Augmented reality and learning in organic chemistry

Realidad aumentada y aprendizaje en la química orgánica

http://dx.doi.org/10.32870/Ap.v12n1.1853

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ABSTRACT

The usage of augmented reality (AR) in the process of Organic Chemistry Teaching-learning it´s considered as an innovation in didactics of this type of content and an opportunity area for the known education 4.0. The aim of this article was to evaluate learning in Organic Chemistry in High school students' trough the usage of AR. A mixed focus was used, using a rubric as principal tool for the evaluation of the augmented reality projects designed trough HP Reveal®, such as a quiz that allowed to evaluate Specific learning on the students. The results showed a mean grade of 8.3/10 on the augmented reality projects, the mean obtained on the quiz was 7.94/10. As a conclusion manner, the usage of AR projects in high school students improves learning conditions in the domain of Chemistry trough the identification of formulas and organic compounds.

Keywords
Augmented reality; organic chemistry; learning; education 4.0

RESUMEN

El uso de la realidad aumentada (RA) en el proceso de enseñanza-aprendizaje de la química orgánica es considerado una innovación en la didáctica de este tipo de contenido y un área de oportunidad para la llamada educación 4.0. El objetivo de este artículo es evaluar el aprendizaje en química orgánica de alumnos de bachillerato con el apoyo de RA. El enfoque del estudio fue mixto y se utilizó una rúbrica como instrumento principal para la evaluación de proyectos con RA diseñados con la aplicación HP Reveal®, así como un examen rápido o quiz que permitió evaluar los aprendizajes específicos de los alumnos. Los resultados mostraron una calificación promedio de 8.3/10 en la calidad de los proyectos con RA; el promedio obtenido en el examen fue de 7.94/10. A manera de conclusión, los proyectos con RA en alumnos de bachillerato mejoran las condiciones de aprendizaje en el área de la química mediante la identificación de fórmulas y nomenclatura de compuestos orgánicos.

Palabras clave
Realidad aumentada; química orgánica; aprendizaje; educación 4.0

Received: November 3, 2019
Accepted: February 19, 2019
Online Published: March 30, 2020

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INTRODUCTION

Currently, the so called education 4.0 has allowed us to generate multiple innovations within the teaching-learning process. The object of the study for the current educational research (De la Iglesia, 2019) is the manner in which new information and communication technologies (ICT) are articulated with the education phenomenon. Among these ICT is augmented reality (AR), which has been employed for educational purposes, within the field of organic chemistry over the last years (Behmke *et al.*, 2018; Cai, Wang & Feng, 2014; Chen, 2013; Martinez, Garcia & Escalona, 2017).

The purpose of this research was to evaluate the learning process of the organic chemistry subject of high school students by using AR. The design of educational projects and digital resources by students allow the development of specific educational competencies, which also are of our concern (Hernandez, Perez & Resendiz, 2017).

Teaching chemistry in Mexico faces a number of challenges: the curriculum, the educational assessment, didactics and their application in daily life; several practical actions are found in the latter, which go from content to student's praxis. These phenomenological activities mainly fall on practical exercises, experiences and research (Perez & Chamizo, 2016). Here, AR could improve contact of young students to the construction of a scientific thought and, above all, pre-college education towards hard sciences within the context of technological educational innovation.

The term augmented reality has different definitions, in this article the proposal of Merino *et al.* (2015) is resumed, who say that it is the combination of real environments to which the information in digital information is incorporated, and which may be seen in a real time screen; that is, the user has the ability to observe, by means of an electronic device with a camera, specific elements (2D or 3D images, either static or with movement) that may be linked to other remote digital resources (webpage, animation, audio recording, video, et cetera).

Using AR in education and, specifically, in sciences, has increased over the last years; however, the methodology, the approach, the instrumentation and interpretations have not been homogeneous (Da Silva *et al.*, 2019), which adds relevance and pertinence to our study. Currently, AR appears as one of the emerging technologies with greater future projection, not only in the educational field of sciences, but also in the field of industrial chemistry (Ministère de L´Économie et des Finances, 2019).

Guiding questions in this research are as follows: how does the generation of projects impact AR in learning organic chemistry on medium-higher education students? and what level of reach do students' projects have for the improvement of the teaching-learning process in functional groups? As an answer and as a hypothetical assumption, it is affirmed that students manage to internalize didactic elements for the nomenclature of organic chemistry structures; likewise, the scope of students is of sufficient nature for the average of projects with AR.

We expect that this work adds to the improvement of field didactics of organic chemistry at the high-school level, as well as to encourage the use of AR as an educational tool of education 4.0.

Using augmented reality to teach chemistry

AR for teaching 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 teaching chemistry has been diverse regarding the design of the didactic sequence, its evaluation and even the tools employed to create virtual environments (Nechypurenko *et al.*, 2018). Therefore, this participation contributes to the improvement of didactics in experimental sciences.

Chemistry, in turn, is considered as complex science, since it is linked to the continuing representation of diverse structures that enable an advance in understanding concepts and definitions. Therefore, the mental design process is to be perfected where the teacher can represent chemical processes and changes with greater reality (Nechypurenko *et al.*, 2016).

Teaching chemistry by means of AR started in 2000 and it is the product of technological advance and the report of diverse didactic sequences and participations. The use of AR in the field of chemistry is related with crystalline networks of the solid state in 3D (Arloon, 2017), chemical reactions (Maier, Tönnis & Klinker, 2009), chemical 3D models printed on textbooks (StudyMarvel, 2016), organic compounds (Virtual Space, 2017), electron clouds and atomic models (Larngear, 2012), handling chemical symbols and laboratory material as a marker or trigger (Daskalos, 2015),

In Mexico, AR has been applied to sciences such as anatomy (Ruiz. 2019), physics (Ruiz & Ruiz, 2015), mechanics (Suarez & Gonzalez, 2016) and mathematics (Medina *et al*., 2016); nonetheless, few research has reported the support of this technology in the teaching of chemistry. Merino *et al*. (2014) addressed the use of didactic sequences in matters of chemical reactivity in bachelor students; likewise, in a report from Zarate *et al*. (2013) some patterns are noticed in the design of markers or triggers to teach laboratory practice in a virtual environment, where printed markers are used as triggers in an Erlenmeyer flask.

METHODOLOGY

Instruments

For the collection of data, we used two instruments: first off, an adapted rubric of Fernandez (2015) (see table 1), whose content was validated by means of the expert opinion technique, which consists of verifying reliability and validity by means of an informed opinion from people with experience in the topic, who may provide information, evidence, opinions and assessments (Neira, Ibañez & Lopez, 2017). Secondly, a quick test or quiz to assess cognitive competencies of students in the organic chemistry subject.

Table 1. Rubric employed in assessing the project with augmented reality

Dimension to evaluate	Levels of accomplishment			
	Need to improve	Sufficient	Good work	Great work
Triggers	There are very few triggers to conduct the work properly. The triggers are not described and do not have	The number of triggers is sufficient but they are not described and in none of them an area has been	Many triggers have been introduced and all of them are described properly. In many of them	Trigger images have been adequately selected. All of them are described and

	coordinates (0.5 points)	marked to insert overlays (1 point)	an area has been selected to insert overlays (1.5 points)	are accompanied (2 points)
Overlays	The linked overlays are insufficient or not related to the work (0.5 points)	The overlays linked to triggers are images without any effect (1 point)	The linked overlays are relevant for the work. Several types of overlays are introduced and in some cases images or video are linked (1.5 points)	All the triggers have several overlays containing images, videos or URLs. Different types of transition effects are introduced. Cell phone is used for the making of the project (2 points)
Final work	The app in which the work is stored cannot be found or the wanted effects are not produced. The final work does not contribute significantly to the project and is nothing but a peculiar tool that is not more than a simple and flashy artifact (0.5 points)	The channel ca be easily found and the expected effects are produced in most of the triggers. The final work helps completing the project and gives it a necessary tool (1 point)	All the triggers appear linked to the overlays, though final effects are limited. The work contributes effectively to the project and contributes a quality element to it (1.5 points)	All the triggers are linked to the programmed overlays with a wide variety of transition effects. The final work contributes outstandingly to accomplish the objectives of the project (4 points)

The method used for validity of content consisted in assessing categories in accordance with the organization of the items, in this case, the proposed rubric. Four experts in the area with a professional education in software development, computer systems, in addition to having post-degrees in education (master's degree) and networks (master's degree), with an average of 15 to 18 years' teaching experience were invited. The Delphi method was used to guarantee anonymity, therefore data collection was performed individually and the proposal altogether was returned to each expert.

Thus, we grouped items in accordance with the proposed dimensions in the original instrument: triggers, overlays and the final work. The experts carried on evaluating each of them and classified them in the following categories per their opinion and experience: 1) does not meet, 2) low level, 3) moderate, 4) high level. Cronbach's alpha analysis on the data is shown in Table 1. Based on Welch & Comer (1998), reliability by means of this alpha assumes that the items are measured in the same construct and that they are highly correlated. The maximum possible score of the rubric was 10 points and the minimum was 1.5, where the basic elements were considered for the project evaluation.

Self-appraisal of the experts' competency was done with the K coefficient or expert competition coefficient, and the calculation thereof was done by means of the following data:

- Knowledge coefficient (Kc), which is information on hand by the expert regarding the topic to be assessed; it is obtained by means of a numerical self-appraisal ranging from 1 to 10, multiplied by 0.1.
- Argument coefficient (Ka) that was obtained from the values in table 2, where the answer of each expert is assessed and assigned in accordance with the sources of the argument of their discourse and influence (high, medium or low); in this table, the researcher should add in accordance with the existence of the substantiation source and the expert's discourse assessment.

Table 2. Valuation of argument sources to obtain the value of Ka

Source of basis	Degree of influence of each of the sources in their criteria		
	High	Medium	Low
Theoretical analyses made by the expert	0.3	0.2	0.1
Experience gained	0.5	0.4	0.2
Study of works on the topic from authors in Mexico	0.05	0.05	0.05

Study of works on the topic from foreign author	0.05	0.05	0.05
Own knowledge on the status of the problem outside of the country	0.05	0.05	0.05
Intuition of the expert	0.05	0.05	0.05

The results of K for each expert are shown in table 3, as well as the values of Kc and Ka. Once the value of K was obtained, we classified the experts in three groups: those with high influence from the sources (K > 0.8), those with medium influence from the sources (K < 0.8 and ≥ 0.5), and those with low influence (K < 0.5). Three of the experts showed a high level of influence (value of K > 0.8) and one, a medium level (value of K < 0.8 and ≥ 0.5), which suggests a good degree of proficiency on the topic of the research (see Table 3).

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

Expert	Kc Value	Ka Value	Coefficient K (K= Kc + Ka)	Level of influence according to the value of K
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	Medium

Supported by the SPSSStatistics program (Macintosh version), we calculated the value of Cronbach's alpha for each item, per dimension, and the average of the total of the instrument, with the purpose of achieving internal reliability and consistency; statistical values are shown in table 4. The rubric presented a low internal consistency with a total Cronbach's alpha of 0.686; the minimum parameter suggested for social sciences is 0.7, in accordance with Celina & Campo (2005), which suggests a future redesign of the instrument aimed to increase the values of internal consistency; it must be mentioned that this is not the object of study of this article.

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

Item number	Value of Cronbach's alpha 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

The quiz consisted in writing 15 relational questions, where the students ought to relate the name of the structure under the system of the International Union of Pure and Applied Chemistry (IUPAC) with the developed, semi-developed or condensed formula. The groups of organic compounds and functional groups that were evaluated were: aliphatic hydrocarbons (open chain and arborescent), aromatic hydrocarbons, alcohols, ketones, and aldehydes. These expected learnings are considered in the curricular program of the Chemistry II subject proposed by the General High School Division (GHSD) (SEP, 2017). In this document, it is established that the student "shall use a chemical language to refer to hydrocarbons and functional groups, by identifying their applications in several areas" (GHSD, 2017 p. 19).

Items of the quick test were designed with the purpose of achieving the expected learnings of the block proposed in the program of the (GHSD), in such a way that, by means of the design of the project with AR, the students could identify and interpret, using a chemical language, the functional groups proposed in the Chemistry II curriculum.

Participants

The sample was of the non-intended statistics type where all of the students officially enrolled in the second semester of the afternoon shift were included, academic term 2018-2019 of the high school of the Universidad de La Salle Bajio, campus Americas in the city of Leon, Guanajuato, Mexico. The population included 118 students, distributed as follows: 39 students of group A, 37 of group B and 42 of group C; 45.5% of the population was male, and 54.5% female, with an age range of 15 to 18 years.

Procedure

The research was divided into three phases: instruction and tutorship, digital resources design, and project evaluation. In the first phase, the students were instructed on the use of the HP Reveal® Studio application, which was employed as the AR project manager. Also, they were explained what the object of the project was and the basic elements to be considered in designing digital inputs; this stage took almost two months. The students set up sub-groups between seven and ten students, they created an account in the HP Reveal® platform and carried on investigating what the referent and theoretical background of the project was; in this case, the topic of organic chemistry, which was part of the content of the official program, in accordance with the GHSD (class of 2017-2020 and subsequent), and which was assigned by the professor.

During the second phase, the students designed the digital resources, it was requested that they created a video containing the following elements: introduction to the topic, definition of the functional group, industrial uses and applications, as well as the structure in 3D of an example molecule. In addition, the video ought to contain the voice of the participants as part of their explanation; some teams used YouTube videos and others made a mixture of these and inserted at the last layer the voice of the members. Afterwards, the students created a new project in the HP Reveal® platform, which is called Aurasma; they selected an image as a marker or trigger, which enables it to be identified by the camera; then, the video was inserted of each of the teams as a layer or overlay, which emerges from the trigger.

Finally, at the project evaluation stage, the rubric was applied to assess the project and, lastly, the quiz, which was printed, therefore we spent twenty-five minutes; this was an individual activity supervised by the teacher.

RESULTS

After recording the information obtained, we performed a quantitative analysis per group, where we obtained the average of each dimension and the scope level of the rubric (see table 5), as well as an average grade of the quick test (see table 6). The evaluation was done with the rubric validated by the experts.

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

Dimension to evaluate	Group A	Group B	Group C	All 3 groups mean
Triggers	35%, need to improve 30%, sufficient	12%, need to improve 32%, sufficient	31%, need to improve 45%, sufficient	26%, need to improve 35.6%, sufficient

	12%, good work 23%, excellent work	23%, good work 33%, excellent work	20%, good work 4%, excellent work	14.66%, good work 20%, excellent work
Overlays	10%, need to improve 25%, sufficient 18%, good work 47%, excellent work	7%, need to improve 8%, sufficient 15%, good work 70%, excellent work	10%, need to improve 42%, sufficient 13%, good work 35%, excellent work	9%, need to improve 25%, sufficient 15.3%, good work 50.6%, excellent work
Final work	15%, need to improve 14%, sufficient 21%, good work 50%, excellent work	5%, need to improve 15%, good work 80%, excellent work	20%, need to improve 20%, sufficient 30%, good work 30%, excellent work	13.33%, need to improve 11.33%, sufficient 22%, good work 53.33%, excellent work
Average grade in the rubric	7.5	8.5	8.9	8.3

Table 6. Average grades obtained in the quick test

	Group A	Group B	Group C
Mean correct answers	11.74	12.49	11.49
Average grade	7.83	8.33	7.66

In the video[1] of one of the projects performed by the students we observed the Aurasma marker or project and the emerging video (overlay). In the triggers dimension, most of the groups obtained a sufficient level (35.6%); in the overlay dimension inserted in the digital project it was excellent (50.6%), as most of the videos included diverse digital elements (self-created videos, edited by the students, a mixture of videos with some pre-existing ones, as well as images, 3D molecular representations and audio recordings); in the last dimension, of the general structure of the project for the final work, the average was excellent. In most of the teams the task was complied with as they presented an AR project with quality digitalized resources (53.33%). The average grade of the whole project, that is, the three dimensions evaluated, was 8.3 in a scale of 10.

Regarding the results obtained in the quick test, the group achieving the highest average was group B, with a grade of 8.33; the one with 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 relevance were identified, for example, using their own voice, editing entries and exits, as well as references employed to prepare the project.[2]

On the other hand, in group A, the projects lacked dynamism on their communicative elements; they only employed the voice of one of its members or they inserted layers with videos of other authors.[3]

DISCUSSION

The data obtained during their participation showed that the quality of digital resources employed by the students (overlays) was diverse regarding sound clarity; another element of relevance that was presented as a heterogeneous factor was the quality of screen recording, because the sharpness of the cellular employed was variable. In a report by Dünder & Billinghurst (2011), the elements evaluated within an AR project are user interphase and the platform, user interaction with the application or the program, handling objects or 3D elements, and user immersion in the AR environment.

In accordance with Jimenez (2019), mostly seen topics of chemistry through AR have been 3D molecule structures –as in this project–

as well as chemical links and intermolecular forces. In this case, only some 3D structures and others in 2D were evaluated. Neither were chemical links the subject of exclusive study of this research.

The advantages of using AR as part of the teaching and learning strategies have included the reduction of costs and the improvement of students' time management; additionally, when the data obtained are crossed in this research, using 2D markers (triggers) comprised part of the teaching process through this type of ICT (Linowes & Babilinski, 2017). Regarding the methodologies employed in the teaching process with AR, experimental designs has mostly stood out and, in the second term, using and designing questionnaires as a data collection instrument (Da Silva, 2019).

A mixed methodology was used for this work (quali- and quanty-) concerning the assessment of projects and the attained educational impact. On the other hand, the objective population which is mostly studied at an international scale for educational use of these emerging technologies has been elementary education and bachelor education, and in the third place is high school, as it was in this case (Sommerauer & Müller, 2014).

Some authors have suggested that the use of AR for teaching exact and experimental sciences in Mexico may improve the performance of students (Gomez, 2017). AR enables a better connection between theoretical aspects and practical experience, which may be verified by data obtained from group B on the quiz.

One of the drawbacks of the past years regarding the use of this type of technologies is the resistance of professors to include AR in their didactics, as well as the exploration of new teaching models and institutional support (Bitner & Bitner, 2002). In the case of this research, the institution provided support for conducting this kind of projects, which will enable teachers of experimental sciences in the future to include these strategies in their assessment and teaching systems.

The current evidence on the evaluation of educational projects including AR is highly heterogeneous; for example, Swan & Gabbard (2009) affirm that only 8% of published investigations on AR include formal assessments, and one of the reasons is the lack of proper methods for the diverse AR interphases (Dünser & Billinghurst, 2011). This study used a rubric which allowed us to value the AR project articulated by the interphase of the application, which in this case was HP Reveal®. The assessment we conducted on the students gave data of a quantitative type, which could only be a numerical approximation, however, of high significance to students, as explained by Da Silva *et al.* (2019) in their systematic review of the perspectives on how to evaluate AR technological tools employed in education.

Designing the evaluation system was complex because the literature suggests that instruments be included of a varied nature (quali- and quanty-) (Da Silva *et al.*, 2019); 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, in this way, the results obtained will be more solid.

CONCLUSION

Research questions were answered as it was evidenced that the use of AR to teach organic chemistry improves improved the identification of chemical formulas, as well as the nomenclature of organic compounds; similarly, the level of the average achievement of the projects of the students was sufficient and a good job in accordance with the rubric employed.

The following are drawbacks we identified:

- Methodologic design: we refer to a pluralistic methodology which allows the inclusion of mixed nature instruments (quali- and quanti-), as well as a sampling design of a statistical nature, with the purpose of improving the results and the degree of reliability.
- The value of internal consistency (reliability) of the rubric employed in the evaluation of the project was low, as we obtained a Cronbach's alpha of 0.686 close to 0.7; notwithstanding, we recommend future studies to improve the construct and the reliability level of the instrument.
- Students' digital competencies was a challenge to them, as some of them have the basic edition and content digitalization skills, which reveals an opportunity area for future work with AR.
- Availability of platforms and applications to design educational projects with AR is still limited; occasionally,

specific promotion of digital competencies of users is required, like video, image and audio edition.

In conclusion, we can affirm that the implementation of project with AR for high-school students improves learning conditions in the organic chemistry area by means of the identification of formulas and nomenclature of compounds. In addition, the inclusion of emerging technologies of education 4.0 enables the most suitable approach to the development of specific educational skills and competencies in the teaching of experimental sciences and their promising future.

[1] An example of screen video can be found at: https://drive.google.com/file/d/1RTp9BTA7_MorLR2Sw1X9bOEHc6Pzc6y5/view?usp=sharing
[2] In the link: https://drive.google.com/open?id=1thUXCLn3DGaMCSbSMcl-1re6Bo88L8nO an example of the project of the group B.
[3] The following link includes an example of the project of group A: https://drive.google.com/open?id=1thUXCLn3DGaMCSbSMcl-1re6Bo88L8nO

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HOW TO CITE

Ruiz Cerrillo, Salvador. (2020). Augmented reality and learning in organic chemistry. *Apertura*, *12*(1), pp. 106-117. http://dx.doi.org/10.32870/Ap.v12n1.1853