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# Incorporation of Augmented Reality for the Development of Visualization Capabilities. A Study of High School Students' Understanding of the Atomic Model

## Incorporación de realidad aumentada en el desarrollo de la visualización. Un estudio con estudiantes de secundaria en torno al modelo atómico

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## Abstract

The article presents the activities that embodied a teaching-learning sequence (TLS) that were then implemented in a high school chemistry class in Bogotá, Colombia. The novel approach to the TLS in the chemistry course was the implementation of augmented reality (AR) to support the visualization of the phenomenon under study. The activities were designed to support participants in being able to describe, relate, explain, and interpret emission spectra and the dual nature of light. The Educational Design Research model was used to understand the impacts of augmented reality on students' visualization capabilities. The data collected correspond to the productions of high school students' visualization capabilities, and are compared with a matrix of levels of representation. The results suggest that, once the TLS is completed, students' initial understanding moved from representations that correspond to an iconic description of the phenomenon towards those that contain a greater semantic and semiotic load. The conclusions indicate that the TLS utilizing AR favors visualization processes for students. Limitations of the study are also discussed.

***Keywords:*** atomic model, augmented reality, Chemistry teaching, secondary education, representation, visualization.

**Post to:**

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## Resumen

El artículo presenta el itinerario realizado para la construcción e implementación de una secuencia de enseñanza aprendizaje en Química, para estudiantes de educación secundaria de la ciudad de Bogotá, que contiene apoyos tecnológicos soportados en realidad aumentada, y cuyo objetivo fue promover la visualización del fenómeno en estudio. Las actividades propuestas buscaron que los participantes fueran capaces de describir, relacionar, explicar e interpretar espectros de emisión y la naturaleza dual de los electrones. Para el diseño, elaboración y evaluación de la secuencia se recurrió al modelo de investigación de diseño educativo. Los datos recolectados corresponden a las producciones de los estudiantes de secundaria, que forman parte de las actividades de la secuencia y son comparados con una matriz de niveles de representación. Los resultados sugieren que, una vez finalizada la secuencia, las producciones elaboradas por los participantes transitan inicialmente desde representaciones que se corresponden con una descripción icónica del fenómeno, hacia aquellas que contienen una mayor carga semántica y semiótica. Se concluye que el recurso podría favorecer los procesos de visualización y se discuten algunas limitaciones del estudio.

***Palabras clave:*** didáctica de la Química, educación secundaria, modelo atómico, realidad aumentada, representación, visualización.

## Introduction

Teaching and learning sciences, and particularly chemistry, with students of different educational levels is a complex task (Childs, Markic, & Ryan, 2015; Childs & Sheehan, 2009). International research indicates that we constantly ask our students to interpret phenomena using entities such as atoms, ions, molecules, and other structures, invisible to the naked eye of anybody, with language that is typical of the subject, but very foreign to our students (Taber, 2018). We also encourage them to write chemical equations on a piece of paper, sometimes without considering the abundant theoretical and experiential burden behind this construct. This process of accessing and reading about the facts of nature through models (Talanquer, 2010), is correlated with the objective of scientific education: to promote the ability to use scientific knowledge, identify problems, draw evidence-based conclusions (and know how to communicate them), and help make decisions about the natural world and the changes produced within it due to human activity (Organisation for Economic Co-operation and Development, OECD, 2018).

Meeting this challenge is not easy, since we need our students to be able to form a visual image of a phenomenon in their minds, which may not be part of their environment or could only be a laboratory phenomenon, such as imagining the movement of particles and thus being able to explain the behavior of a gas and thereby understand what happens to the tires of a bicycle when they are exposed to the sun. This ability is known as *visualization* and it is an essential skill to understand science (Gilbert, 2005; 2008), since it seeks to construct causal explanations of phenomena through experiences with the world and some of them are not necessarily visible to the human eye (Jones, Gardner, Taylor, Wiebe, & Forrester, 2011).

In spite of this, it is one thing to imagine a corpuscular model to explain the nature of matter and quite another to imagine the internal structure of an atom and the rules under which it functions (Merino & Sanmartí, 2008). For example, Bohr's atomic model is still used in schools to explain the nature of light and colors because of its simplicity and expressive quality (Taber, 2003). In contrast, at present Schrödinger and Dirac's equations, which respond to a set of possible results and their probability distribution, are used for studying the atom in chemistry.

Research in the area of this topic is certainly wide-ranging and extensive (Barker, 2000). The results have enabled the creation of a vast spectrum of resources, texts, simulators, and applications, among others (for example, English Physics Education Technology, PhET), to aid understanding. However, Bohr's atomic model continues to be widely used in school texts, with information supported by images, schematics, and drawings, so students are expected to be able to answer questions that are seemingly simple: such as what is the nature of light?, or what is the origin of color?, among many others.

Various technological resources, such as Android Application Package (APK) for mobile devices, are currently used as a strategy to promote the organization of information or the use and testing of the model[1]. In accordance with the ideas outlined above and in terms of science didactics as a science of the design of school scientific activity (Izquierdo, 2007), our interest was in promoting visualization in students and, in order to do this, this paper shows the results of the implementation of a teaching-learning sequence (TLS) with the inclusion of technology, documenting possible progress of students in their ability to visualize light phenomena.

## Visualization and its importance for science classes

Visualization is a field of research in science education that has grown rapidly. In a review referring to the interpretation of visualization, Gilbert (2008) highlights three uses of the term in the field of psychology and educational research:

A. Visualization as external representation, which refers to forms of representation for didactic purposes (graphs, diagrams, etc.).

B. Visualization as internal representation, defined as mental constructs or mental models.

C. Visualization as spatial ability, which considers the ability to represent, analyze, and manipulate objects mentally.

To this we must add the contributions of Gilbert, Reiner, and Nakhleh (2007), who added two meanings to visualization. The first is used as a "verb" (to visualize an object, observe and attribute meaning), where issues are highlighted in relation to a form of visual presentation (internal or external), becoming knowledge. In the second meaning, visualization is assumed to be a "name", that is, as something that was given for a public, material, or virtual object. In this latter sense, the impact of virtual representations or their use in combination with various visual tools in learning is analyzed.

Gilbert and Justi (2016) state that visualization is related to the formation of an internal representation based on an external representation, in such a way that the essence and temporal and spatial relations that are characteristic of the external representation are retained.

1. We can find examples of this on the websites of well-known universities, such as the University of Colorado (https://phet.colorado.edu/es/simulation/legacy/hydrogen-atom), and in the resources portal of the Royal Society of Chemistry (http://www.rsc.org/learn-chemistry).

Reviewing the relationships between teaching chemistry and visualization, Wu and Shah (2004), concluded that visuospatial skills and more general reasoning abilities are relevant to learning this subject, since some of the conceptual errors of students in this area are specifically because of these difficulties, and certain visualization tools have been effective in helping them overcome these errors. As an alternative, the authors propose five principles for designing resources to promote visualization:

A. Include multiple representations and descriptions, for example, images, diagrams, schematics.

B. Make the reference connections visible, for example, how the spatial relationships of the molecules of a substance with its state of aggregation are verified.

C. Show the dynamic and interactive nature of chemistry, for example, explain the provisional nature of a model (atom).

D. Promote the transformation between 2D and 3D, for example, by using free software that facilitates this with predesigned templates.

E. Reduce the cognitive load by making the information explicit and integrate information for students.

Nevertheless, these recommendations—strictly speaking—are not necessarily specifically for the design of an activity that promotes visualization. In fact, the principles of universal design for learning include these suggestions—among others—that allow us to expand the repertoire of criteria for the design of resources (Duque, Merino, & Contreras, 2012).

All of these elements were retaken when designing the sequence described in this paper, such as the inclusion of Augmented Reality (AR)[2]. However, the use of resources to promote visualization does not necessarily guarantee success in a teaching intervention, since this requires a guided process, reflection, and constant dialogue between students and the resource, which makes it possible to understand the phenomenon being studied from different perspectives, with new descriptions and changes of scale (Moro, Stromberga, Raikos, & Stirling, 2017).

Having said this, based on the social semiotics of the representations, the images with which the mental process of visualization is promoted are part of the symbolic system of the human being (such as letters or numbers) and they serve to collect, package, and present information in the learning process. For example, in chemistry classes this would involve reading the chemical symbols, their meaning, and the properties behind each of them. These symbols are part of science teaching in classrooms (chemistry), understood as a resource for the student to learn disciplinary knowledge and, as such, this influences the ideas of mental representation and the retention of information (Kress & Leeuwen, 2006).

That is why images can be useful for visual discrimination and for transmission of functional concepts, guiding part of the complexity of learning processes towards the generation of reference relationships between students' ideas and real objects or phenomena (Lloréns, 1991). These cognitive processes of images go beyond visual perception, so they are known as *metavisual capacity*, that is, a property that explains the multidimensionality of aspects that affect visual cognition and their influences on learning (Padilla, 2009). We can see an example of this when textbooks present a phenomenon with images that provide different information to the reader, which are not organized according to their complexity and richness, for example. So a photograph of a sunny day can be shown and we appreciate how the contrast of light influences the perception of colors of a hill, as well as how

2. This information is available at the following link: https://specto.pucv.cl/wp-content/uploads/2019/04/ModeloMecanoCuanticoVF.pdf

rays of light could appear on a camera lens when it points directly at the sun, that is, a real image can coexist on a page on the school textbook along with an illustration of a representation of the atom in order to explain a certain phenomenon as a whole. This example also illustrates the possible difficulties in the learning process, since the levels of representation and scale are not present. For example, students may consider that the model they see in an illustration is real and relate it in the same way as the picture of a landscape on the same page of the textbook, without having a size reference scale (for example, 1 mm in the photo is proportional to 1 cm in the real object) (Prieto & Velasco, 2008).

## Difficulties in learning science when visualization ability has not been developed

In the teaching-learning process, the interaction between teacher and student is constantly carried through active communication, so both parties must share the same language (Taber, 2014; 2015). However, the language used in science classes—and particularly in chemistry classes—is specific and different from that used on a day-to-day basis, so images as symbols form part of the explanation, interpretation, and analysis of cases. These models of interaction between teacher and students constitute a symbolic language that plays an important role in the process of visualization of non-visible entities, such as the models of atoms, electrons, and vectors of the forces acting on a body, among others (Nappa & Pandiella, 2013).

We therefore see that these representations are part of a resource to help build disciplinary knowledge, so the teacher responsible for teaching must implement the most appropriate symbolic systems for this purpose, in order for students to be familiar with their own visual language and able to interpret it. From this viewpoint, expressing the importance of reading images to extract information about the different phenomena is a completely different skill from the written interpretation of school texts, since it develops an alternative strategy for teaching or learning scientific phenomena (Savinainen, Mäkynen, Nieminen, & Viiri, 2017).

However, for images to have a significant role in learning, it is essential for teachers to guide students so that they can perceive illustrations, photographs, or images of models through attention, exploration, or interpretation in the optical process driven by the stimulus when observing an image and, thus achieve visualization and be able to process and assimilate information. The observational approach in students opens up a cognitive universe, because despite the fact that some intuitive skills to read images can be acquired, people with little experience have problems in fully understanding the iconic information. This indicates that the language of the images is not universal and requires explicit teaching, particularly if the goal is for students to be able to obtain the most information in the visualization processes (Berney, Bétrancourt, Molinari, & Hoyek, 2015). In addition, Evagoru, Erduran, & Mäntylä (2015) state that in teaching science, the emphasis on visualization must go beyond cognitive understanding (using the products of science to understand the content) and, thus, participate in visualization processes. They also suggest that it is essential to design curricular materials and learning environments that create a social and epistemic context, inviting students to participate in the practice of visualization as evidence, reasoning, experimental procedure, or a means of communication, and then reflecting on these practices. This would be a key factor in the design of interdisciplinary activities that include, for example, a comprehensive approach between science, technology, engineering, and mathematics[3].

3. A larger bibliography may be found for this approach under the acronym STEM.

### Some guidelines for the design of learning sequences with technology

One line of active research in scientific education is the design, implementation, and epistemological analysis of the activities present in a TLS in science (Méheut & Psillos, 2004; Testa & Monroy, 2016). Nevertheless, the design of a sequence that includes external visualizations to promote certain skills requires considering certain ontological and epistemological that point to the nature of scientific knowledge (Méheut & Psillos, 2004).

Learning seen from the paradigm of situated cognition and from the multidimensionality of the learning process requires many variables for students to develop effective learning (Méheut & Psillos, 2004), in accordance with the constructivist view of teaching. However, one way of guiding the process is through a cycle of explicit learning, which is built from activities whose contents and procedures are supported by metacognitive processes and teacher regulation. In this case, activities are oriented based on the ideas and phenomena familiar to students and then the complexity and abstraction of the concepts they want to address are gradually increased (Merino & Sanmartí, 2008).

On the other hand, in the last decade, learning supported by technology has been reinforced by the application of emerging resources such as mobile computing and AR, which allow real-world objects to be combined with virtual objects that appear to coexist in the same space (Azuma et al., 2001; Azuma, 1997; Azuma, 1993). With AR, students can thus benefit from the relationship that objects in the space that surrounds them have with the concepts learned, acquiring skills in their learning process to interpret knowledge with experiences and experimentation in the real world (Fabri et al., 2008).

Likewise, highly interactive materials can be integrated into the teaching process in situations and environments where the description of the objects, the way they function, and the concepts related to them are difficult to explain and involve greater effort to learn. In recent years there has been a tendency to combine technologies with AR to create applications that benefit from portability, immediate access, and conciseness in the information attained, for example, with mobile devices (Papagiannakis, Singh, & Magnenat-Thalmann, 2008). However, this combination and its application in educational settings is still an area of open research. In fact, although there is an abundance of resources, it seems that there is a lack of guidelines to describe educational content "based on or with augmented reality" and methodologies for the design and creation of these highly interactive materials to achieve personalized learning anywhere and at any time.

That said, in science education, creation of applications with AR uses data that is computer-generated and superimposed in the user's field of vision to provide additional information about their environment or to act as a visual guide to accomplish a task (Yu, Jin, Luo, Lai, & Huang, 2010). The integration of these types of applications into the design of sequences to promote visualization is a challenge and an opportunity that would allow students to be provided with highly interactive content that responds to their expectations and requirements, in order to enable them to interpret this content and relate it to the real world, as well as to promote the development of skills to address the problems associated with the environment (Merino, Pino, Meyer, Garrido, & Gallardo, 2015).

## Methodology

Since our objective was to study how students' visualization ability is encouraged by studying light phenomena through the implementation of a TLS with the inclusion of technology, we used an educational design research approach (Plomp, 2009), which proposes three phases of work: information gathering, preparation, and evaluation.

The process to validate the resource entailed two stages: a first that we called *internal*, where we used an adaptation of the model of John Elliot (1990) that involves planning and design of the activities, their implementation in the classroom, the collection of information, and decision-making for the change (in this case, of the activities), and a second stage we called *external*, in which we use Robert Stake's (2004) responsive evaluation model, which involved raising ideas about planning, in contrast to the implementation of the ideas worked on in the classroom, in order to achieve a degree of consequence and consistency in the instrument implemented.

## Gathering of information

In order to select the topics addressed by the TLS in this study, we prepared a digital questionnaire to find out the teachers' opinions regarding the most difficult topics to teach in the school chemistry curriculum and where the technological resource (AR) could be of help. To prepare this questionnaire, all of the learning units of the Chilean chemistry curriculum for the first and second year of secondary education were listed based on the adjusted 2012 curriculum (Ministerio de Educación de Chile, Mineduc, 2009). Teachers were also asked to select a maximum of six units from the list of contents that, in their opinion, would have high potential to be used with AR. The questionnaire included some representative examples so that the participants had a better reference for the resource. The first example was an activity where only the visualization of an object is used, while in the second example reference was made to an activity that included interaction and animation (see Annex 1). In addition, the questionnaire was submitted for the validation of external judges with training in science education and researchers in the area, who studied each of the elements in the instrument and the items of the contents to be assessed, putting together a final version.

Review of Chilean school textbooks was also considered in order to build a perspective on how written and illustrative information is organized in these educational books. For this purpose, we selected the school textbooks most widely used by students between 14 and 15 years of age[4]. For the review, we used an image function criterion in the sequence proposed entirely by the authors Perales and Jiménez (1996), which we have used in other studies to establish a baseline (Quiroz & Merino, 2015). The criteria to review the images and find out their didactic function in the sequence were the following:

A. Evocation. Reference is made to a fact of everyday experience or a concept that is assumed to be familiar to the student.

B. Definition. The meaning of a new term in its theoretical context is established.

C. Application. An example that extends or consolidates a definition.

D. Description. This refers to non-everyday facts or events that are assumed to be unfamiliar to the reader and which provide a necessary context.

E. Interpretation. Explanatory passages in which theoretical concepts are used to describe the relationships between experimental events.

F. Problematization. Non-rhetorical questions are proposed that cannot be resolved with the concepts already defined.

The results of the questionnaire given to teachers regarding the most difficult subjects to teach and the review of texts with the criteria indicated above were used as the basic information for the design and construction of a sequence based on the chosen learning objectives.

4. These were Química, from the publishing house Calicanto (2013) and Química, from the publishing house Mc Graw Hill (2015).

## Preparation of the sequence and APK

Based on the information-gathering phase, and particularly the review of the textbooks, we created a sequence whose explicit intention was to obtain a drawing of the ideas developed in classes for each activity the students carried out, in order to record the data and subsequently analyze it.

Table 1 contains a description of the learning objectives of each of the activities included in the sequence. In relation to their temporality, in the field tests we foresaw that this will depend on the teacher's working conditions, the school infrastructure, and the students' capacity for work, among other factors. However, we recommended a maximum of two activities in each 45-minute session.

*Table 1.* Sequencing of activities

| Name of activity | Learning objective of activity |
|---|---|
| A1. How do fireworks work? | Identify the characteristics of the structures of fireworks and provide initial questions about the origin of their coloration. |
| A2. The nature of light | Incorporate new variables to study phenomena based on corpuscular and wave theories of light. |
| A3. The fingerprint of fireworks | Explain the absorption and emission spectra and their relationship with the visible light spectrum. |
| A4. The hydrogen atom and Niels Bohr's model | Use the Bohr model to explain the absorption or emission of quantized energy (photons) and its relationship with the visible light spectrum. |
| A5. Virtual flame tests with salts | Anticipate and explain the behavior of certain salts exposed to an energy source and relate the color of the flame to the visible light spectrum and fireworks. |

*Source: Prepared by the authors.*

The sequence built was formalized in a student workbook, available in PDF format, and in worksheets in Microsoft Word format[5].

An add-on is required for the operation of the sequence with AR, which is an application (APK) that is available on the GooglePlay platform for free download and use[6]. The APK SPECTO© (PUCV, 2017) can be loaded on any mobile device with an Android 4.1 operating system or later. This operating system was chosen because it is software that is mostly present on school education systems.

Implementation of this resource was done using Unity 3D (Unity Technologies, 2019) as a development environment, as it was free and because of its versatility in packaging the product for various platforms, the amount of existing documentation, and extensive support to find solutions. Unity allows the development of the environment, layout, lighting effects, sound programming, etc., while we used the Vuforia SDK software, version 5.0.6 (PTC Technologies, 2019) for the incorporation of AR. Both software packages are free as long as the development is not for commercial purposes. We initially selected Metaio as SDK to develop AR, but after a short time this ceased to be a free development tool, which forced us to review the available options and use Vuforia SDK.

5. The information is available on the website: http://specto.pucv.cl. In addition to this sequence others can be found in the areas of chemistry, physics, and biology for secondary and university education, as well as a gallery of registration images for different implementations.
6. Direct access at https://play.google.com/store/apps/details?id=cl.PUCV.SpectoModeloMecanicoCuantico&hl=es

We used Blender software version 2.72 (The Blender Foundation, 2019) to develop animated 2D and 3D objects. The development of AR applications is well documented in technical terms, but it is not necessarily possible to find sufficient documentation in terms of the development methodology where the various professionals agree.

Another of the difficulties we faced in development was related to the images used as tags. Since our theme is specifically the ability for visualization, it is vitally important for each image or icon to have a value beyond mere decoration within a work guide (Figure 1). In this regard, the images that were used as a tag to activate visual resources became a problem, since they had to meet various criteria to be accepted: a) being representative and valuable from the perspective of the content; b) coming from own sources or being distributed under a creative commons license to protect copyright; and c) having an ideal five-star rating in the Vuforia SDK. Another of the difficulties that had to be overcome were the tags whose 3D object load was spatially very large in order to give the idea of proportionality. This problem was resolved by programming in C Sharp language (C#).

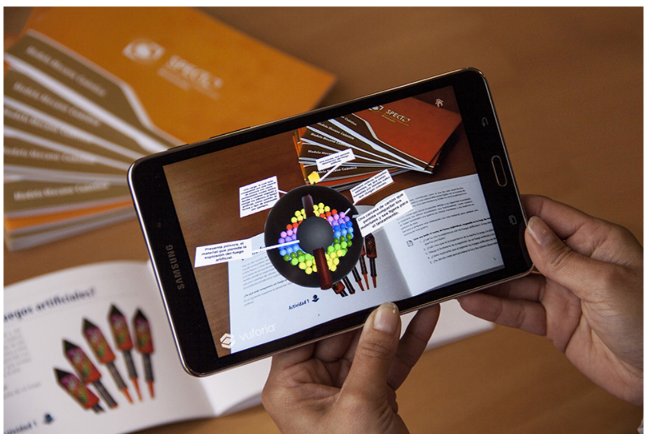


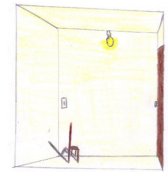
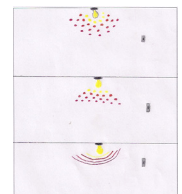
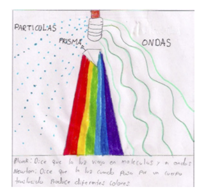

*Figure 1.* Resource formed by the work guide and the application.
*Source: Prepared by the authors.*

## Evaluation of students' productions using the resource

In the specialized literature it is possible to find an abundance of studies in the area of health sciences that refer to the use of AR to support formative processes, particularly in topics related to knowledge of anatomy (Almenara, Barroso, & Obrador, 2017; Küçük, Kapakin, & Göktas, 2016; Moro et al., 2017). However, these studies mostly resort to methodological approaches from a quantitative paradigm and quasi-experimental designs, with pencil and paper tests focused purely on the appropriation of disciplinary knowledge.

In our case, since we are interested in being able to study the relationship between the use of the resource and assessing possible changes or developments among the students in their ability to visualize the phenomenon under study, for the example of light, we find a ranking in Kozma & Russell's (2005) proposal based on levels of representation and visualization in science (Table 2), which we have adapted to associate it with the phenomenon being studied. Other studies have also used this proposal, developing categories and protocols (Philipp, Johnson, & Yezierski, 2014), and therefore we also considered it to review the students' productions.

*Table 2.* Kozma & Russell's (2005) levels of representation

| Code | Levels | Description | Example drawing |
|---|---|---|---|
| N1 | Level 1. Representation as a description. | When asked to represent a physical phenomenon, the person generates representations based only on their physical characteristics. That is, the representation is an isomorph, an iconic description of the phenomenon at a certain point in time. |  |
| N2 | Level 2. Primitive symbolic abilities. | The student may be familiar with a formal representation system, but their use is nothing more than a literal reading of the characteristics of the superficial representation, without taking into account the syntax and semantics. |  |
| N3 | Level 3. Syntactic use of formal representations. | The student is capable of making connections through two different representations of the same phenomenon, based solely on the syntactic rules or shared superficial characteristics, instead of the underlying meaning of the different representations and their shared characteristics. |  |
| N4 | Level 4. Semantic use of formal representations. | The student can provide an underlying common meaning for several types of representations that are superficially different and transform any given representation into an equivalent representation in another form. The student spontaneously uses representations to explain a phenomenon, solve a problem, or make a prediction. |  |
| N5 | Level 5. Reflective use. | The student can use the specific characteristics of the representation to justify the problems within a social and rhetorical context. They can select or construct the most appropriate representation for a particular situation and explain why the representation is more appropriate than another. |  |

*Source: Korzma & Rusell, 2005.*

For the operationalization of the variables, the students' productions were reviewed and classified according to the levels described in Table 2. The variable [M] is thus considered as the total number of students; while the Kozma-Russell levels (also cited in Gilbert, 2005) were represented with the variable [N] and the values fluctuated from 1 to 5, where Level 1 (N1) was the simplest level of representation and Level 5 (N5) was the most complex and robust.

In order to validate the matrix, we used the kappa coefficient (index of concordance) between two experts in the content (chemistry and in the didactics of the specialty). There are several proposed indices of concordance, where the most reliable is the proportion of agreements observed, that is (a + d) /N, being a highly intuitive and easily interpretable index, since it uses values between 0 (*total disagreement*) and 1 (*maximum agreement*). However, as an indicator of reproducibility it has the disadvantage that even if the two observers potentially classify with independent criteria, a certain level of agreement could be produced by chance. It is desirable for an index of concordance to take this fact into account and, in some way, indicate the degree of agreement that exists above what would be expected by chance. In this regard, the most frequently used index is that proposed by Cohen (equation 1), called the kappa coefficient (k) which is defined as:

$$K = \frac{P_0 - P_c}{1 - P_c}$$

Where P0 is the proportion of agreements observed and Pc is the proportion of agreements expected in the hypothesis of independence between the observers, that is, agreements by chance. In our case, the level of agreement in the classification of the drawings was 0.8011 for the pre-test and 0.6323 for the post-test, while, according to the K value, for the classification of the pre-test drawings there would be maximum agreement of 80.0% and 20.0% expected by chance, and in the case of the post-test there would be 63.2% agreement between the two pairs of experts and 36.8% associated with chance. According to Cerda and Villaroel (2008), for values obtained within the range [0.61-0.80], the level of agreement is considered to be substantial

## The sample

In the spirit of avoiding influencing the students' results, we sought a sample as external as possible in which to implement the resource. For that reason we invited the Grupo de Investigación en Educación en Ciencias Experimentales (in English, the Research Group in Experimental Science Education, GREECE) at the Universidad Distrital Francisco José de Caldas, to select a school establishment where the process can be carried out en masse. So, the original sample corresponds to a total of 106 students aged between 14 and 15, distributed among three 10th grade courses: A (17 women and 19 men), B (13 women and 22 men), and C (13 women and 22 men), belonging to Institución Educativa Distrital Marsella (Bogotá, Colombia). Before the implementation, the students and parents and guardians were informed of their participation in the study and they signed an informed consent letter (Annex 2), which protects their identity and integrity.

# Results

## Regarding the topic selected for design of the sequence

The questionnaire to select the topics from the Chilean school chemistry curriculum for which the technological resource (AR) would be most relevant was sent in electronic format to 5,166 educational establishments in Chile—through the directorate of the Ministerial Secretariat—being addressed to science teachers at each establishment. Some 268 responses were received and of these 132 answered effectively (2.6%). Although the response rate was not sufficiently representative, the six topics selected most frequently by the teachers that would have a high potential to be used with AR through a learning resource were: a) the quantum-mechanical model (28.7%); b) the spatial distribution of molecules (28.0%); c) intermolecular forces (23.4%); d) colligative properties (21.9%); e) the physical-chemical properties of carbon (18.9%); and, g) stereochemistry and isomerism (25.0%). From the previous exercise and for the development of this study, we chose the atomic model because it is content with a high level of abstraction, since it represents microscopic phenomena of matter and the atomic model is generally accompanied by visual representations such as drawings, graphics, and schematics (Nappa & Pandiella, 2013).

## Review of the texts

The aforementioned questionnaire allowed us to select the topic for the design of the sequence, that is, the emission spectra and the dual nature of electrons, according to Bohr's atomic model. After that, we proceeded to review how it was presented in the school textbooks, for which the two most widely distributed school textbooks, already mentioned, were selected. Next, we selected the images on the pages where the reading topic is addressed. A total of 23 images were obtained, which, when reviewed with Perales and Jiménez's (1996) criteria, showed the following percentage frequencies: a) evocation (21.7%); b) definition (13.0%); c) application (26.0%); d) description (21.7%); e) interpretation (17.3%); and f) problematization (0%). We can thus observe the absence of problematization and a low percentage in definition, while there is a high frequency of images where the primary function is application (26.0%). In accordance with this mapping, we believed that the images present in the design of the sequence would be a contribution in the aspects of evocation, interpretation, and problematization.

## Regarding the analysis of the students' productions

Before starting to work with the sequence and applying it, the Colombian students were instructed to draw the following situation:

> Consider that you are in a room where there is only one bulb, like the one shown below. If you turn on the light bulb in the room with a switch:
>
> In the following image draw how the light rays would be distributed from the lit bulb in the room.

Of the original sample of participants (*n* = 106), only the drawings by the students who completed the pre-test and post-test were selected, thus reducing the sample to 92 pairs of instruments reviewed. The drawings were classified by two experts (teachers of chemistry and didactics of science).

## The pre-test

In accordance with the instruction provided to explain how a lit bulb in a room emits light, but in contrast to the levels of representation (Table 2), of the total student drawings, 9.8% (9 students) were classified at Level 1, considering a solid representation of the phenomenon, that is, their drawings include observable details, but do not model unobservable phenomena. Some 89.1% of the students' drawings (82 students) were classified at Level 2, with their drawings including representations of both observable and unobservable phenomena, with the detail that they included their own symbols to express unobservable ideas. Meanwhile, 1.1% of the drawings (1 student) were classified at Level 3, including representations of the observable and unobservable phenomena, although unlike the above drawings, they were able to represent processes of temporality. Finally, no drawings were observed that could be classified at levels 4 or 5.

## The post-test

Once the five activities included in the sequence were carried out, where each of them was supported with AR, the same instrument was reapplied, this time as a post-test, using drawings and text to explain the phenomenon (how a light bulb emits a light in a room). In contrast to the levels of representation, 6.5% of the drawings (6 students) were classified at Level 1, considering a solid representation of the phenomenon, with observable details, but without modeling unobservable phenomena; 52.2% of the drawings (48 students) were classified at Level 2, considering that their drawings were representations of both observable and unobservable phenomena, and including their own symbols to express the unobservable idea; 38.0% of the drawings (35 students) were classified at Level 3, with representations of the observable and unobservable phenomena, although unlike the previous ones, they were able to represent initial, middle, or final processes; 3.3% of the drawings (3 students) were classified at representation Level 4, where there is a process to explain the phenomenon of the lit bulb in the representation, implementing models of ideas valid for the topic under study. No drawings were classified at Level 5 (Figure 2).

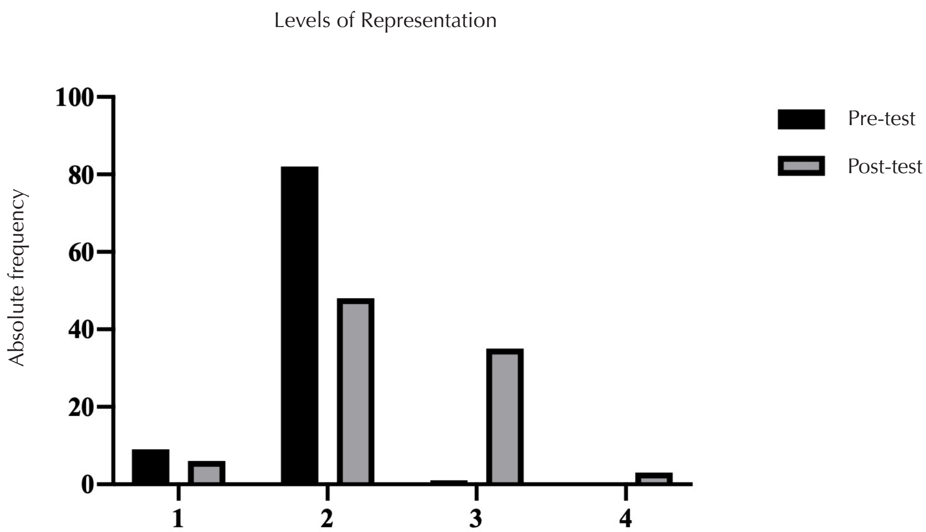
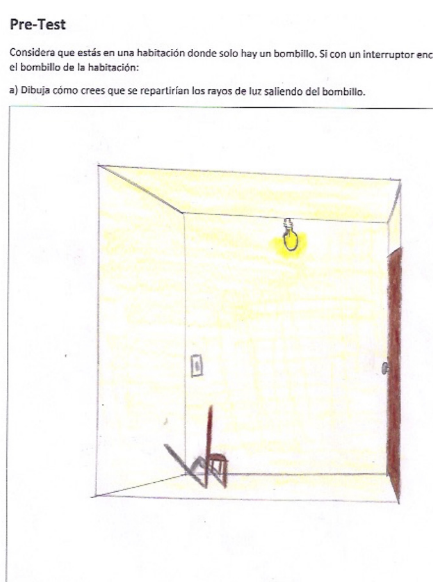
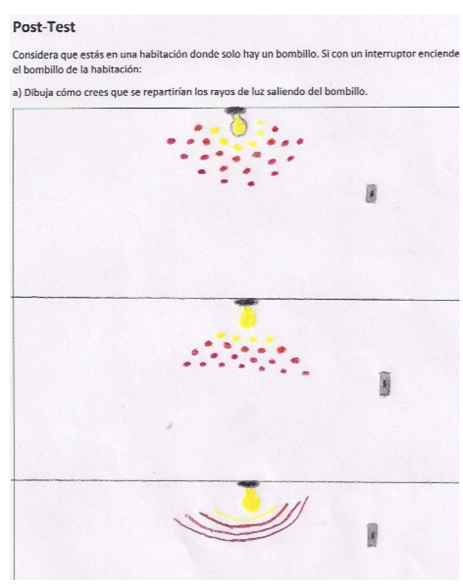



*Figure 2.* Representation levels identified (*n* = 92).
*Source: Prepared by the authors.*

When comparing the results between the initial and final situation, we were able to observe a transition from the initial levels (N1 and N2) to more robust levels (N3 and N4). This could indicate that, in a certain way, the resource complements and promotes the visualization of non-observable aspects. Figure 3 supports this idea, since we observe an initial representation of an iconic description of the phenomenon (Figure 3-A), which transitions towards those that contain a greater semantic and semiotic load (Figure 3-B).

*Drawing A.* Example of a Level 1 representation




*Drawing B.* Example of a Level 3 representation in pre-test and post-test.
*Source: Prepared by the authors.*

*Figure 3.* Examples of drawings created by a student

Meanwhile, the non-parametric Wilcoxon test, used to compare the differences between two samples of data taken before and after the sequence with AR, indicates that the value of the T statistic is equal to 4.48. Thus, with a comparison table value of Z = 1.64 and an alpha of 0.05, we observe that the value obtained from the statistic would be outside the acceptance range that would establish a value of the medians equal to zero. Consequently, there is statistical evidence to reject Ho, that is, there are significant differences between the pre-test and post-test. In addition, when all the data is graphed the students show a better performance in the post-test.

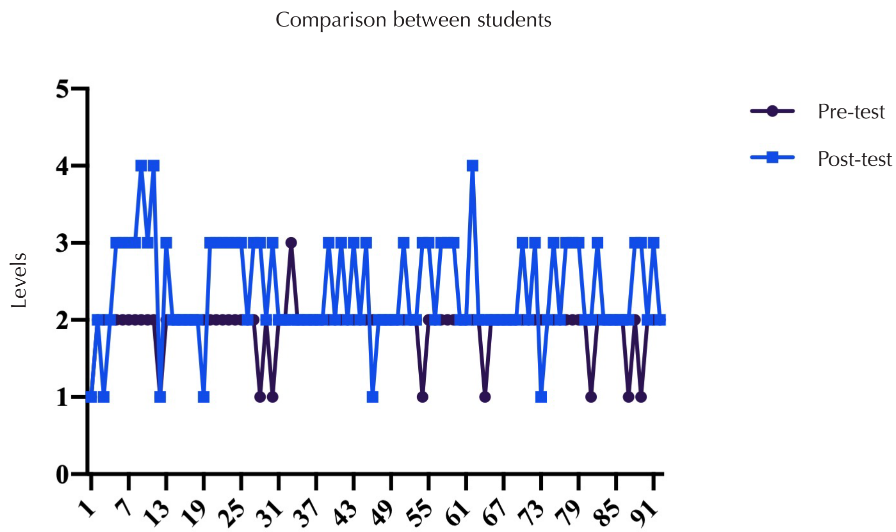



*Figure 4.* Distribution of the students' drawings ($n$ = 92).
*Source: Prepared by the authors.*

## Discussion and conclusions

According to the preliminary results obtained, where we observe a transition between the levels of representation between the pre-test and post-test, we believe that the resource favored visualization in the participants, as in the case of other studies where it was implemented (Almenara et al., 2017). We also considered the coexistence of representations according to the highly organized levels of representation proposed by Kozma and Russell (2005). In the preparation of the students' drawings we also observe support in the corresponding visual representations with the macroscopic, microscopic, and symbolic levels of the subject (Órdenes, Arellano, Jara, & Author, 2014). We emphasize that the first two activities in the sequence were precursors in the modeling of processes, particularly to explain the phenomenon of pyrotechnics.

With respect to the ideas of visualization and metavisual capacity (Gilbert, 2005) that were developed in the activities proposed in the sequence, according to Sanmartí (2002), we note that the phases of the sequence showed an epistemological organization and a didactic function that established specific and contingent ideas as a point of reference, and that while these activities were carried out in an order grew in complexity and abstraction, the levels of representation and their progression were also promoted.

This allowed the students to interact in each of the proposed activities, being able to create representations in all of them, which, when analyzed later, showed that the students had changed their levels of representation regarding the first instance. In fact, the pre-test analysis for all students showed that the frequencies of representation for the drawings showed very specific levels in the explanations, which changed as they followed the guide with AR, since those specific levels of representation, compared to the levels of representation that were recorded in the post-test, decreased considerably, as did some of the examples presented in the studies by Gilbert et al. (Gilbert, 2008; Gilbert et al., 2007). Based on this observation, we could state that the sequence with AR firstly managed to promote the visualization of the phenomenon studied.

As we mentioned previously, the task of visualization in science should be constantly guided by teachers when explaining or interpreting different phenomena, since it is an alternative resource to writing and is very useful to extract information from the relationships that students show between the levels of organization (macro, micro, and symbolic). The implementation of digital strategies to work on scientific knowledge is just as important as encouraging the follow-up of students' drawings or illustrations in textbooks, since most of this knowledge is difficult to represent, particularly the processes, interactions, and composition of various phenomena, such as the emission of light in fireworks. In this regard, modeling with AR and other activities related to audiovisual resources is of great help, because they constitute platforms that students can manage and they allow them to interact with other media, promoting different ways of learning the same phenomena.

## Limitation of the study

Five sessions were planned for the activities, each of which were 45 minutes long. These were implemented at the required times using the proposed material and using the recording instruments, without making any changes to the planning. With this, we were able to determine that the work time allocated to carry out the activities was very short and many students left the answers blank, specifically the questions in the guide where they had to explain the phenomena using words, since the instructions specified that the important thing about each activity was that they made a drawing. This is the reason why, in this article, we can only explain what we observed in the pre-test and post-test.

Finally, we believe that, in order to provide more support for our observations, new studies with larger samples are required, and new proposals are needed to analyze the drawings that allow us to obtain and communicate metrics to extrapolate the data to different populations.

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## Annex 1

### List of teachers' preferences of subject content in chemistry to be used with augmented reality

Dear Teacher,

We would first like to thank you for your willingness to collaborate in this Fondecyt 2015 research (1150659) by responding to this instrument. Through this document we would like to collect your opinion on which 9th and 10th grade contents in the subject of chemistry you would potentially suggest to design learning activities that include applications with augmented reality. Augmented reality consists of a set of devices that add virtual information to existing physical information, that is, it involves adding am artificial virtual aspect to what is real. A view of a physical environment in the real world is combined with virtual elements to create a mixed reality in real time. We firmly believe that one of the difficulties in learning chemistry is the articulation between its three modes of representation (macro, micro, and symbolic). If we have resources that allow us to establish bridges between these levels, we would be able to make progress in achieving more sustainable learning over time. The information that will be collected here will be very important to prepare future proposals for teaching-learning sequences in chemistry, for which we would also like to invite you to be part for the process of implementation and validation in your school. We want to make it clear that our purpose is NOT to judge your intelligence and/or personality and that all information collected is confidential. Finally, we would also like to state that we have committed ourselves to deliver an individual report to you, which in no way is an assessment.

**Instructions:**

- Carefully read the list of contents in 9th and 10th grade.
- Choose six (6) of them that you believe would have high potential to be used with augmented reality.
- If you believe that the list does not contain content that you consider relevant, or you think that it does not have a high educational need to have materials using augmented reality, please explain why.
- In order to deliver the reports, it is essential that you complete the following information:

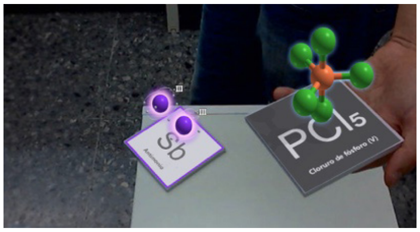
Name: ______________________________

Establishmen:_________________________

Email:________________________________

Dear Teacher, the following are examples of activities with learning that uses augmented reality in order to give you an idea of the definition provided in this instrument. Two examples are given: the first corresponds to activities where only one object is displayed, while in the second (YouTube) you can see an activity that includes interaction and animation.

**Example 1:**






*Source: Digital AV Magazine ©* *Source: Zientia ©* *Source: Pinterest ©*

**Example 2:**


*Source: https://www.*youtube.com/watch?v=IpNrwkqfq6Q

Dear Teacher, below are the contents of the Study Program for 9th and 10th grade. Choose six (6) topics that you think are difficult to teach and for which you think augmented reality could help in the teaching process.

| Content for 9th grade | Yes | No |
|---|---|---|
| 1. The behavior of electrons in the atom based on principles (notions) of the quantum mechanical model. | | |
| 2. Classic or contemporary scientific research related to the quantum-mechanic model. | | |
| 3. Organization of electrons at each of the energy levels of various atoms. | | |
| 4. Classic or contemporary scientific research related to the constitution of the periodic table. | | |
| 5. Electronic structure of atoms with their order in the periodic table and their physical and chemical properties. | | |
| 6. Periodic properties of the elements. | | |
| 7. Interaction and electronic structure between atoms. | | |
| 8. Spatial distribution of molecules based on the electronic properties of the constituent atoms. | | |
| 9. Intermolecular forces that allow different molecules to be held together with each other and with other species (ions). | | |
| 10. Laws of chemical combination in chemical reactions that give rise to common compounds. | | |
| 11. Quantitative relationships in various chemical reactions. | | |
| 12. Weighting laws and concepts of stoichiometry in problem solving that reflect the mastery of the content and the processes involved. | | |
| 13. Others: | | |

| Content for 10th grade | Yes | No |
|---|---|---|
| 1. Characteristics of solutions according to their general properties: physical state, solubility, concentration, electrical conductivity. | | |
| 2. Concentration of solutions, units of concentration of solutions. | | |
| 3. Preparation of solutions at defined concentrations. | | |
| 4. Stoichiometry of chemical reactions in solution. | | |
| 5. Technological applications of chemical solutions. | | |
| 6. Colligative properties of solutions: vapor pressure, boiling point, freezing point, and osmotic pressure. | | |
| 7. Relationship between vapor pressure and concentration of solutions: vapor pressure and Raoult's law. | | |

| Content for 10th grade | Yes | No |
|---|---|---|
| 8. Relationship between temperature and concentration of solutions: ebullioscopic elevation (non-volatile solute), cryoscopic depression, and osmotic pressure. | | |
| 9. Electrical conductivity of solutions. | | |
| 10. Origin of oil, theories about the origin of oil and its derivatives. | | |
| 11. Physicochemical properties of carbon: tetravalence, hybridization, bond angles, distances, and bond energy. | | |
| 12. Nomenclature of organic compounds, rules for naming organic compounds. | | |
| 13. Representation of organic molecules in various forms: molecular formulae, expanded structural formulae, condensed structural formulae, ball-and-stick model, linear or topological formulae. | | |
| 14. Functional groups present in organic compounds: names of organic compounds, physicochemical properties that characterize compounds with a specific functional group, industrial uses, and technological applications. | | |
| 15. Three-dimensional structure of organic molecules: perspective formulae, Newman projections, sawhorse projections, cyclic compound formations. | | |
| 16. Stereochemistry and isomerism in organic compounds: constitutional isomers and stereoisomers, R and S configurations. | | |
| 17. Others: | | |

Dear Teacher, below are presented the scientific thinking skills (STS). Choose three (3) skills for which development could be facilitated by the use of augmented reality.

| STS | Yes | No |
|---|---|---|
| Organize and interpret data and formulate explanations. | | |
| Describe classical scientific studies. | | |
| Identify relationships between socio-historical context and scientific research. | | |
| Describe the origin and historical development of concepts and theories. | | |
| The importance of theories and models to understand reality. | | |
| Understand the importance of the laws, theories and hypotheses of scientific research and distinguish them from each other. | | |
| Identify the limitations presented by scientific models and theories. | | |

# Annex 2

## Signing of informed consent

Principal investigator: Cristian Merino Rubilar

Title of study: Design, validation, and evaluation of teaching-learning sequences in science to promote metavisual capacity through augmented reality

I have read the description of the research and I understand that:

- My participation is voluntary. I can refuse to participate or stop participating at any time without consequences of any kind for me.
- The investigator may withdraw me from the study at their professional discretion.
- My participation in this project is anonymous, and my identification or other personal data will not be disclosed in the publications or reports for the project.
- If I have questions about my participation in this study, I can contact the principal investigator, Cristian Merino Rubilar, who will answer my questions. His email address is cristian.merino@pucv.cl
- If at any time I have comments or concerns related to my rights as a participating research subject, I may contact the Ethics Committee of Pontificia Universidad Católica de Valparaíso via Dr. Joel Saavedra A., Vice Chancellor for Research and Advanced Studies at Pontificia Universidad Católica de Valparaíso.
- I understand that a copy of this consent document will be given to me and that I may request information about the results of this study when it has been completed.

By clicking the "agree" button, this means that you agree to participate in this study.