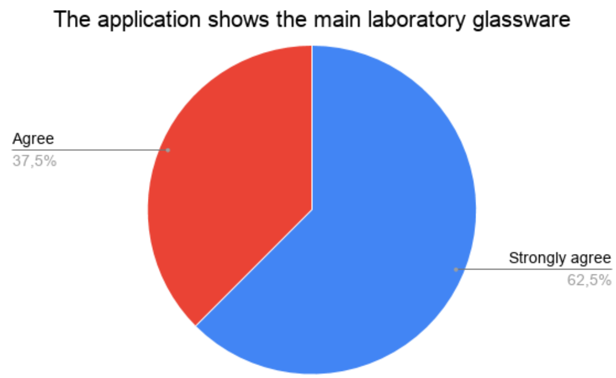

Figure 8: The application shows the main laboratory glassware.

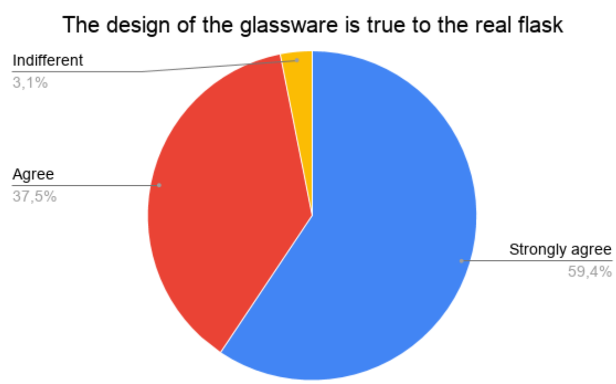

Figure 9: The design of the glassware is true to the real flask.

As a substitute for an ordinary lab class: 41% agreed that it could be used and 36% strongly agreed (see Figure 10). Despite that, about less than 10% reported some concern with it being used as replacement, and 4% strongly disagreed.

When asked about if it is possible to learn the functions of glassware using ARLab 60% strongly agreed and 33% agreed

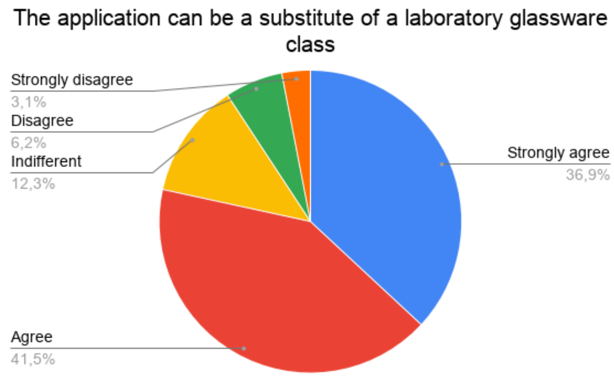

Figure 10: The application can be a substitute of a laboratory glassware class.

(see Figure 11). This question is greatly related with the realism of the 3D models, the rendering on screen, and the correct description of the flasks and the applications.

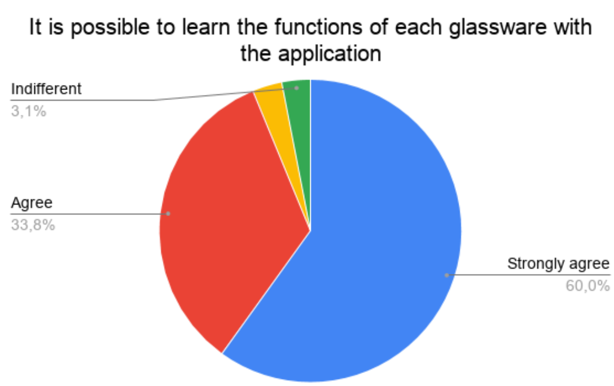

Figure 11: It is possible to learn the functions of each glassware with the application.

Almost all users (64% strongly agreed and 33% agreed) declared that the application can be of help for users studying for a test, as show on Figure 12.

Participants were also asked to write down opinions, suggestions and critics about AR Lab in an open question format. Again most remarks were favourable and will be discussed on the next section.

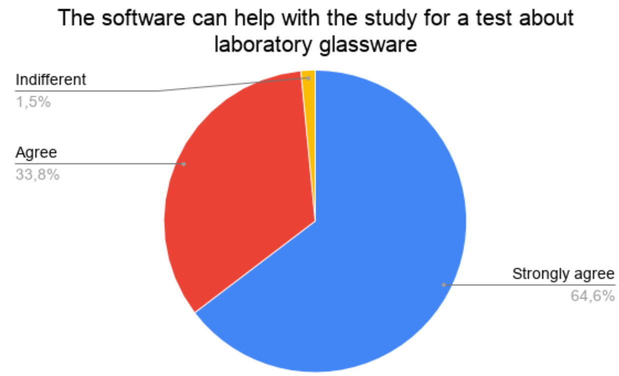

Figure 12: The software can help with the study for a test about laboratory glassware.

7 CONCLUSION

In this work we proposed a novel tool for chemistry glassware learning, presenting an augmented reality app, developed for Android devices. The app features the description of a comprehensive set of glassware, commonly used in labs. There's also a review mode where users can test their knowledge about the subject.

We designed an experiment to investigate AR Lab as a replacement of a regular class in lab. Results evidenced a strong potential it to be used as a substitute, specially for schools without science labs, or even as a support teaching tool.

The qualitative answers about AR Lab were very positive. Most students considered the app a viable substitute for laboratory glassware classes and a way of study.

In addition, statistical analysis did not show difference on the means of students' marks across the group that used and that did not use the software which points that the proposed method is, at least as good as having a lab, for glassware teaching, having the benefit of lower cost and higher safety. This could allow schools that lack the necessary structure an alternative way of teaching through the application.

Discussion

After collecting the data and possessing the students' grades, we can conclude that both a chemistry lab class and a class using the application have a very similar impact on glassware learning.

Students also gave suggestions for improving the application like adding the possibility of conducting chemical experiments and increasing the number of glassware available for use, including different sizes of the same flask. They also asked that if the answer was wrong, in the questionnaire, the correct option to assist with the studies should be shown. Another idea was that the visualization of glassware should be possible without the paper marker however due to the limitation of the API we used in this project it is not yet possible.

Future works may include audio description for the glassware which can be an important factor for accessibility of visually impaired users.

One remarkable feedback received pointed that future versions should have a mode for teachers to setup lecture content (i.e. available glassware and description), quiz editor and final quiz grades summary, similar to a virtual classroom.

Finally, it was noted too during the experiment that support for other platforms, above all, iOS, is crucial for broad use. New features such as the possibility to perform chemical reactions using the glassware in augmented reality, with special effects for water and fire is a strong consideration too.

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