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ORIGINAL RESEARCH ARTICLE

Augmented reality and learning in organic chemistry

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ABSTRACT

The use of augmented reality (AR) in the teaching-learning process of organic chemistry is considered an innovation in the didactics of this type of content and an area of opportunity for the so-called education 4.0. The aim of this article is to evaluate the learning in organic chemistry of bachelor's degree students with the support of AR. The approach of the study was mixed and a rubric was used as the main instrument for the evaluation of AR projects designed with the HP Reveal® application, as well as a quick test or quiz that allowed the evaluation of specific student learning. The results showed an average score of 8.3/10 in the quality of the AR projects; the average obtained in the exam was 7.94/10. In conclusion, AR projects in high school students improve learning conditions in the area of chemistry through the identification of formulas and nomenclature of organic compounds.

Keywords: augmented reality; organic chemistry; learning; education 4.0

1. Introduction

Currently, the so-called education 4.0 has made it possible to generate a plurality of innovations within the teaching-learning process. The object of study for the current educational research[1] is the way in which new information and communication technologies (ICT) are articulated with the educational phenomenon. Among these ICTs is augmented reality (AR), which has been employed for educational purposes within the field of organic chemistry in recent years[2–5].

The purpose of this research was to evaluate the learning in organic chemistry of high school students using AR. The design of educational projects and digital resources by students allows the development of specific educational competencies, which are also of our interest[6].

The teaching of chemistry in Mexico faces a series of challenges: curriculum, educational evaluation, didactics and its application in daily life; within the latter, practical actions are located, which go from the contents to the student's praxis. These phenological activities mainly involve practical exercises, experiences and research[7]. Here, AR could improve the approach of young people to the construction of scientific thinking and, above all, pre-university training in the hard sciences in a context of educational technological innovation.

The term augmented reality has different definitions; this article takes up the proposal of Merino et al.[8], who state that it is the combination of real environments to which information in digital format is incorporated, which can be visualized in a real-time display; that is, the user has the ability to observe, through an electronic device with a camera, certain

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elements (2D or 3D images, static or moving) that can be linked to other remote digital resources (web page, animation, audio-recording, video, etc.).

The use of AR in education, and specifically in the sciences, has increased in recent years; however, the methodology, approach, instrumentation and interpretations have not been homogeneous[9], a situation that adds importance and relevance to our study. Currently, AR figures as one of the emerging technologies with the greatest projection into the future, not only in the educational field of science, but also in the field of industrial chemistry[10].

The questions guiding this research are: How does the generation of projects with AR impact on the learning of organic chemistry in high school students, and what is the scope level of the students' projects for the improvement of the teaching-learning process in functional groups? As an answer and as a hypothetical assumption, it is affirmed that the students manage to internalize didactic elements for the nomenclature of organic chemical structures; likewise, the level of scope of the students' projects is sufficient for the average of the projects with AR.

We hope that this work contributes to the improvement of didactics in the field of organic chemistry in high school, as well as to encourage the use of AR as an educational tool belonging to education 4.0.

1.1. The use of augmented reality in chemistry education

The use of AR in the teaching of organic chemistry is an innovative intervention in the field of educational technology. There are few reports of this type of technology applied to the disciplinary field of chemistry in Mexico; its use in chemistry teaching has been diverse in terms of the design of the didactic sequence, its evaluation and even the tools used to create virtual environments[11]. Therefore, this intervention contributes to the improvement of didactics in experimental sciences.

Chemistry, in turn, is considered a complex science, since it is linked to the continuous representation of various structures that allow an advance in the understanding of concepts and definitions. Therefore, it is necessary to improve the process of mental design in which the student can represent chemical processes and changes with greater reality[12].

The teaching of chemistry through AR began in 2000, and is a product of technological advancement and the report of various didactic sequences and interventions. The uses of AR in the field of chemistry are related to 3D solid state crystal lattices[13], chemical reactions[14], 3D chemical models printed in textbooks[15], organic compounds[16], electron clouds and atomic models[17], management of chemical symbols and laboratory material as a marker or trigger[18].

In Mexico, AR has been applied in sciences such as anatomy[19], physics[20], mechanics[21] and mathematics[22]; however, little research has reported the support of this technology in chemistry teaching. Merino et al.[8] addressed the use of didactic sequences in chemistry reactivity issues in undergraduate students; similarly, a report by Zarate et al.[23] noticed some patterns of design of markers or triggers for teaching laboratory practices in a virtual environment, in which printed markers are used as triggers of an Erlenmeyer flask.

2. Methodology

2.1. Instruments

For data collection, we resorted to two instruments: first, a rubric adapted from Fernández[24] (see **Table 1**), which was validated in its content using the expert judgment technique, which consists of verifying the reliability and validity through an informed opinion of people with a background in the subject, who can provide information, evidence, judgments and assessments[25]. Second, a quick test or quiz to assess students' cognitive competencies in organic chemistry.

The method for content validity consisted in the evaluation of categories according to the organization of the items, in this case, the proposed rubric. Four experts in the area were invited, who had a professional background in software development, computational systems, as well as postgraduate degrees in education (master's degree) and networks (master's degree), with an average of 15 to 18 years of teaching experience. To guarantee anonymity, the Delphi method was used, so that data collection was carried out individually and each expert was given back the proposal.

The teaching of chemistry through AR began in 2000, and is a product of technological progress and the report of various didactic sequences and interventions.

Table 1. Rubric used in the evaluation of the project with augmented reality

Dimension to be evaluated	Levels of achievement			
	Must improve	**Sufficient**	**Good work**	**Excellent work**
Triggers	There are few triggers for a correct realization of the work. Triggers do not have a description or coordinates (0.5 points).	The number of triggers is sufficient, but they lack a description and none of them have marked areas to insert the overlays (1 point).	A large number of triggers have been introduced and all have an adequate description. In many of them areas for inserting overlays have been selected (1.5 points).	A good selection of trigger images has been made. All have a correct description and are accompanied (2 points).
Layers (overlays)	Associated layers are insufficient or not related to the work (0.5 points)	Layers associated with triggers are images without any effect (1 point)	Associated layers are relevant to the work; layers of various types are introduced and in some cases images or videos are linked (1.5 points)	All triggers have several overlays in which images, videos or URLs are included. Different types of transition effects are introduced. The cell phone is used for the creation of the project (2 points).
Final work	The app in which the work is hosted is not found or the desired effects are not produced. The final work does not contribute anything significant to the project and is a curious tool that does not go beyond being a simple eye-catching artifact (0.5 points).	The channel is easy to find and most of the triggers produce the expected effects. The final work helps to complete the project and provide it with a necessary tool (1 point).	All triggers are associated with the overlays, although the final effects are limited. The final work contributes effectively to the project and brings an element of quality to the project (1.5 points).	All triggers are associated with the programmed layers with a wide variety of transition effects. The final work makes an outstanding contribution to achieving the project objectives (4 points).

Source: adapted from Fernandez (2015).

Thus, we grouped the items according to the dimensions proposed in the original instrument: triggers, layers (overlays) and final work. The experts were given the task of evaluating each one and classified them into the following categories according to their judgment and experience: 1) does not meet, 2) low level, 3) moderate, and 4) high level. Cronbach's alpha analysis of the data is shown in **Table 1**. Based on Welch and Comer[26], reliability using this alpha assumes that the items measure the same construct and that they are highly correlated. The maximum possible score of the rubric was 10 points and the minimum, 1.5, in which the basic elements for the evaluation of the project were considered.

The self-assessment of the experts' competence was carried out with the K coefficient or expert competence coefficient, and its calculation was made using the following data:

- Knowledge coefficient (Kc), which is the expert's knowledge of the subject to be evaluated; it is obtained through a numerical self-assessment ranging from 1 to 10, multiplied by 0.1.
- Argumentation coefficient (Ka), obtained from the values in **Table 2**, in which the response of

each expert is evaluated and assigned according to the sources of argumentation of his or her discourse and its influence (high, medium or low); in this table, the researcher must add according to the existence of the source of argumentation and the evaluation of the expert's discourse.

The results of K for each expert are shown in **Table 3**, as well as the values of Kc and Ka. Once the K value was obtained, we classified the experts into three groups: those with high source influence (K > 0.8), those with medium source influence (K < 0.8 and ≥ 0.5), and those with low influence (K < 0.5). Of the experts, three of them showed a high level of influence (K > 0.8) and one, medium (K value < 0.8 and ≥ 0.5), suggesting a good degree of mastery of the research topic (see **Table 3**).

With the support of the SPSS Statistics program (version for Macintosh), we calculated the Cronbach's alpha value for each item, by dimension, and the average of the total instrument, with the aim of achieving reliability and internal consistency; the statistical values are shown in **Table 4**. The rubric presented a low internal consistency with a total Cronbach's alpha value of 0.686; the minimum parameter suggested for the social sciences is 0.7, according to Celina and Campo[27], which suggests a future redesign of the instrument in order to increase its internal consistency values; it is worth mentioning that this is not the object of study of this article.

Table 2. Assessment of the sources of argumentation to obtain the value of Ka

Source of argumentation	**Degree of influence of each of the sources in their criteria**		
	High	**Medium**	**Low**
Theoretical analysis by the expert	0.3	0.2	0.1
Experience gained	0.5	0.4	0.2
Study of works on the subject of authors in Mexico	0.05	0.05	0.05
Study of works on the subject by foreign authors	0.05	0.05	0.05
Own knowledge about the state of the problem abroad	0.05	0.05	0.05
Expert's intuition	0.05	0.05	0.05

Source: adapted from Cabero and Barroso (2013).

Table 3. Values of the coefficient of expert competence (K) obtained for each expert

Expert	**Value of Kc**	**Value of KA**	**K coefficient (K= Kc + Ka)**	**Influence level according to K VALUE**
1	1	0.7	1.7	High
2	0.8	0.5	1.3	High
3	0.7	0.6	1.3	High
4	0.6	0.1	0.7	Average

Source: own elaboration.

The quiz consisted of 15 relationship questions, in which the students had to relate the name of the structure under an IUPAC (International Union of Pure Applied Chemistry) system with the developed, semi-developed or condensed formula. The groups of organic compounds and functional groups that were evaluated are: aliphatic hydrocarbons (open chain and arborescent), aromatic hydrocarbons, alcohols, ketones and aldehydes. These expected learning are considered in the curricular program of the subject of Chemistry II proposed by the Dirección General de Bachillerato[28]. This document states that the student "will use chemical language to refer to hydrocarbons and functional groups, identifying their applications in various fields". The items of the quick test were designed with the objective of achieving the expected learning of the block proposed in the DGB program, so that, through the design of the project with AR,

Table 4. Cronbach's alpha analysis of the items of the rubric

Item number	Cronbach's alpha value per item
Item 1	0.691
Item 2	0.642
Item 3	0.691
Item 4	0.691
Item 5	0.691
Item 6	0.579
Item 7	0.691
Item 8	0.691
Item 9	0.550
Item 10	0.691
Item 11	0.691
Item 12	0.550

Source: own elaboration.

students could identify and interpret, through a chemical language, the functional groups proposed in the Chemistry II curriculum.

2.2. Participants

The sample was a non-statistical purposive sample that included all students officially enrolled in the second semester of the afternoon shift, 2018-2019 school year at the high school of the Universidad de la Salle Bajío, campus Américas in León, Guanajuato, Mexico. The population consisted of 118 students, distributed as follows: 39 students from group A, 37 from group B and 42 from group C; 45.5% of the population was male and 54.5%, female, with an age range of 15 to 18 years.

2.3. Procedure

The research was divided into three phases: instruction and tutoring, design of the digital resources, and evaluation of the project. In the first phase, the students were instructed on the use of the HP Reveal® Studio application, which was used as the AR project manager. The objective of the project and the basic elements to be considered in the design of the digital inputs were also explained to them; this stage took almost two months. The students formed subgroups of between seven and ten students, created an account on the HP Reveal® platform and set themselves the task of researching the reference and theoretical background of the project; in this case, the topic of organic chemistry, which was part of the official program content, according to the DGB (generation 2017-2020 and subsequent), and which was assigned by the professor.

During the second phase, the students designed the digital resources, they were asked to create a video that had the following elements: introduction to the topic, definition of the functional group, uses and industrial applications, as well as the 3D structure of an example molecule. The video also had to contain the voice of the participants as part of their explanation; some teams used YouTube videos and others made a mix of these and inserted the voice of the participants as the last layer. Afterwards, the students created a new project in the HP Reveal® platform, called Aurasma; they selected an image as a marker or trigger, which can be identified by the camera; then the video of each of the teams was inserted as a layer or overlay, which arises from the trigger.

Finally, in the project evaluation stage, the rubric for project evaluation was applied and, finally, the quiz was printed, for which we dedicated a time of twenty-five minutes; the activity was individual and supervised by the teacher.

3. Results

After recording the data obtained, we performed a quantitative analysis by group, from which we obtained the average of each dimension and the level of achievement of the rubric (see **Table 5**), as well as the average score of the quick test (see **Table 6**). The evaluation was done with the rubric validated by the experts.

In the video of one of the projects carried out by the students, we observed the marker of the Aurasm or project and the pop-up video (overlay). In the dimension of triggers, most of the groups obtained a sufficient level (35.6%); in the dimension of layers inserted in the digital project it was excellent (50.6%), since in most of the videos varied digital elements were incorporated (videos of their own creation, edited, etc.). representations and audio recordings); in the last dimension, corresponding to the general structure of the project for the final work, the promise was excellent. Most of the teams fulfilled the task of presenting an AR project with quality digitized resources (53.33%). The average rating of the entire integrated project, i.e., of the three dimensions evaluated, was 8.3 on a scale of 10.

Regarding the results obtained in the rapid test, the group that achieved the highest average was group B, with a score of 8.33; the group with the lowest average was group C, with a value of 7.66 (see **Table 6**). Among the AR projects of group B, elements of visual and digital importance were identified, for example, the use of their own voice, the editing of inputs and outputs, as well as the references used for the elaboration of the project.

On the other hand, in group A the projects lacked dynamism in their communicative elements; they only used the voice of one of their partners, or they inserted layers with videos of other authors.

Table 5. Results obtained from the rubric by group in percentages

Dimension to evaluate	Group A	Group B	Group C	Average of 3 groups
Triggers	35%, must improve 30%, good enough 12%, good job 23%, excellent job	12%, must improve 32%, good enough 23%, good job 33%, excellent job	31%, must improve 45%, good enough 20%, good job 4%, excellent job	26%, must improve 35.6%, enough 14.66%, good job 20%, excellent job
Overlays	10%, must improve 25%, sufficient 18%, good job 47%, excellent work	7%, must improve 8%, good enough 15%, good job 70%, excellent job	10%, must improve 42%, good enough 13%, good job 35%, excellent job	9%, must improve 25%, good enough 15.3%, good job 50.6%, excellent work
Final work	15%, must improve 14%, sufficient 21%, good work 50%, excellent work	5%, you must improve 15%, good work 80%, excellent work	20%, must improve 20%, enough 30%, good job 30%, excellent work	13.33%, must improve 11.33%, sufficient 22%, good work 53.33%, excellent work
Average score obtained in the rubric	7.5	8.5	8.9	8.3

Source: Own elaboration. by the students, mixing videos with some pre-existing ones, as well as images, 3D molecular

Table 6. Average scores obtained in the rapid test

	Group A	Group B	Group C
Average number of correct answers	11.74	12.49	11.49
Average grade obtained	7.83	8.33	7.66

Source: Own elaboration.

4. Discussions

The data obtained in the intervention showed that the quality of digital resources used by the students (overlays) was diverse in terms of sound clarity; another important element that presented itself as a heterogeneous factor was the quality of the screen recording, since the sharpness of the cell phones used was variable. In a report by Dunser and Billinghurst[29], the elements that are evaluated within an AR project are the user interface and platform, user interaction with the application or program, manipulation of objects or 3D elements, and user immersion in the AR environment.

According to Jiménez[30], the chemistry topics most addressed through AR have been 3D molecule structures-as in this project-as well as chemical bonds and intermolecular forces. In this case, only some structures were evaluated in 3D and others in 2D. Nor were chemical bonds the exclusive object of study in this research.

The advantages of employing AR as part of the learning and teaching strategies have been the decrease in costs and the improvement in the students' time management; in the same way, when crossing the data obtained in this research, the use of 2D markers (triggers) constituted part of the teaching through this type of ICT[31]. Regarding the methodologies employed in teaching with AR, the one that has stood out the most has been experimental designs and, secondly, the use and design of questionnaires as a data collection instrument[9].

In this work, a mixed methodology (quali- and quanti-) was used regarding the evaluation of the projects and the educational impact achieved. On the other hand, the target population most studied internationally for the educational use of these emerging technologies has been primary and undergraduate students, and in third place high school students, as in this case[32].

Some authors have suggested that the use of AR in the teaching of exact and experimental sciences in Mexico can improve student performance[33]. AR allows a better connection between theoretical aspects and practical experience, which can be corroborated with the data obtained from group B on the quiz.

One of the limitations in recent years regarding the use of this type of technology is the resistance of teachers to the inclusion of AR in their didactics, as well as the exploration of new teaching models and support from institutions[34]. In the case of the present research, the institution supported the realization of this kind of projects, which will allow teachers of the experimental sciences academy to incorporate these strategies in their evaluation and teaching systems in the future.

The current evidence on the evaluation of educational projects using AR is very heterogeneous; for example, Swan and Gabbard[35] state that only 8% of the published research on AR includes formal evaluations, and one of the reasons is the lack of adequate methods for the various AR interfaces[29]. This study used a rubric that allowed us to assess the AR project articulated with the application interface which, in this case, was HP Reveal®. The evaluation we made to the students yielded quantitative data, which could be only a numerical approximation, but of high significance for the students, as explained by Da Silva et al.[9] in their systematic review of perspectives on how to evaluate AR technology tools used in education.

The design of the evaluation system was complex, since the literature suggests the inclusion of instruments with a varied nature (quali- and quanti-)[9]; in this work, we used two instruments of both natures (rubric and quick test); however, the internal consistency of the instruments needs to be improved as a recommendation for future interventions with AR, since, thus, the emission of the results will have greater robustness.

5. Conclusions

The research questions were resolved by the finding that the use of AR in the teaching of organic chemistry improves the identification of chemical formulas, as well as the nomenclature of organic compounds; likewise, the average level of scope of the students' projects was sufficient and a good job according to the rubric used.

Some of the limitations we identified were:

- The methodological design: we allude to a methodology that allows the inclusion of instruments with a mixed nature (quali- and quanti-), as well as a statistical sampling design, in order to improve the results and their degree of reliability.
- The internal consistency value (reliability) of the rubric used in the evaluation of the project was low, since we obtained a Cronbach's alpha of 0.686, close to 0.7; however, we recommend future studies to improve the construct and the level of reliability of the instrument.
- Digital competencies in students proved to be a challenge for them, as some of them have basic editing and content digitization skills, which reveals an area of opportunity for future work with AR.

- The availability of platforms and applications for the design of educational projects with AR is still limited; it also requires, at times, a specific promotion of digital competencies in users, such as knowledge of video, image and audio editing.

To conclude, we can affirm that the realization of AR projects in high school students improves learning conditions in the area of organic chemistry through the identification of formulas and Nome clo-ture of compounds. In addition, the inclusion of emerging technologies of education 4.0 allows a more adequate approach to the development of specific educational skills and competencies in the teaching of experimental sciences and its priming future.

Conflict of interest

The author declares no conflict of interest.

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