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ReAQ: An Intelligent Tutoring System with Augmented Reality Technology Focused on Chemistry

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Abstract. This paper presents a learning tool called ReAQ, that combines an intelligent tutoring system and augmented reality-oriented to the subject of chemistry. ReAQ facilitates student learning through interaction, three-dimensional visualization, and dynamic adaptation of the content in real-time based on the student's abilities, causing the student to be committed to their learning. Based on an analysis of the educational requirements carried out by 8 teachers of the subject, activities have been designed in a learning tool focused on the topic of "chemical elements, chemical compounds, and chemical reactions". The intelligent tutoring system implements a fuzzy logic module that determines the level of difficulty that the next exercise will have based on the performance of the previous exercise that the student has solved.

Keywords: Augmented reality, intelligent tutor systems, fuzzy logic.

1 Introduction

Chemistry is considered one of the most complicated subjects to learn due to the nature of their abstract contents, which represents a difficult challenge concerning the visualization of chemical elements and compounds [1]. Most students show resistance to identifying chemical elements and forming chemical compounds. Today, with the importance given to Science, Technology, Engineer, and Mathematics (STEM), it is crucial that a student possess the ability to reason and solve problems. Also, the subject of Chemistry in schools tends to play an important role for students to develop the spatial skills that augmented reality offers to them [2].

Augmented Reality (AR) is a technology that allows the user to superimpose digital elements that can be audio, video, image, or three-dimensional element in a real environment [3].

AR might facilitate the visualization of elements that allow the user to understand basic topics. In recent years, many researchers focused their attention on applying AR to different fields like STEM [4,5,6], industry [7], training [8], and customer experiences [9].

On the other hand, Intelligent Tutor Systems (ITSs) provide personalized and real-time help to students. Their capability to adapt feedback according to students' profile allow to deploy instructional methods such as "learning by doing" [10,11,12]. An ITS can be implemented using artificial intelligence techniques like Neuronal Network [13], Data Mining [14], Ruled-based expert systems [15], Fuzzy Logic [6], proving their efficiency in many different fields of knowledge. An effective alternative is incorporating AR into an intelligent tutoring system [16,17].

This work presents an ITS combined with AR technology to learn Chemistry topics aimed at students from the middle-high school. The activities were designed based on the curricular objectives of the chemistry subject of Mexican schools.

2 Related Works

This section presents the works related to AR focused on STEM learning and AR integrated into ITS.

Santamaria [18] used a method to fuse gestures, smart equipment, and digital elements to learn Chemistry experiments. They implement a gesture recognition model trained by a convolutional neural network to recognize gestures in AR and to activate feedback after recognizing a five-finger gesture. According to Chen [19], an AR learning tool remained effectively satisfied with students learning chemistry, Chen focused on the effects of AR learning activities from the perspective of the teacher-centered approach and the student-centered practice approach, to know the conceptual understanding of chemistry topics and the student's interest in the science. Romano [10] presents AR Lab, a learning tool that assists chemistry students during their learning of chemistry glassware, using AR, to help them to assimilate the equipment used in a chemistry lab and their respective functions. Ibañez [20] presents a learning tool where the students can learn the basic principles of geometry to solve area and volume from regular prisms and identify sections of cut made on cylinders and cones. They conducted an interview applying Keller's CIS and IMMS instruments to prove the motivation and usability of the application.

On the other hand, there are several works for developing Intelligent Tutoring Systems focused on the study of STEM. Westerfield [17] presents an ITS combined with AR to teach users how to assemble hardware components on a computer motherboard. The author highlights that the users who interacted with the tutor were faster to do the work compared to the same AR training system without intelligent support. LaViola presents ARWild [21], a tool for the soldier and marine training to master physical tasks in the wild, in places where there is no formal training infrastructure. Almiyad [22] presents Smart AR homework tutoring for medical professionals.

The objective is to teach the user the angle of insertion and the distance traveled by the needle within the patient to perform a successful procedure, through intuitive and adaptive feedback to assist the user. Hsieh [23] presents learning that tool consists of a learning aid, a virtual tutor, and a guiding mechanism for mathematics problem-solving. Students receive feedback immediately after the current exercise. In motivation, the authors affirm that the students show no significant differences between the experimental and control groups. They remarked that guidance and personalization are key to enhance learning with motivation and engagement.

3 Learning Application

ReAQ is an ITS combined with AR focused on the topics of chemical bonds and chemical reactions, of the subject of Sciences at the middle-high school of Mexico. ReAQ provides to the student with tools to identify chemical elements, recognize their symbols and nomenclature, visualize their physical form and their description, as well as formulate chemical compounds, and reactions that are sometimes difficult to visualize. ReAQ is a learning tool developed in Unity 2019 for android devices, implementing Vuforia for AR, SQLite, and Firebase for data persistence.

3.1 Architecture

The architecture of the system follows the traditional architecture of an Intelligent Tutoring System [24, 25] with 4 modules to encapsulate the main processes: KnowledgeModel, PedagogicalModel, StudentModel, and UserAR. Each component within the architecture is briefly described below, and Figure 1 shows ReAQ architecture.

UserAR: In this component, the students interact with the ITS, and is responsible for showing and adapting the required scenes according to the student's level of knowledge obtained from the result of the interaction. This component contains sub-components that allow you to display elements and chemical reactions and select the best options to control the flow of the tutor's execution. The subcomponent **ARSharedGUI** dynamically adapt the content on the screen of the mobile device. The subcomponent **ARSetScenes** contains the set of scenes designed for each of the elements of the learning tool. The subcomponent **ARControlScene** controls the scene in which the user is interacting with the system and the ITS executes different processes based on user decisions; and the subcomponent **ARAssets** contains and manage all the assets necessary to display the exercises on the screen indicated by the tutor.

The **StudentModel** represents the student's model, which contains the student's profile and personal information (chemistry). The subcomponent *StudentKnowledge* is responsible for creating a representation of the cognitive model of the students. It exchanges information with *TutorController* concerning the observed topics and consults information in the student's database and writes the information on the current session.

The **KnowledgeModel** is responsible for manage the didactic material: basic concepts and the exercises necessary to learn to identify elements, chemical compounds, chemical reactions, the feedback, and the level of difficulty. This component accesses the Exercises and Elements database and interacts with the ARModel component to produce the necessary resources to emulate the AR. The component **ARModel** is responsible for providing UserAR with the digital elements that Vuforia emulates.

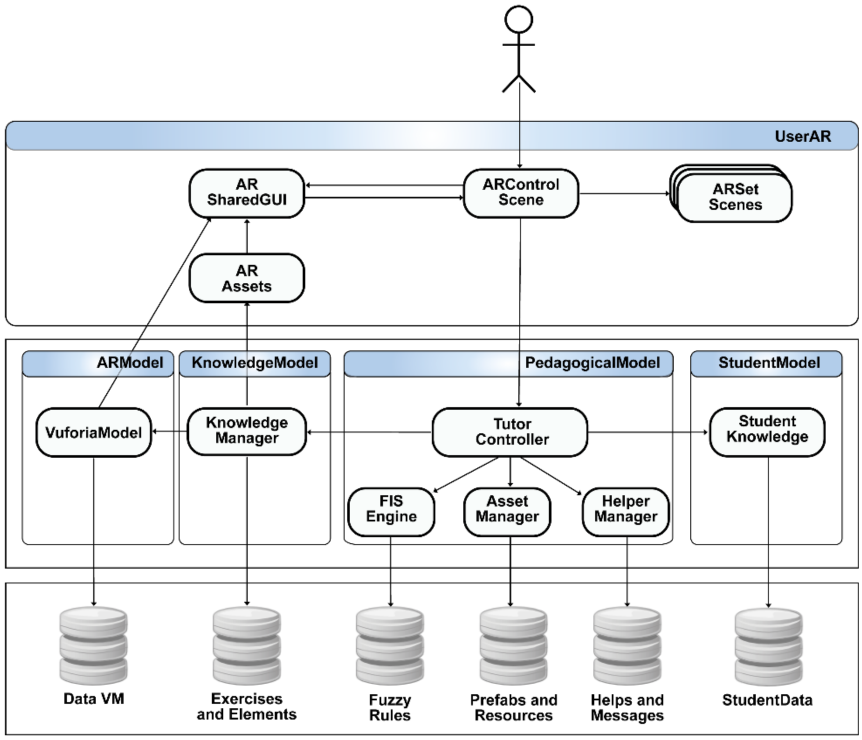

Fig. 1. ReAQ architecture.

The **PedagogicalModel** is responsible for making decisions during the teaching-learning process. The system adapts the information to be displayed to the user's needs depending on the information produced by the student's interaction. The subcomponent *TutorController* is responsible for selecting the exercises that students should perform based on the recommendations made by the FISEngine and providing feedback to the student. The subcomponent *FISEngine* handles the fuzzy inference in the system to adapt the pedagogical model to the student's needs. It also controls the flow and rules of the current exercise. *FISEngine* contains the linguistic variables, fuzzy sets, and various labels. The input variables are the number of correct answers, the number of mistakes made by the student, the number of times the student requests help, and the time required to solve the exercise.

Each fuzzy input variable is normalized to a range of values between 0 and 1. The result of the inference is an output variable called the level of difficulty applicable to the following exercise with the fuzzy values of Weak, Very Weak, Normal Difficult, and Very Difficult. For this work, 81 fuzzy rules were defined. Figure 2 shows an example of the definitions of the fuzzy rules. The subcomponent *AssetManager* controls the flow of scenes from the main menu and accesses databases of prefabs, resources, and plugins to configure the current exercise based on user needs. The subcomponent *HelperManager* manages help messages to solve the exercises.

1. If (answer is high) and (mistake is low) and (time is fast) and (help is low) then (level is veryHard)
2. If (answer is high) and (mistake is regular) and (time is fast) and (help is regular) then (level is hard)
3. If (answer is high) and (mistake is high) and (time is normal) and (help is high) then (level is normal)
4. If (answer is low) and (mistake is high) and (time is high) and (help is low) then (level is normal)
5. If (answer is low) and (mistake is low) and (time is slow) and (help is high) then (level is veryWeak)
6. If (answer is low) and (mistake is low) and (time is regular) and (help is regular) then (level is normal)
7. If (answer is low) and (mistake is high) and (time is fast) and (help is low) then (level is weak)

Fig. 2. Fuzzy Rules defined to determinate the next level of difficulty.

3.2 Exercise Content

The first exercise consists of the student identifying five elements out of 25 available. Each element has a marker with its Symbol. Once the five elements are completed, the student, through the information marker, can select between 5 chemical compounds to display relevant information about the compound on the screen using the info marker.

The second, third, and fourth exercises consist of the student forming a covalent bond, an ionic bond, or a metallic bond respectively. The student must collide two elements, through the use of markers required to solve the exercise. If the combination of the two elements is correct, information about the link is displayed and in turn, an animation with a physical appearance is displayed. The goal is to form 5 bonds. In the event of an error, a message is displayed indicating that the combination of elements does not form the compound of the requested link. Figure 3 shows an example of an exercise covalent bond and ionic bond.

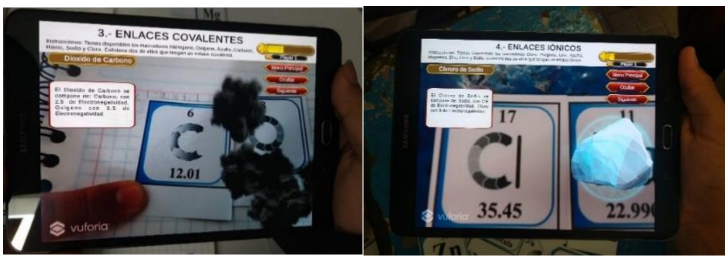

Fig. 3. Covalent bond example (left image) and Ionic bond (right image).

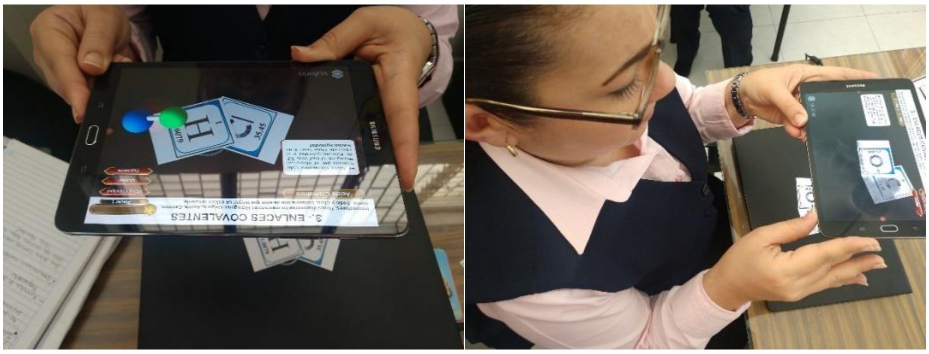

Fig. 4. Teachers interaction with ReAQ.

Table 1. Teachers comments.

Teacher	Type of comment	Comment
Teacher 1	Interesting content	It would be a good element to strengthen student learning.
Teacher 2	Easy to use	Easy to use, looks simple, friendly, eye-catching, and colors match. Even if they do not know how to use it, it is very intuitive and easy to use.
Teacher 3	Easy to use	It is easy to use; the instructions are noticeable clear, and I think they have a lot of skills to master the mobile device.
Teacher 4	GUI friendly	The graphical interface is friendly for the user.
Teacher 5	Improve learning, interesting content	Ideally, the student can receive immediate feedback to improve their skills. I consider that the content is very well structured according to the study program. I believe that students will participate in the classroom using the application.
Teacher 6	Suggestion	It is suggested that the learning tool add an exercise on chemical reactions, where it is observed that reaction occurs when an acid is mixed with little water, an acid with a lot of water, and even mixed with bicarbonate or earth.
Teacher 7	Suggestion	It is suggested that the learning tool must show in the instructions the markers to make the compound required.
Teacher 8	Easy to use, suggestion	It is easy to use. Be careful of the language to be shown in the instructions and to define the objective to fulfill the exercise in use. Remember that the students are younger and maybe irresponsible in the use of the application.

4 Evaluation of the Learning Tool by Experts

This section presents the result of the evaluation and the feedback that the Chemistry teachers gave us. Each teacher was aware of the goal of evaluating the learning tool. Later, the teachers interacted with ReAQ to assess its usability. Teachers believe that ReAQ is innovative, easy to use, and able to hold the student's attention, and agreed that it was feasible to implement it with students in the classroom.

They consider that a learning tool that allows them to visualize or imagine the formation of chemical compounds influences the student to become motivated and lose a little resistance when learning chemistry. Teachers showed interest in implementing it in their teaching practices as a class activity. Also gave us some suggestions to improve the design and use of the application. Figure 4 shows a teacher using ReAQ, and Table 1 shows some of the teacher's comments on the ReAQ application.

5 Conclusions and Future Work

The learning tool can adapt the contents to the current level of the student due to the fuzzy inference that allows adapting the learning material according to the student's abilities. In the pedagogy, and usability evaluation of ReAQ we got a positive reaction from those who teache the subject and by expert doctors in Chemistry. We got excellent feedback and suggestions to improve the learning tool. It has been concluded that students can feel satisfied, motivated, and confident with the achievements they obtain when interacting with the learning tool and, that they can easily master the learning tool thanks to its friendly interface.

As future work, we will develop the teachers' suggestion component to give robustness to the learning tool. We also plan to do some experiments with students using ReAQ to analyze the impact it will have on learning gains, and to evaluate the student's motivation and ReAQ usability.

References

1. Liu, Y., Taber, K.S.: Analysing symbolic expressions in secondary school chemistry: their functions and implications for pedagogy. Chem. Educ. Res. Pract., 17(3), pp. 439–451 (2016)
2. Stieff, M., Uttal, D.: How much can spatial training improve STEM achievement? Educational Psychology Review, 27(4), pp. 607–615 (2015)
3. Azuma, R.: A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6(4), pp. 355–385 (1997)
4. Laine, T.H.: Mobile educational augmented reality games: A systematic literature review and two case studies. Computers, 7(1), pp. 19 (2018)
5. Majid, N.A.A., Mohammed, H., Sulaiman, R.: Students' perception of mobile augmented reality applications in learning computer organization. Procedia - Social and Behavioral Sciences, 176, pp. 111–116 (2015)
6. Peña-Rios, A., Hagras, H., Gardner, M., Owusu, G.: A fuzzy logic based system for geolocated augmented reality field service support. In: IEEE International Conference on Fuzzy Systems (2017)
7. Röltgen, D., Dumitrescu, R.: Classification of industrial augmented reality use cases. Procedia CIRP, 91, pp. 93–100 (2020)
8. Sorko, S.R., Brunnhofer, M.: Potentials of augmented reality in training. Procedia Manufacturing, 31, pp. 85–90 (2019)
9. Romano, B., Sands, S., Pallant, J.I.: Augmented reality and the customer journey: An exploratory study. Australasian Marketing Journal (AMJ) (2020)

10. Almasri, A., Ahmed, A., Al-Masri, N., Sultan, Y.A., Mahmoud, A.Y., Zaqout, I., Akkila, A. N., Abu-Naser, S.S.: Intelligent tutoring systems survey for the period 2000-2018. International Journal of Academic Engineering Research, 3(5), pp. 21–37 (2019)
11. Khella, R.A., Abu-Naser, S.S.: An Intelligent Tutoring System for Teaching French (2018)
12. Teresa, I., Torres, M., Sentí, V.E.: Intelligent tutor system for learning object oriented programming. pp. 1–7 (2017)
13. Chen, C.-M., Li, Y.-L.: Personalised context-aware ubiquitous learning system for supporting effective English vocabulary learning. Interactive Learning Environments, 18(4), pp. 341–364 (2010)
14. Taele, P., Hammond, T.: BopoNoto: An intelligent sketch education application for learning zhuyin phonetic script. DMS, pp. 101–107 (2015)
15. Grivokostopoulou, F., Perikos, I., Hatzilygeroudis, I.: An educational system for learning search algorithms and automatically assessing student performance. International Journal of Artificial Intelligence in Education, 27(1), pp. 207–240 (2017)
16. Herbert, B., Ens, B., Weerasinghe, A., Billinghurst, M., Wigley, G.: Design considerations for combining augmented reality with intelligent tutors. Computers & Graphics, 77, pp. 166–182 (2018)
17. Westerfield, G., Mitrovic, A., Billinghurst, M.: Intelligent augmented reality training for motherboard assembly. International Journal of Artificial Intelligence in Education, 25(1), pp. 157–172 (2015)
18. Santamaría-Bonfil, G., Ibáñez, M.B., Pérez-Ramírez, M., Arroyo-Figueroa, G., Martínez-Álvarez, F.: Learning analytics for student modeling in virtual reality training systems: Lineworkers case. Computers & Education, 151, 103871 (2020)
19. Chen, S. Y., Liu, S.Y.: Using augmented reality to experiment with elements in a chemistry course. Computers in Human Behavior, 111, 106418 (2020)
20. Ibáñez, M.B., Uriarte Portillo, A., Zatarain Cabada, R., Barrón, M.L.: Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course. Computers and Education, 145 (2020)
21. LaViola, J., Williamson, B., Brooks, C., Veazanchin, S., Sottilare, R., Garrity, P.: Using augmented reality to tutor military tasks in the wild. pp.1–10 (2016)
22. Almiyad, M.A., Oakden, L., Weerasinghe, A., Billinghurst, M.: Intelligent augmented reality tutoring for physical tasks with medical professionals. In: International Conference on Artificial Intelligence in Education, pp. 450–454 (2017)
23. Hsieh, M.-C., Chen, S.-H.: Intelligence augmented reality tutoring system for mathematics teaching and learning. Journal of Internet Technology, 20(5), pp. 1673–1681 (2019)
24. Sottilare, R.A., Holden, H.K.: Motivations for a generalized intelligent framework for tutoring (GIFT) for authoring, instruction and analysis. In: AIED 2013 Workshops Proceedings, 7 (2013)
25. Al-Nakhal, M.A.M., Abu-Naser, S.S.: Adaptive intelligent tutoring system for learning computer theoryadaptive intelligent tutoring system for learning computer theory. B+) European Academic Research, 9(10), pp. 8770–8782 (2017)