JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

A Game-Based Approach To Learning the Idea of Chemical Elements and Their Periodic Classification

Antonio Joaquín Franco-Mariscal,[*,†,‡] José María Oliva-Martínez,[§] Ángel Blanco-López,[†] and Enrique España-Ramos[†]

[†]Universidad de Málaga, Facultad de Ciencias de la Educación, Málaga 29071, Spain

[‡]IES Juan Ramón Jiménez, Málaga 29006, Spain

[§]Universidad de Cádiz, Facultad de Ciencias de la Educación, Puerto Real, Cádiz 11519, Spain

ABSTRACT: In this paper, the characteristics and results of a teaching unit based on the use of educational games to learn the idea of chemical elements and their periodic classification in secondary education are analyzed. The method is aimed at Spanish students aged 15−16 and consists of 24 1-h sessions. The results obtained on implementing the teaching unit are assessed with a focus on the development of students' understanding of the topics covered and their perceptions toward the role of games in the learning process. The data collection methods used included a learning assessment test (administered before the unit was started and one month after completion of the unit) and a questionnaire to assess the students' learning experience. As a complementary method to acquire data, the teacher keeps a diary. The main conclusion was that students progressed significantly in the areas of learning related to knowledge of the Periodic Table and its nature and history, but a lower level of progress was found in the application of knowledge and the use of evidence to draw conclusions. Furthermore, to some extent, the teaching unit helps to overcome learning difficulties associated with the study of this subject. In addition, most responses to the questionnaire indicated that students who followed the teaching unit with games achieved statistically better final results than those in the control group, who followed a traditionally taught program. A positive assessment was provided by students concerning the role of games in the proposed unit, and there were also positive perceptions regarding the influence of games on learning and their potential to encourage participation in the classroom. Finally, this research identifies a new type of educational resource, namely task involving play (TIP), that can be defined as intermediate between play and game scenarios. The TIPs may include artistic or technological creations by the student, and they allow the student to play an active role in the learning process. Such tasks help students to improve their learning through educational games, and they can be perceived as intermediate in terms of their simplicity, usefulness, attractiveness, and interest with respect to educational games.

KEYWORDS: *First-Year Undergraduate/General, High School/Introductory Chemistry, Chemical Education Research, Collaborative/Cooperative Learning, Humor/Puzzles/Games, Nomenclature/Units/Symbols, Student-Centered Learning, Periodicity/Periodic Table*

FEATURE: Chemical Education Research

■ PERIODIC TABLE TEACHING

The Periodic Table (PT) is considered to be one of the cornerstones in the history of chemistry,[1,2] and it is an essential topic in the teaching and learning of science at all educational levels. From a functional point of view, the PT has come to be considered as a kind of roadmap of the chemical elements and their reactivity,[3] and it constitutes a basic tool of induction.[4] The importance of this topic has made it one of the most attractive and commonly discussed areas in the chemical education literature.

A review of the literature shows that most of the research carried out in this area is focused on historical and epistemological issues,[5,6] with little attention paid to the difficulties encountered by students in learning this subject. Thus, with a few exceptions,[4,7−16] this field remains relatively unexplored in terms of research studies at the school level, despite the importance of the PT in the curriculum for introductory chemistry courses at the secondary and university levels.[2]

The understanding that high school students (16−18 years) have of the concept of chemical elements and their periodic classification is rather weak in most cases. The results of a recent study in Spain indicated a limited degree of progression in students' knowledge around the notion of the chemical elements and their classification during Baccalaureate schooling.[16] This limited progress can be interpreted by considering the existence of significant difficulties and obstacles in understanding the concept of the chemical element in its different aspects.[16] For instance, students often find it difficult to understand the double meaning of the concept of the chemical element as a simple or elementary substance that cannot be broken down into a simpler form or as a collection of atoms with the same atomic number. Another common difficulty concerns some atomic properties such as the atomic volume and electron configuration. A previous study[14,15]

Received: October 22, 2015
Revised: April 6, 2016

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

carried out by ourselves, in conjunction with Spanish experts in science education, revealed that the learning difficulties often encountered by high school students on this topic could be characterized into seven categories:

(1) attempts to memorize instead of learning
(2) misconceptions in the lesson
(3) misunderstanding of the properties used as classification criteria
(4) the notion of periodicity and the perception of its usefulness
(5) complexe nature of concepts related with the PT
(6) the abstract nature of the concepts involved and the reasoning required
(7) deficiencies in the teaching process.

These experts also suggest that attitudinal aspects related to the student's motivation for the topic could have an influence on the difficulties encountered. Given these difficulties, any teaching approach should focus on achieving a greater degree of student involvement and intellectual commitment to learning. This could be achieved, for example, by motivating students and highlighting their learning through the use of educational games, as proposed in this research.[17−19]

In addition to the studies outlined above, in recent years, a large number of educational approaches have been proposed for the teaching of the chemical elements and the PT at different educational levels (see review[20,21]). Many of these approaches involve the use of a variety of educational games and other recreational resources such as a range of puzzles, board games, word games, card games, bingo, computer games, etc.[22] The activities based on games are augmented by other strategies that do not rely on games per se but involve the use of a playful setting. The design of this type of approach is valued by teachers as it fits well with their desire to seek new and motivational ways of teaching this subject.[9] However, educational innovation should always be accompanied by a critical analysis of the changes that are made as well as a rigorous evaluation of the relevance of such changes. As a consequence, it is of great educational value to carry out systematic investigations into the effects produced by the use of new resources and to develop strategies to improve the teaching and learning of this topic. In this respect, the novel aspect of the research presented in this paper concerns the design of a teaching unit focused on educational games to learn about the PT and a study to evaluate its implementation in the classroom. The unit described here was aimed at Spanish students aged 15−16, corresponding to 10th grade.

■ THEORETICAL FRAMEWORK

Role of Games in the Learning and Teaching of Science

The use of games as a tool to enhance learning has been widely explored in the field of chemistry education,[23] and this approach has often been used to teach preschool and elementary age in particular. However, research into game-based approaches for secondary school students and adults is far less common.

The concepts of play and educational games are very difficult to define as they depend on numerous transient, contradictory, and context-dependent qualities. Play is often defined in terms of its opposite, that is, serious work.[24] The commonly accepted boundaries are often broken or blurred during play and, as such, it can be difficult to differentiate between work and play.[25] It has been proposed that the process of learning requires both of the aforementioned conditions,[26] and these include the formal and informal knowledge, with activities often involving play. Chazan[27] suggested that "Play occupies a realm outside of everyday events. It has to do with imaginings and trial action. Anything is possible." The definitions outlined above, among others, highlight how play can be considered in a number of different ways. Despite the variety of definitions of "play", Henricks[28] defined the main characteristics as follows: (1) Play is an experience; (2) it has intrinsic rather than extrinsic motives; (3) the process is more important than the outcome; and (4) it involves some level of active engagement.

Game studies make a distinction between play and game,[29] usually tied to Caillois' concept of *paidia* and *ludus* as two poles of play activities.[30] Whereas *paidia* (or "playing") denotes a more freeform, expressive, improvisational, even "tumultuous" recombination of behaviors and meanings, *ludus* (or "gaming") captures playing structured by rules and competitive strife toward goals. Dempsey et al.[31] define game as "a set of activities, involving one or more players... (with) goals, constraints, payoffs, and consequences... is rule-guided... (and) involves some aspect of competition is with oneself". According to Salen and Zimmerman,[32] a game is a "system in which players engage in artificial conflict, defined by rules, that results in a quantifiable outcome". Hence, any game has a challenging component in terms of the rules and purposes by raising either a personal challenge or a competitive drive.[33]

The definitions of what constitutes play and game are very broad. However, the qualities outlined above to define playful activities are closely related to some aspects of good practice in learning theory and teaching.[34] Play is perceived as being beneficial in the development and promotion of creativity, imagination, and spontaneous learning.[35−37] Such creative skills are best developed using a range of approaches so that students can explore issues from different perspectives.

According to Torres,[38] the use of educational games can also encourage and stimulate certain moral qualities in students such as self-control, honesty, safety, attention and concentration on the task, reflection, the search for alternative ways to win, respect for the rules, initiative, common sense, a sense of solidarity with colleagues, and, above all, fair play. Torres[38] also believes that games introduce competition as a stimulus for learning.

Some researchers argue that the fundamental motivation for all game is to learn, and it is a safe way to learn,[39] because games are effective substitutes for traditional classroom activities in educational settings of all levels.[40,41] Educational approaches based on game lie within a constructivist theory of learning.[42] A requirement of constructivism is that students are challenged, meaning that they engage at times with knowledge that is considered difficult. Such challenges enable each student to construct their own knowledge but will also require alternative teaching methods. One of the possible ways to engage students and facilitate learning involves the use of educational games.

One of the fundamental aspects of education and the building of knowledge is critical thinking.[43,44] In this respect, students can arrive at the truth for themselves by carrying out activities and then applying reason, that is, sensation and then reflection. The application of approaches that involve play or game in education may require activity and sensation, but learning cannot necessarily be achieved by experience alone, and critical thinking is required to turn the experience into learning.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Games are also commonly used to raise levels of interest and to ensure that students participate actively in the learning process. Indeed, Orlik[19] carried out a comprehensive study on active methodologies for the teaching of science in general, and chemistry in particular, and found the use of games to be one of the most important approaches. In fact, an inherent characteristic of games is the challenging nature of their rules and aims, which often consist of a personal challenge or some competitive goal.

From the point of view of education, even when games are employed in academic activities, the pleasure or recreation must primarily be a didactic function. Games can act as a bridge to unite the formal teaching of science with science in more informal settings.[45] For instance, Mondeja et al.[46] defined a set of qualities and requirements that games must have to make them useful in the development of teaching and learning:

(1) Games must help to boost the activity of students in a variety of ways within the organization of teaching and, once motivated, the students must develop their cognitive activity, thus consolidating their learning in an active way.
(2) Games must indirectly improve the efficiency of the educational process as they require more reflective activity by the teacher.
(3) Games must be carried out in a well-planned manner in keeping with the educational targets and their implications in the classroom.[47]

On the other hand, the cognitive potential of computer and video games has been largely ignored by educators.[48] Recent years have seen a rapid proliferation of mass-market consumer software that takes inspiration from computer/video games. This trend is known as "gamification" or the use of game design elements in nongame contexts.[29] As a consequence, the popularity of educational games that involve contemporary digital technology applications has transcended entertainment crossing into the world of education[49,50] offering new educational possibilities.[48,51,52] According to Gee,[53] "computer and videogames incorporate a whole set of fundamentally sound learning principles, principles that can be used in other settings, for example, in teaching science in schools".

In this context, methods based on play, game, or videogames are particularly applicable as they encourage and facilitate alternative ways to view a given topic. Moreover, the use of educational games could improve the students' motivation in chemistry education and thereby contribute to the development of positive perceptions toward science, which is an essential aspect of the learning of science in general and chemistry in particular.[54,55] Indeed, it is recognized that cognitive processes are highly influenced by feelings and emotions,[56] and, as a result, there is a profound relationship between emotional variables and the learning process.[57] It is evident that attitudes play an essential role not only in learning science at a basic level, but they are also a key factor in the development of scientific vocations among students.[58]

In short, the acquisition of knowledge through games arises from opportunities to create and develop a range of mental structures,[59] thus opening the way to the development of abstract thinking.[36,60] Additionally, we can consider that games are an inherent part of a constructivist theory of learning, they can generate student motivation, and they require experience and reflection as part of the learning process. In this respect, educational games can be a powerful tool in the learning process for students.

Educational Games for the Teaching of the PT

With the assumptions described above as a starting point, many teachers have designed a variety of different games to enable students to learn chemistry. The use of games has spread throughout the educational stages from high school to university.[46,61−69]

If we focus on the teaching of the PT, Franco-Mariscal, Oliva-Martínez, and Bernal-Márquez[20,21] carried out a thorough review of the literature with the aim of categorizing the different teaching approaches that involve the use of educational games to teach this topic. These authors identified two large groups based on the content considered: first, approaches that rely on games for knowledge and familiarity with the PT and, second, approaches aimed at the understanding, application, or use of the PT. The role of games in the first group is associated with resources aimed at memorizing the names and symbols of the most important chemical elements and their arrangement in periods and families. These resources include word formation games,[70−73] anagrams,[74] crosswords,[68,75] card games,[62,67,76] mnemonic rules,[77] drawings,[78,79] songs,[80] three-dimensional cutouts,[81] and contexts in the daily life.[82] The second set of teaching resources has deeper aims that go beyond memorizing the names and chemical symbols, and these are related to the understanding and study of the PT. Franco-Mariscal, Oliva-Martínez, and Bernal-Márquez[21] classified the issues raised by this type of resource into the following five topics: (1) the etymology of the chemical elements and their identification in everyday life,[83] (2) the macroscopic physical and chemical properties of the chemical elements,[84] (3) the various models of the atom and atomic properties,[85,86] (4) the idea of periodicity and different attempts to classify the chemical elements throughout history,[87,88] and (5) other more general topics.[89,90]

■ METHODS

Purpose of the Investigation

This study is specifically aimed at exploring the student's learning through the use of games as educational instruments in the chemistry class. To evaluate the effect of the use of educational games with Spanish secondary school students (15−16 years old), a teaching unit was designed that focused on this type of learning resource for the chemical elements and the PT. The unit was developed as part of a doctoral thesis[91] at the University of Cádiz (Cádiz, Spain). The main novel feature of this work is the use of a variety of different games incorporated into a single teaching unit to provide a context of rich and intense education from which the role of educational games in learning could be investigated. This approach contrasts with most literature references on games, which are typically used in isolation, and offers the ability to motivate students and retain their attention throughout the course, which is expected to have a positive impact on learning. Furthermore, the games are resources that serve as content-related learning goals. Indeed, the games have been developed to create a climate of participation, involvement, and motivation for the students in an effort to help overcome the view that the PT is an arid and complicated issue[14] as precieved from a transmissive teaching approach.

Therefore, the main objective of the research is to evaluate the effect produced on learning by the integration of a wide

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 1. Items in the Assessment and Their Relationships with Learning Areas[a]

Item	Learning Area and Tasks
Acquisition of Scientific Knowledge (K)	
1	What do you think differentiates an element from a chemical compound?
2A	Give the names and symbols of five metallic chemical elements
2B	Give the names and symbols of five nonmetals
5A	List some properties that distinguish elements from one another
Application of Knowledge in Different Contexts and Situations (A)	
4	A large proportion of the chemical elements form part of objects and materials that are present in our daily lives. Try to identify all the chemicals you know (up to a maximum of ten) along with the materials or objects in which they are present in items that you have at home. It does not matter if the elements are components of chemical compounds
6	Classify the following elements according to their similarities to one another: sulfur, hydrogen, fluorine, sodium, calcium, oxygen, chlorine, copper, silver, potassium. Explain your criteria for grouping the elements
9	List the following atoms in ascending order of size and explain the reasons for the order given: oxygen, hydrogen, uranium, iron, chlorine
10	With the help of the Periodic Table, can you state how many protons, electrons and neutrons there are in an atom of iron? Give an explanation
12	Explain why chlorine tends to form negative ions (Cl^-), while sodium forms positive ions (Na^+)
Use of Scientific Evidence to Draw Conclusions (U)	
3	Imagine a spaceship that takes you to a faraway place in the universe. Do you think you would find the same chemical elements as on Earth? Or do you think there would be other totally different elements? Give an explanation.
5B	Do you think there are elements that have similar properties to each other? Why?
11	The element chlorine has an atomic mass of 35.45 amu. Why is this value not an integer unlike the mass numbers of other elements?
Understanding the Nature of Science (N)	
7	How old do you think the Periodic Table is? Do you think that it has always had the same form and structure or do you think that it has changed?
8	Do you think that the Periodic Table is able to explain everything relating to the atoms or does it have its limitations? If "yes" give reasons and if not give some of the limitations and defects that you know

[a]Adapted from ref 16.

range of games in a teaching unit on the PT. This is embodied by the following research questions:

(1) What knowledge do students have before and after experiencing the teaching unit on the PT?
(2) Are there differences in the knowledge shown by students who have followed this teaching unit relative to others who have followed a more traditional teaching method?
(3) What are the perceptions of students concerning the influence of games in learning chemistry?

Sample of Students

Two samples of Spanish students were employed to answer the three research questions. The first sample (the experimental group) attended the teaching unit on the PT that incorporated games, while the second sample (the control group) followed a traditional teaching approach.

The experimental group was composed of 38 10th grade students from a rural public secondary school in southern Spain. This sample consisted of two groups of pupils containing 17 and 21 students, respectively, who were enrolled in the teaching unit during 2008−2009 and 2009−2010. A total of 55.3% of the participants were male, and 44.7% were female. The students' ages ranged from 15−16 years. They were enrolled in a chemistry course as an optional subject in the final year of compulsory secondary education, had received chemistry preparation in the previous year, and intended to study science options in the future. The profile of the students showed that they had similar characteristics in terms of their academic performance in science and in their attitudes toward study. The students were taught by the same teacher, who also served as a researcher and observer, as in numerous research studies focused on educational practice[92] where a real situation is studied in a natural context in an effort to understand and interpret the learning process.

The subjects for the control group were 67 10th grade students from three different secondary schools in Spain with similar characteristics to the experimental group. The study was conducted in the academic year 2009−2010.[16] A total of 49.2% of the participants were male, and 50.8% were female.

Data Collection and Analysis

A variety of techniques and tools were used to collect information. The sample is relatively small because our aim was not only to gather quantitative data to allow comparisons to be made before and after the unit, but also to provide qualitative in-depth data on the overall process, although a discussion of this is beyond the scope of this article. In this study, the data from two of the questionnaires (Questionnarie 1 and Questionnarie 2) are discussed in particular. The aim of Questionnarie 1 was to evaluate the knowledge of students before starting the unit and one month after completing the unit, while the focus of Questionaire 2 was to assess the perceptions of students regarding their learning from the resources employed. Questionnaire 1 also served to compare the knowledge acquired by students in the experimental group and the group control.

Questionnaire 1: Assessment of Learning

Questionnaire 1 was validated in a previous study.[16] This consisted of 14 items that involve learning the four areas that are considered important in learning science:[93] the acquisition of scientific knowledge (K), the application of knowledge to different contexts and situations (A), the use of scientific evidence to draw conclusions (U), and knowledge about the nature and history of science (N). These aspects all form part of the science assessment in PISA.[94] Overviews of each of the items, along with the corresponding learning area, are summarized in Table 1, adapted from ref 16.

The students from the experimental group answered the questionnaire before taking part in the teaching unit (pretest), as an initial test to determine the starting level and to make

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 2. Scope of the Analysis, Items Developed, and Criteria Considered for Appropriate and Partially Appropriate Responses for Each Question[a]

Scope of Analysis	Learning Area	Question	Criteria Considered for Appropriate Responses and Examples	Criteria Considered for Partially Appropriate Responses and Examples
Concepts of the chemical element and compound	K	(1) Formulating the difference between an element and a compound	Conception of chemical element as a substance made from atoms with the same atomic number, and of a compound made up from two or more types of atoms or elements (submicroscopic explanation). Example: "An element is made up from atoms of the same type. In contrast, compounds are formed by different atoms"	Understand the element as a simple substance denoted by a single symbol. Understand that a compound is formed by various elements. Compound is sometimes defined without stating what is meant by element (macroscopic or symbolic explanation). Example: "A chemical compound is formed by various atoms"
Criteria to classify the chemical elements	A	(6) Given a set of known elements, classify them and explain the criteria used	Perform broad classifications of elements in accordance with the main families of the periodic table Examples: "Metals: hydrogen, sodium, calcium, copper, silver, potassium. Non-metals: sulphur, fluorine, oxygen, chlorine" "The elements are classified into their respective groups because elements from the same groups have similar properties: fluorine and chlorine; copper and silver; hydrogen, sodium and potassium; calcium; oxygen and sulphur"	Combine criteria based on the metallic or nonmetallic character with other states based on aggregation states or nonchemical concepts Example: "Metals: copper, silver, sodium, calcium. Non-metals: sulphur, fluorine, chlorine. Gases: hydrogen, oxygen"
Atomic number (number of protons) as a way to identify chemical elements	U	(3) Universiality or not of the chemical elements	The atomic number uniquely identifies a chemical element Thus, the presence of the same elements in all the universe is explained. Example: "The Universe contains the same elements as the Earth because each element is characterized by the number of protons, which does not change"	Explain the universality of the chemical elements through reasons that do not involve a submicroscopic model based on the existence of elemental particles. Example: "The Universe contains the same elements as there are on Earth because they were formed during the creation of a star and were spread during the transformation and explosion of a supernova. The same elements are formed always"
The Periodic Table as a model	N	(8) Copy of reality versus approach with limits	Understand that the Periodic Table has limitations. Ability to describe a problem or limitation on the basis of chemical knowledge Example: "The Periodic Table has limitations. For example, the location of hydrogen is ambiguous and the order of atomic masses has been changed in some cases in order to accommodate other properties"	Understand that the Periodic Table has limitations but unable to outline the limitations. Understand that the Periodic Table lacks certain information Examples: "It has some limitations" "The valencies and isotopes do not appear in some tables"

[a]Adapted from ref 16.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

medium-term comparisons, and also after of completing the unit (post-test) to their final level of knowledge and progress. Taking advantage of the winter break, the post-test was administered a month after the completion of the unit with the aim of assessing longer term learning rather than just short-term recall. The students from the control group answered the same questionnaire one month after completion of their studies.

The responses of the students in the pretest and post-test were evaluated by establishing a system of categories with three levels: inappropriate or blank, partially appropriate, and appropriate, that were quantified on a scale of 0, 1, or 2 points, respectively. Some examples and criteria of partially appropriate and appropriate student responses are provided in Table 2.[16] Although it was initially intended to evaluate separately each of the four factors in Table 1, the corresponding reliability values were fairly low. This situation suggested that it would be better to analyze the results for each item separately or to make a joint assessment of all items on the questionnaire because, in this case, the reliability was acceptable. Reliability estimates (Cronbach's alpha) were 0.72 and 0.70 for the pretest and post-test, respectively, for the experimental group, and 0.73 for the control group.

The data were processed with the statistical software package SPSS 21.0 using nonparametric tests (Wilcoxon and Kolmogorov–Smirnov) to compare groups. The Wilkoxon test was used to verify the existence of significant differences in the quantitative comparisons between pretest and post-test in the experimental group. This test is suitable to evaluate changes in ordinal distributions in related samples such as those used in this study, in which students repeated an identical questionnaire at two different stages of the investigation. The aim of this test is to analyze whether significant differences result from the application of the educational method in question. The completion of the post-test one month after the implementation of the unit also allowed us to assess whether the acquired learning was stable and durable. The Kolmogorov–Smirnov test was used to verify the existence of significant differences in the quantitative comparisons between experimental and control groups.

Questionnaire 2: Assessment of Students' Perceptions Concerning the Use of Educational Games

The feedback provided by the students showed that they were more willing to learn through the game-based approach. Several questions concerning students' perceptions of the unit were adderessed. How did the students find their experience with the unit? Did they see the unit as relevant and interesting, and why? To achieve this goal, the students answered a questionnaire (Questionnaire 2) at end of the unit on learning chemistry through games, with the intention of determining their perceptions about their own learning process and to assess the utility of games and activities in terms of their interest in the subject matter.

The questionnaire consists of two parts. The first part contains 13 items in which students assess their level of agreement or disagreement with the proposed statements on a Likert scale with 5 options (strongly disagree, disagree, undecided, agree, strongly agree). These items address three areas regarding games in general: their influence on learning, the stimulation of classroom participation, and their qualities as educational resources. Each area is related to different value judgments, some positive and others negative, to avoid any systematic bias in responses. The responses of the students to this part of the questionnaire provided some judgements on the role of games from a cognitive learning point of view (e.g., "Educational games have helped me to gain a better understanding of the chemistry content", item 3). However, other items on the questionnaire reflect contributions from an emotional standpoint, which in some cases offers a way to evaluate the attitude of students toward the games employed (e.g., "I found the educational games that we used attractive", item 5) and to chemistry classes in others (e.g., "By using educational games some chemical content has been made interesting and even enjoyable subject matter", item 10). This part was validated in a previous study.[33] The resulting scale showed a Cronbach-alpha coefficient of 0.80 for this study.

The second part of the questionnaire involves an individual assessment of each of the games used in the teaching unit. In this context, the students scored each of the educational games and tasks involving play on a scale from 0–10, and they chose the two best and worst rated games according to some of their percieved qualities (simplicity, usefulness, attractiveness, or interest).

Diary of Observations

Also, a teacher-observer's diary was used to record two different aspects: (1) how each session progressed, and faithful approximations of the discussions that took place during them, based on field notes; and (2) reflections on the teaching and learning processes that were taking place.

■ TEACHING UNIT AND ITS IMPLEMENTATION

Unit on the PT Based on Educational Games

The teaching approach adopted in the unit can be classified as within a socio-constructivist framework,[42,95] in which the student plays an active, participatory role, being engaged in the learning process. This participation was channeled through games seeking to stimulate cooperative work within groups and the competition between groups.

The teaching unit incorporates a variety of materials and tasks in which educational games have a central role above more traditional activities. In this approach, three types of tasks can be distinguished: educational games (EGs), tasks involving play (TIPs), and other tasks (OTs). In this research, an EG is understood to be a recreational task governed by a set of rules and purposes and competitive strife toward goals, according to the definitions of game of Caillous,[30] Dempsey et al.,[31] Salen and Zimmerman,[32] and Mondeja et al.[46] Some educational games are traditional games (puzzles, card games, etc.) that are adapted to the educational level or, alternatively, they can be educational resources (webquest) that are presented to the student as a game. TIPs scenarios are intermediate between play and a game, and they can include some sort of artistic or technological creativity by the student and offer them a more active role. Some such tasks involve drawing or building a model. Furthermore, some of the educational games or tasks involving play are related to the daily lives of the students,[76,88,96] and the aim of these was to foster teamwork. Finally, there are other tasks in the teaching unit that do not adhere to the characteristics outlined for the previous two categories. These tasks include making a chart, answering questions after reading, or creating a video summary.

Most of the games described in this unit were designed by the first two authors of this paper, and some others were taken from the literature. In designing each activity, the authors took

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX–XXX

Table 3. Objectives for the Different Learning Areas

Learning Area	Objective
K	K1. To understand the idea of chemical element, as a species of atoms, all atoms with the same number of protons in the atomic nucleus, and as a pure chemical substance composed of atoms with the same number of protons in the atomic nucleus.[98]
	K2. To know the names and symbols of chemical elements and main groups of the PT. To recognize the importance of using universal symbols for the identification of chemical elements.
	K3. To know some useful physical and chemical properties (e.g., melting and boiling points, electrical conductivity) to classify the elements.
	K4. To know some basic properties of the chemical elements (atomic number, mass number, atomic mass, isotopes, octet rule) and their relationship with the periodic classification.
	K5. To know what a model is and understand atomic models (Dalton, Thomson, Rutherford and shells).
A	A1. To identify some chemical elements in the surrounding materials and to appreciate the importance of chemistry in daily life.
	A2. To analyze data from the PT to infer the atomic structure.
	A3. To infer the trends of atomic properties.
U	U1. To identify the universality of the chemical elements.
	U2. To interpret and predict the stability of atoms and their chemical reactivity.
	U3. To answer questions about the constitution and properties of the elements.
	U4. To propose a model from experimental data.
N	N1. To estimate the limitations and open-to-revision nature of the present form of the PT of elements.
	N2. To appreciate the usefulness of scientific models, to explain and predict events and phenomena, and to recognize the strengths and limitations of classifications of elements and atomic models (Dalton, Thomson, Rutherford, shells and the PT itself).

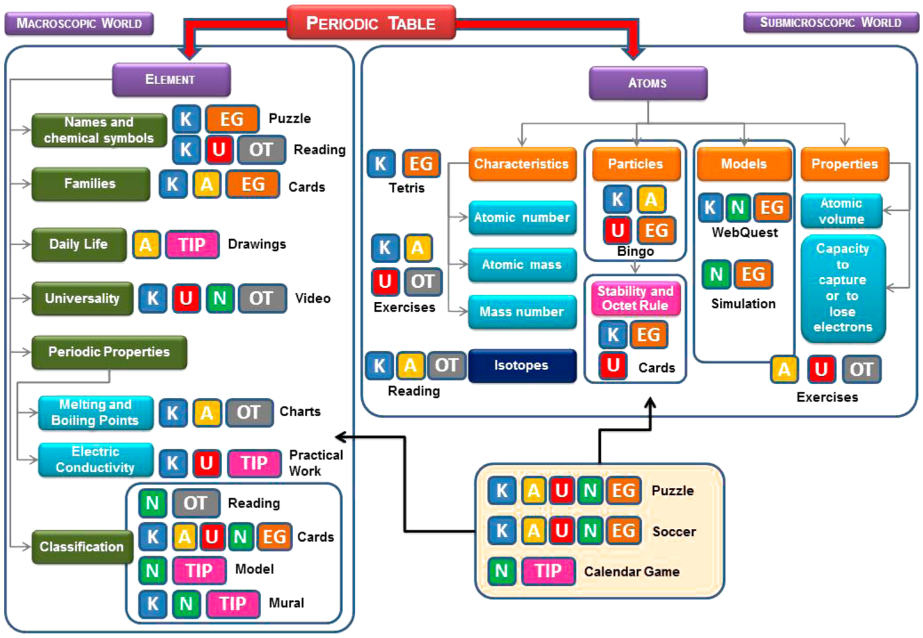


Figure 1. Content of the unit on the PT and its relationship with the learning areas and type of task employed.

into account the learning difficulties[14,15] often encountered by high school students on this topic, which are characterized within the theoretical framework. Previously, the games selected had been assessed by the authors in an individual way with different groups of students to obtain empirical evidence[76,82,90,97] according to the criteria suggested by Mondeja et al.[46] to improve learning.

Learning Aims of the Unit

The unit addresses the four learning areas (K, A, U, N) discussed above. The objectives associated with each of the learning areas are presented in Table 3.

Content of the Unit

The content of the unit is summarized in Figure 1. The areas of learning associated with each game are indicated along with the type of task used: educational game (EG), task involving play (TIP), and other tasks (OT).

It can be seen that the unit addresses the PT from two perspectives: macroscopic (chemical element) and submicroscopic (atom). The macroscopic view concerns the names and symbols of the chemical elements, their grouping into families, the presence of chemicals in the environment, the universality of the elements, some physical and chemical properties of the elements (melting point, boiling point, and electrical conductivity), and the various attempts to classify elements throughout history (Lavoisier, Döbereiner, Newlands, De Chancourtois, and Mendeleev). The submicroscopic perspective addresses the characteristics that identify an atom (atomic number, mass number, and atomic mass), the constituent particles, some atomic models (Dalton, Thomson, Rutherford, and the shell model), and some submicroscopic properties (atomic volume and the ability to capture or lose electrons).

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 4. Sequence of Tasks in the Teaching Unit

Task	Type	Learning Area	Objective (See Table 3)	Learning Difficulty To Be Overcome[a]	Description	Type of Students' Work[b]
Questionnaire 1	OT	K, A, U, N	All the items	1, 2, 3, 4, 5, 6	Complete the questionnaire 1 (Table 1) to assess the students' previous knowledge of the PT	I
50 States and the Chemical Elements[72]	EG (Puzzle)	K	K2 and teach American geography to the Spanish student	1	Identify the name of each US state from a series of chemical elements included as clues. To solve the puzzle, pupils must find the symbols that correspond to the elemental names and rearrange them into the states names. For example, _ _ _ Z _ _ _ (oxygen, sodium, argon, iodine) is ArIZONa.	P
Reading: A little salt	OT (Reading)	K U	K1 U1	2, 5	Read and discuss an informative text to learn about the properties of some elements and compounds. This task concerns the evolution of the concept of the chemical element throughout history and how it differs from a compound. The lesson then focuses on the properties of the elements sodium and chlorine and the compound sodium chloride.	I
Families of Chemical Elements Card Game[76]	EG (Card Game)	K A	K2 A1	1	Students should collect complete main-group families of the elements, that is, families 1, 2, 13−18. The card game combines features of Gin Rummy and Go Fish.	SG
Identification of the chemical elements in pictures[96]	TIP (Drawings)	A	A1	1, 2	Produce a drawing of an environment close to the student to identify different everyday objects and materials in which chemical elements are present. An example of a drawing can be seen in Franco-Mariscal,[82] where students search for elements in the parts of a car.	I
Melting and boiling point data	OT (Chart)	K A	K3 A3	3, 5, 6	Represent graphically the melting and boiling points of the first 36 elements to understand some characteristic properties of elements and their regularity.	P
Conductors and Insulators[99]	TIP (Practical Work)	K U	K3 U3	3	Use a simple electric circuit to predict and determine the conducting or insulating nature of different materials and everyday objects	P
Classifications of the chemical elements	OT (Reading)	N	N1	3, 5, 6	Understand the major classifications of the chemical elements (metals and nonmetals, Döbereiner triads, Newlands law of octaves, and De Chancourtois' telluric screw) by reading different texts. Answer questions such as why it is important to classify chemical elements, which properties do you consider to be important to classify them, what are the advantages and limitations of each classification.	I
Model of the telluric screw[100]	TIP (Model)	N	N2	3, 4, 5	Build a model of De Chancourtois' telluric helix on a cardboard cylinder to classify elements according to the information contained in the original publication.[100] To discuss the trends that exist between the elements.	I
Building the PT[101]	EG (Puzzle)	K A U N	K2, K3 A2 U2 N2	3, 4, 5, 6	Build a part of the PT in a card game with some properties of selected elements (metallic or nonmetallic character, melting and boiling points, reactivity in water, formulas of the oxides) to introduce students to the concept of periodicity. The elements given are lithium, calcium, magnesium, beryllium, bromine, argon, fluorine, potassium, chlorine, and helium.	P
Periodic classification of Mendeleev	OT (Exercises)	N	N1	4, 6	Answer different questions about the Mendeleev PT and discuss the advantages and disadvantages of this system from the principles of his work.	I
PT murals	TIP (Mural)	K N	K3 N1, N2	4	Produce murals about the different classifications of chemical elements and show these to fellow students to explain these classifications.	SG
Lives of stars[102]	OT (Video)	K U N	K1, K4 U1 N2	2, 5	Extract the main ideas and summarize the documentary "The Lives of Stars" from the series *Cosmos*[82] to recognize the universality of the chemical elements.	I
WebQuest[103]	EG (ICT)	K N	K4, K5 N2	2, 5, 6	Complete the webquest titled "A journey to the inside of nothing" about atomic models to recognize the scope and limitations of the atomic models (Dalton, Thomson, Rutherford, and the shell model). This webquest can be considered as a competition in which the final work presented by each group involves telling a story about a trip into an aluminum atom of a soda can.	P
Rutherford's experiment game[85]	EG (Marbles and Simulation)	N	K5 U4 N2	5, 6	Identify the hidden objects in different containers by analyzing the trajectories of marbles thrown into the container, as an analogy to the Rutherford experiment, and perform a computer simulation of the experiment for the Rutherford atomic model.	SG
Tetris game	EG (Computer game)	K	K2	1	Place "tabs" in the appropriate box in the PT in a variant of the computer game Tetris to familiarize students with the locations of the chemical elements in the PT	I
Bingo game[86]	EG (Bingo)	K A	K4 A2	2	Produce and play a bingo game in which numbers are replaced by chemical elements. Students should fill out the bingo card with information about the number of protons, electrons, or neutrons in the atoms	SG

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 4. continued

Task	Type	Learning Area	Objective (See Table 3)	Learning Difficulty To Be Overcome[a]	Description	Type of Students' Work[b]
		U	U3			
Calculate the particles	OT (Exercises)	K A U	K4 A2 U3	2	Identify the atomic number; mass number; number of protons, electrons, or neutrons of different elements.	I
Carbon isotopes	OT (Reading)	K A	K4 A2	2	Read and discuss a scientific text on carbon isotopes and their applications. Explain whether the isotope C-15 could exist and answer different numeric questions about atomic structure of other isotopes.	I
Octet rule card game[91]	EG (Card Game)	K U	K4 U2	4, 5, 6	Form combinations of cards totaling eight in a card game designed to highlight the octet rule as a criterion for the stability of atoms.	SG
Periodic properties at the macroscopic level	OT (Exercises)	A U	A3 U2	5, 6	Carry out activities on the properties of atoms, atomic volume and capacity to capture or lose electrons, to learn the rules for periodic properties. Compare the atomic volumes of Li, K, Mg, C, and F; predict the capacity to capture electrons of Al, O, F, Ne, and Li; and predict the capacity to lose electrons of C, Li, Fe, F, and Cs.	I
Clues and elements[90]	EG (Crossword)	K, A, U, N	All the items	1, 2, 3, 4, 5, 6	Solve a crossword based on questions about the chemical elements and the PT to apply the knowledge learned in the unit.	P
Calendar game[88]	TIP (Daily life context)	N	N1 N2	4	Identify situations in daily life and use the analogy of a calendar to compare it with the PT. Determine similarities, differences, strengths, and limitations of the current PT and discuss its advantages and limitations.	P
Soccer World Cup game[104]	EG (Board Game)	K, A, U, N	All the items	1, 2, 3, 4, 5, 6	Simulate different matches in the soccer World Cup to apply the knowledge learned in the unit. Each student makes up the players of a soccer team from the chemical symbols included in the name of the team. Students compete in the different phases of the Soccer World Cup by solving chemistry questions.	SG

[a]The reader can consult the seven learning difficulties in Periodic Table Teaching section. Learning difficulty 7 (deficiencies in the teaching process) is not associated with any particular task since all games attempt to circumvent the traditional teaching methodology and thus provide a more stimulating and participatory education that aims to address this difficulty. [b]Abbreviations: I, individual; P, pairs; SG, small group.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

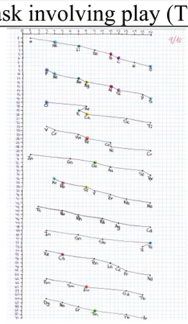
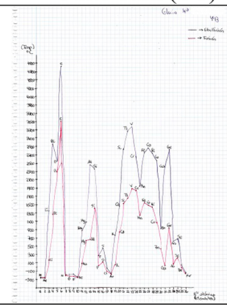
Educational Game (EG)	Task involving play (TIP)	Other Task (OT)
		
Families of Chemical Elements Card Game	Model of the Telluric Screw	Melting and Boling Points Chart

Figure 2. Examples of type of tasks in the teaching unit.

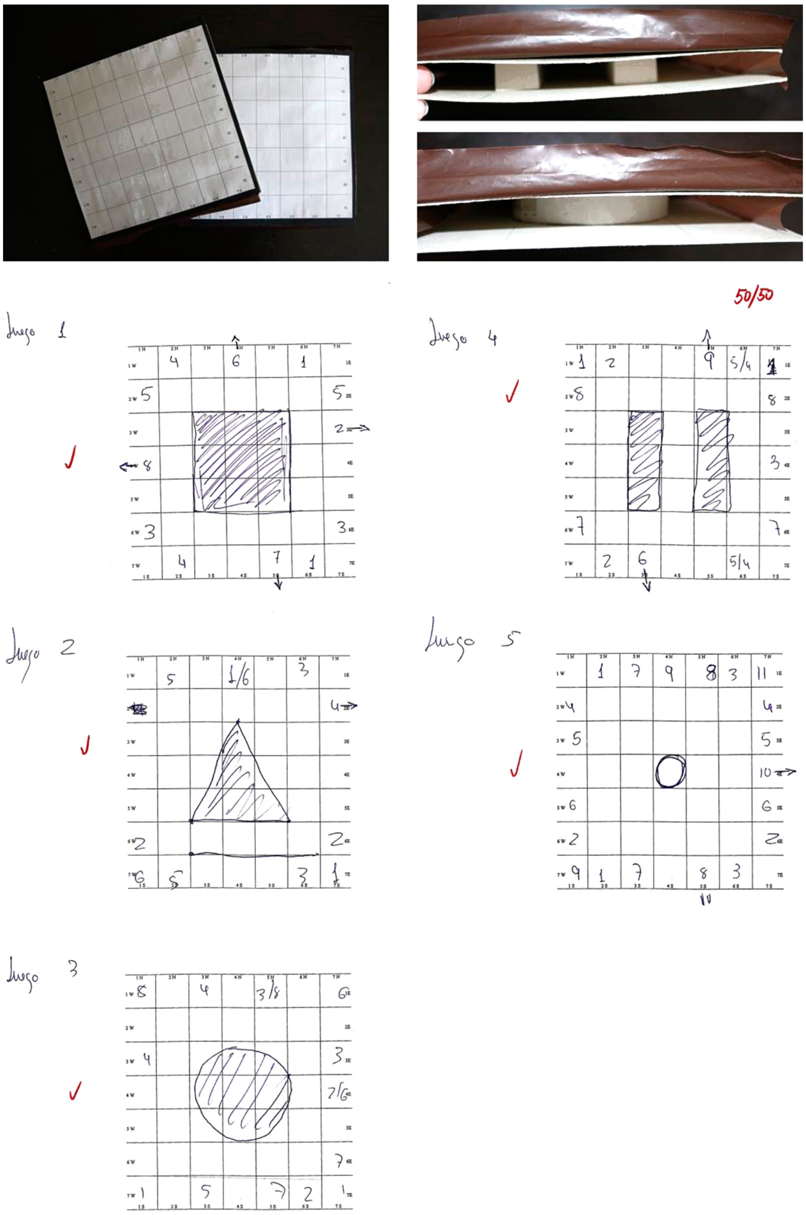


Figure 3. Outside and inside of two containers (top); student worksheet (bottom).

Teaching Sequence

An overview of the teaching sequence is given in Table 4 along with details of the tasks: type, learning area, objectives, learning difficulty to be overcome, description, and how the work is carried out (individual, I; pairs, P; small group, SG) by students in the classroom.

It can be seen from Table 4 that a broader spectrum of educational games including both traditional (various puzzles,

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

cards games, bingo, simulation of soccer competition, and a game in which marbles and containers with hidden objects are used) and digital technology-driven educational games (a variant of Tetris, simulations, and webquest) is used in this unit. The tasks involving play include the production of drawings and murals, building a model, practical work to measure the conductivity of everyday materials, and the calendar task, which involves putting everyday situations in the form of a challenge. Some examples of each type of tasks are shown in Figure 2.

Implementation in the Classroom

The teaching unit was implemented in two courses given to two classes of students aged 15−16. The unit was run over 24 sessions of 1 h, with three sessions per week in the period between October and December, including an initial session to assess the previous knowledge of the students and two sessions for evaluation. Most sessions took place in the classroom, although some were carried out in the laboratory if the task required space to work or computers with Internet access. The sessions with EGs and TIPs were structured in three parts: (1) an introduction by the teacher to explain the chemical knowledge and the objectives of the game and its rules, (2) the way in which the game or TIP develops (either individually, in pairs or in small groups), and (3) sharing information with the wider group to relate the characteristics of the game with the chemical knowledge involved. This aspect was particularly important so that the students were conscious of the transfer of knowledge about the PT through the use of games. Although the tasks were designed to foster collaboration and teamwork between students, in some cases, a level of competitiveness between different groups of students was observed.

Description of Rutherford’s Experiment Educational Game

To provide the reader with an overview of how learning the knowledge of the PT through games worked in the classroom and to understand how students would be stimulated, a description of “Rutherford’s Experiment Educational Game” is presented below.

In this game, three areas of learning are addressed, and these concern atomic models: (1) acquisition of scientific knowledge (K) (knowledge of what a model is and an understanding of Rutherford’s atomic model) (K5), (2) the use of scientific evidence to draw conclusions (U) (propose a model from experimental data) (U4), and (3) knowledge about the nature of science (N) (to appreciate the usefulness of scientific models and to recognize the strengths and limitations of atomic models) (N2). This game involves a simulation of Rutherford’s experiment at the macroscopic level. Bombardment with alpha particles is replaced by the release of glass marbles, and gold foil is replaced by a container with a hidden object secured between two boards. The aim of the game is to define the shape and size of a hidden object after throwing marbles at various angles into the container. This goal is achieved by analyzing the trajectory of the emerging marbles after passing through or bouncing off the hidden object. The activity is inspired by the famous work on black boxes by Haber-Schaim et al.,[105] which was proposed to provide an analogy between the process of inquiry aimed at finding out the hidden contents of a locked box and the investigative process carried out by scientists to develop models. It is this analogy that allows inferences to be made about the nature of the models from metacognitive reflection on the work carried out with the black box. In this context, and given that the box or container can never be opened by the student, it is easy to understand the tentative, approximate, and incomplete nature of any scientific model, while working with such a model does allow explanations and predictions within certain limits.

The equipment required for the game was designed by the first two authors of this paper and consists of five containers (each 22 × 22 cm^2). One of the following geometric figures is fixed inside each container: a square with sides of 10 cm, an equilateral triangle with sides of 10 cm, a circle with a radius of 5 cm, a circle with a radius of 3 cm, or two rectangles (10 × 2.5 cm^2) with a 5 cm gap between them. To facilitate the student’s work, the top cover of the container has a numbered grid (Figure 3). The student worksheet also contains a similar grid so that students can note how the marbles enter and exit the container.

The educational game was played in a 1 h session in the laboratory as it required the use of large tables. The laboratory is divided into five rotating positions, one for each of the containers containing the different shapes, with students changing position every 10 min. The students worked in groups of four.

First, the teacher introduced the game and demonstrated its use. The students immediately showed great enthusiasm and very quickly started to play the game, a fact that demonstrates the high level of interest aroused. The instructions were clear and easy, and it was evident that the students understood them. Thus, the students quickly developed a strategy to score throws on the numbered grid by crossing out the corresponding row if the marble had passed through in a straight line, which indicated that an object was not present.

The levels of involvement, interest, and commitment of the students in this task were confirmed by the following observations made by the teacher in their research diary: “The students were honest and did not look inside the containers”. This aspect was confirmed when several groups of students asked at the end if their solution was correct and also by a statement made by a student at the end of the class: “The best thing was to discover what was inside”. Further evidence of the involvement of students was the consistent level of interest of the students throughout the session. Furthermore, students did not complain about repeating the same type of game five times, but a proportion of the students did not have sufficient time to identify all of the objects. One example of this was that once the class had finished, a group of students remained in the classroom to identify the last shape, and when the teacher asked them to leave the students responded: “We want to find out what it is!”.

Another positive aspect that is worth highlighting was the collaboration observed between students in each group on the distribution of releases and their work to fill the record sheets on the input of new trigger points and reaching a consensus on the nature of the hidden object.

Finally, the game was also helpful for most students to enhance their understanding of what constitutes a scientific model and how it is produced. This was shown by the fact that although only 20% of the groups were able to correctly identify the five objects, most students were able to deduce the nature of all the objects, albeit not always with the correct dimensions.

■ RESULTS OF THE STUDY

In this section, the results of the analysis with respect to the learning of the PT and the students’ perceptions are presented.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 5. Distribution of Percentages of Appropriate and Partially Pretest and Post-test Responses in the Experimental Group and Wilcoxon Test To Evaluate the Differences

			Pretest (%)		Post-test (%)		Wilcoxon Test	
Item	Learning Area and Tasks	Learning Difficulty	Appropriate	Partially Appropriate	Appropriate	Partially Appropriate	Z (df = 2)	p-values (N = 38)[a]
Acquisition of Scientific Knowledge (K)								
1 (OT)	Differentiate between element and chemical compound	2, 5	5	74	13	74	−1.897	NS
2A (EG)	Identify names and symbols of a series of metals	1	34	16	74	13	−3.536	0.000
2B (EG)	Identify names and symbols of a series of nonmetals	1	18	21	63	16	−3.707	0.000
5A (EG)	Properties that distinguish elements from one another	3, 5, 6	66	13	95	3	−2.944	0.003
Application of Knowledge in Different Contexts and Situations (A)								
4 (TIP)	Identify chemical elements in materials in the environment	1, 2	21	63	63	34	−3.424	0.001
6 (EG)	Classify a series of elements based on their properties	3, 5, 6	55	32	89	8	−3.090	0.002
9 (OT)	Sort a series of elements in order of descending atomic volume	5, 6	0	74	3	92	−1.291	NS
10 (EG)	Determine the atomic composition of a series of elements	2	0	5	50	34	−5.025	0.000
12 (EG)	Predict the most stable ions of two elements (sodium and chlorine)	4, 5, 6	0	42	5	66	−3.357	0.001
Use of Scientific Evidence to Draw Conclusions (U)								
3 (OT)	Are the same chemical elements anywhere else?	2, 5	3	66	16	84	−3.710	0.000
5B (TIP)	Explain trends in the properties of the elements	3	37	24	76	8	−2.200	0.028
11 (OT)	Interpret the atomic masses of elements using the concept of isotopes	2	0	5	0	10	−0.816	NS
Understanding the Nature of Science (N)								
7 (TIP)	Indicate the static or progressive nature of the PT and, where appropriate, describe the changes	4, 6	42	34	84	13	−3.806	0.000
8 (TIP)	Indicate the definite or limited character of the PT and, where appropriate, discuss the limitations	4	0	45	71	26	−5.273	0.000

[a]Statistically significant differences: $p < 0.05$; NS indicates no significant differences from a statistical point of view.

Learning of the PT (Question Research 1)

The percentages of appropriate and partially appropriate pretest and post-test responses (Table 5) obtained for the experimental group in the learning assessment are discussed below for each of the tasks and learning areas. For each item, the nature of the task employed is also indicated using the letter code described above.

The Wilkoxon test was used to verify the existence of significant differences in the quantitative comparisons between pretest and post-test in the experimental group. It can be seen from the data in Table 5 that, in general, the implementation of the teaching unit in the experimental group improved the percentage of appropriate responses for all items and also led to an increase in partially appropriate responses between the pretest and post-test. It can also be observed that the differences in pretest and post-test results are significant in all cases with the exception of items 1, 9, and 11, that is, those tasks that are not related to games. Furthemore, the mean values obtained for this scale were 10.8 ± 0.7 for the pretest and 18.5 ± 0.5 for the post-test. The nonparametric Wilcoxon test to evaluate the difference between paired (dependent) samples showed significant differences between groups, thus indicating a statistically significant evolution in knowledge ($Z = -5.320$, $p = 0.000$).

In particular, the positive contribution of the unit concerned the learning of aspects related to knowledge of the PT (K) and its nature and history (N), where the students understanding evolved in a more meaningful way. This is the case for items related to the acquisition of knowledge of the PT through discrimination between metallic and nonmetallic elements (items 2A and 2B), some aspects of the nature of the PT model, such as its changing and evolving nature (item 7), and the existence of limitations in the system for the classification of the elements (item 8).

Moreover, although positive results were observed for some learning tasks related to the application of knowledge (A) and the use of evidence (U), the improvement in all of these cases was usually lower than in those areas highlighted above. Several items with very positive results were found within the scope of application (A), particularly those related to the identification of elements in the immediate environment (item 4) and the calculation of the atomic composition of elements (item 10). However, little or no progress was found in explaining the arrangement of different atoms in terms of their size using the shell model and its relation to the electronic configuration (item 9). In addition, improvements in learning were not found in the proportion of fully correct responses for item 6, which concerns the different criteria for metallic or nonmetallic character to classify elements with similar properties, or in the reasoning of students to explain the stability of the elements and their electronic configurations (item 12). Regarding the use of scientific evidence (U), there was no discernible progress in conceptualizing elements as a mixture of isotopes and, consequently, in explaining the inexact value for the atomic mass (item 11).

The items for which significant differences were not obtained are associated with three learning difficulties: misconceptions in the lesson (difficulty 2), complex nature of concepts related with the PT (difficulty 5), and the abstract nature of the concepts involved and the reasoning required (difficulty 6). It should be noted, however, that the same difficulties do appear to have been overcome in other items in which they were also

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 6. Final Student Performance in Experimental and Control Group and Kolmogorov−Smirnov Test

		Control Group (%) (N = 67)		Experimental Group (%) (N = 38)		Kolmogorov-Smirnov Test	
Item	Learning Area and Tasks	Appropriate	Partially Appropriate	Appropriate	Partially Appropriate	Z (df = 2)	p-Values[a]
Acquisition of Scientific Knowledge (K)							
1	Differentiate between element and chemical compound	1	81	13	74	0.963	NS
2A	Identify names and symbols of a series of metals	48	16	74	13	1.276	NS
2B	Identify names and symbols of a series of nonmetals	34	22	63	16	1.420	0.036
5A	Properties that distinguish elements from one another	54	27	95	3	2.019	0.001
Application of Knowledge in Different Contexts and Situations (A)							
4	Identify chemical elements in materials in the environment	63	36	63	34	0.056	NS
6	Classify a series of elements based on their properties	55	19	89	8	1.687	0.007
9	Sort a series of elements in order of descending atomic volume	1	75	3	92	0.398	NS
10	Determine the atomic composition of a series of elements	3	55	50	34	2.315	0.000
12	Predict the most stable ions of two elements (sodium and chlorine)	4	48	5	66	0.926	NS
Use of Scientific Evidence to Draw Conclusions (U)							
3	Are the same chemical elements anywhere else?	6	61	16	84	1.617	0.011
5B	Explain trends in the properties of the elements	19	24	76	8	1.895	0.002
11	Interpret the atomic masses of elements using the concept of isotopes	3	28	0	10	1.025	NS
Understanding the Nature of Science (N)							
7	Indicate the static or progressive nature of the PT and, where appropriate, describe the changes	47	43	84	13	1.795	0.003
8	Indicate the definite or limited character of the PT and, where appropriate, discuss the limitations	9	45	71	26	3.058	0.000

[a]Statistically significant differences: $p < 0.05$; NS indicates no significant differences from a statistical point of view.

evaluated. For example, difficulty 2 appears to be partially overcome with items 3, 4, and 10, whereas difficulty 5 was overcome to some extent in items 3, 5A, 6, and 12. Challenge 6 also led to improvements in student responses for 5A, 6, 7, and 12. Finally, improvements were obtained in all items related to the remaining difficulties. It can therefore be stated that the teaching unit contributed, at least to some extent, to overcoming the learning difficulties outlined above.

A very interesting relationship was found between the learning results and whether or not the use of games was involved in the tasks. The results show that tasks involving both educational games and play help students to improve their learning of the PT. However, it is clear that the majority of the topics that involved the use of other tasks (items 1, 9 and 11) gave rise to the worst results as significant differences were not found in these cases. Despite the aforementioned limitations in the type of learning promoted by the use of games, one must consider that the learning acquired appears to be quite stable and durable for a large number of students who took part in this study. This knowledge was retained one month after completing the unit, especially in the areas that concerned knowledge (K) and the nature of science (N).

This finding indicates that the teaching unit contributed substantially to student learning, and it can be inferred that the use of a game-based approach is likely to be a beneficial resource for the learning process. Other factors that could have contributed to the progress made by students in the experimental group are active and participatory role that the students have, the collaborative work developed within groups, or even the very structure and sequence of content planned for the teaching unit. It is possible that progress was due to a combination of these factors, which together would form an ideal setting for the games employed and the development of their potential.

Comparing Experimental Group with Control Group (Question Research 2)

The data in Table 6 allow a comparison of the final level of knowledge obtained by students who completed the teaching unit with games (experimental group) and that achieved by other students who followed a more traditional teaching approach (control group).[16] The Kolmogorov−Smirnov test was used to verify the existence of significant differences in the quantitative comparisons between groups.

It can be seen that in eight of the 14 test items, the differences between groups are statistically significant and in all of these cases in favor of the experimental group. Although there are significant differences in items in the four areas, it is worth highlighting area N, in which these differences include the two items in the test. These data suggest that students who followed the teaching unit that incorporated educational games performed better than those who were taught by traditional methods. These differences may be due to the benefits associated with the games used, but this conclusion is not unequivocal since in our design a pretest was not carried out on the control group so their starting level is not known in comparison to the other students. However, it seems reasonable to consider that the initial levels of both groups of students were not dissimilar.

Students' Perceptions (Question Research 3)

The opinions of the students on the role of games in learning were analyzed from the data obtained in the assessment questionnaire 2. The percentages of students who agreed or strongly agreed for each of the 13 items addressed in the first part of the questionnaire are listed in Table 7.

First, it should be noted that the educational games employed in this study were positively received by students in all three areas considered, as most of the items had high positive percentage scores and low negative percentages.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 7. Distribution of Percentages of Students in Agreement or Strong Agreement for Each of the Items in the Evaluation Questionnaire

Item	Area and Statement	% of Students in Agreement or Strong Agreement
Influence of the Games on Learning		
1	The use of educational games makes it easier for me to study chemistry	92.1
2	The ideas in chemistry involved in the games seemed difficult	60.5
3	Educational games have helped me to gain a better understanding of the chemistry content	81.6
4	I do not find educational games to be an appropriate way to learn chemistry	7.9
5	By using educational games some chemical content has been made interesting and even enjoyable subject matter	73.7
6	Despite the use of educational games, I definitely do not like chemistry	44.7
7	Educational games have contributed to me seeing chemistry as an important area in my life	52.6
Use of Games To Encourage Classroom Participation		
8	Educational games have allowed me to become much more involved and participate in classroom tasks	78.9
9	Game-based activities helped students to work as a team	84.2
Quality of Games as an Educational Resource		
10	I found the educational games that we used attractive	76.4
11	I think that educational games are very boring	23.7
12	The rules of the educational games were simple and easy to follow	55.3
13	Some educational games have confusing rules. Nobody knew what we should do	44.7

Influence of the Games on Learning. A total of 92% of students believed that the use of games improved their perceptions toward the study of chemistry (item 1), with 82% of students believing that the use of games favored the learning process (item 3) and 74% indicating that games made the content more interesting (item 5). Similarly, the games seem to enhance the level of motivation to study chemistry for 53% of students, as exemplified by the case of Rutherford's experiment game. Clearly some of this motivation was extrinsic in nature (success, better grades, winning the game, etc.), but there are some indications to suggest that there was also some intrinsic motivation, which would lead to the development of positive perceptions toward chemistry and learning.[106,107] This intrinsic motivation is again exemplified by Rutherford's experiment game through the interest shown by the students in carrying out this task and even repeating it several times to identify the hidden objects in all containers. However, within this favorable perception of the influence of games in learning chemistry, one must also recognize the existence of a significant percentage of students who consider that the chemical content is difficult despite it being presented through the use of games (item 2). This finding serves to highlight the importance of the results obtained with games-based tasks.

Use of Games To Encourage Classroom Participation. Regarding the second area to be addressed, students agreed that the use of educational games is successful in encouraging both individual student participation (79%, item 8) and cooperation and teamwork (84%, item 9), as demonstrated, for example, in the case described.

General Qualities of Games. A total of 76% of students indicated the attractiveness of games (item 10), although 45% of the students stated that the rules of the games were confusing (item 13). In contrast, only 55% of the students said that the rules of the games were easy to follow (item 12). This aspect can therefore be highlighted as one that requires improvement.

Evaluation of the Educational Games and Tasks Involving Play. The results show that the games employed in this study were well-received by the students, who gave them an average score of 7 out of 10. Scores for each of the games are available in the publication by Franco-Mariscal, Oliva-Martínez, and Bernal-Márquez.[76] In this sense, the two card games (Families and Octet) and the World Cup game were the most highly valued, all with a mean score close to 9. The best and worst rated games according to some of their perceived qualities (simplicity, usefulness, attractiveness, or interest) were chosen by students as well (Table 8).

Table 8. Best and Worst EG or TIP Tasks Rated by Students According to Their Qualities

Valuation Level	Qualities	Title	Type	% Students[a]
Most valued	Simplicity	Families card game	EG	45
		Octet card game	EG	40
	Usefulness	Soccer World Cup game	EG	29
		WebQuest	EG	29
	Attractiveness	Soccer World Cup game	EG	42
		Families card game	EG	42
		Octet card game	EG	37
	Interest	Soccer World Cup game	EG	42
		Octet card game	EG	29
Least valued	Simplicity	WebQuest	EG	71
		50 states puzzle	EG	42
	Usefulness	50 states puzzle	EG	40
	Attractiveness	WebQuest	EG	66
		50 states puzzle	EG	29
	Interest	WebQuest	EG	40
		50 states puzzle	EG	32

[a]Each student chose the two best and worst tasks in a list.

It can be seen from the information in Table 8 that the most and least valued tasks were the EGs, whereas the TIPs were ranked in intermediate positions. The three most highly valued EGs were also given a high rating in at least two of the four qualities analyzed. In the case of the two card games (Families and Octet), the high valuations obtained may be due to their familiar and attractive nature and the fact that they involved relatively simple knowledge management such as the names and symbols of the elements or characteristics of an atom. The popularity of the World Cup game may lie in the group (participation of the whole class) and competitive nature of this game. In addition, this game is based on soccer, which is the most popular sport in Spain.

At the other extreme are the WebQuest and 50 states puzzle (see Table 4) games as these received the lowest scores for virtually all of the qualities analyzed. The 50 states puzzle was considered to be too simple, unattractive, of little interest, and ultimately unhelpful. These opinions were all probably caused by a lack of knowledge of the American states, which represents

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

an added difficulty to solve the task successfully. Similarly, the lack of interest in the WebQuest task probably arose because the students were not familiar with this type of exercise as it is the first time that this type of work had been carried out, which meant that more time was required to become familiar with the process. Students also had difficulty in finding information on the Internet, and these drawbacks are interrelated. In addition, the final task required a great capacity for creativity on the part of the student, which in turn increased the level of complexity (see description in Table 4).

■ CONCLUSIONS

The results obtained in this study allowed us to draw a series of conclusions in response to research questions.

The teaching unit involving the use of game-based approach (educational games and tasks involving play) led, in general, to significant progress in learning the PT for secondary school students aged 15−16. This is evidenced on the one hand by the statistically significant differences between pretest and post-test results in the experimental group for most of the items in the assessment (Question 1) and, on the other hand, by the even greater progress in many of the test items compared to the results obtained by students who took traditional classes (i.e., the control group) (Question 2). The teaching unit contributed to the students overcoming, at least to some extent, the learning difficulties associated with this topic.[14,15]

These results are extremely encouraging when we compare them with those obtained by students who learn using traditional approaches. Indeed, as we have noted in a previous research,[16] students who learn by traditional methods improve their level of competency on this topic in a more limited way throughout the stage of secondary education. In contrast, in this study, the achievements made by students who learned through a game-based approach were far more satisfactory.

Furthermore, the students gave a positive perception on the role of games in the teaching unit. The students had positive perceptions of the influence of games on learning and their potential to generate classroom participation (Question 3). In this way, students feel that the games employed were generally simple and attractive, they generated interest and motivated students for the tasks and the content studied, and facilitated the learning process.[39,42−44] In particular, the highest rated games, mainly due to their simplicity, attractiveness, and interest, were the card games and those involving the application of knowledge in which the entire group of students participated as the simulation of soccer competition. A characteristic of a large number of activities in the unit is that they are competetive in nature, such as the World Cup game. Overall, it appears that the teaching unit that includes a number of educational games and tasks involving play is perceived as a positive factor in the learning process of the students who participated in the experimental group, thus reinforcing the proposals made by various authors in previous studies.[19,32,34,38,46]

However, despite the relative success, the use of educational games is not a panacea, and although improved learning was achieved in some areas, we recognize that the teaching unit described here did not overcome all of the learning difficulties that are usually encountered in the study of this subject. The unit proved to be quite beneficial for learning in the areas of knowledge (K) and nature and history (N) but was more limited in the areas of application of knowledge (A) and the use of evidence (U). It is worth noting that the absence of games or play in some of tasks could have an influence on learning. This is demonstrated by three items in the assessment test, in which significant differences were not found pre- and post-test (items 1, 9, and 11), where other tasks were used in the classroom. This finding reinforces the potential of games as resources in teaching and learning chemistry. In this sense, the design of a new games generation must be improved in terms of the application of knowledge (A) and the use of evidence (U), where lower levels of learning were found. It is difficult to identify the types of games that are the most suitable to generate learning, especially in the two areas mentioned above, although card games and group activities that involve a high levels of knowledge seem to be the best alternatives as they are highly rated by students.

One should exercise caution when generalizing about the results obtained in this study owing to the known limitations. One of the main limitations of this research lies in the fact that it is unreasonable to expect that such a large number of educational games will be used as part of an educational course unit. However, in the study reported here, the design of the research required the use of a variety of games to provide a strong context from which to consider the role of games in learning. On the other hand, another limitation is that the initial level of knowledge of the students in the control group was not assessed. Although the curriculum studied was the same for both groups, and samples of students came from very similar student populations in terms of skills and socio-economic level, the design used did not ensure categorically that the starting knowledge in the control group was similar to that of the experimental group. In this regard, future studies are required that take this variable into account.

Finally, the work described here contributes to the use of games in teaching chemistry by raising the integrated use of this educational resource in a teaching unit that has proven to be effective for students learning about the PT. This research has identified a new type of educational resource that has been named TIP. This new approach allows a more accurate evaluation of nondigital educational resources from the point of view of their play-based nature (play and educational games).[29−31] TIP scenarios are intermediate between play and games, and these may include any artistic or technological creation by the student and offer an active role to the pupil. Some of the tasks involve building a model or drawing. The results obtained show that these tasks helped students to improve their learning in the same way as educational games.[19,34,38,46] However, the perception of students about TIP is intermediate in terms of an assessment of their simplicity, utility, attractiveness, and interest when compared to educational games, many of which are the tasks that were valued the most. Further work on these tasks is required to make them more simple, useful, attractive, and interesting.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: antoniojoaquin.franco@uma.es.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work is part of the "I+D Excelencia" project "Development and evaluation of scientific competences through context-based and modelling teaching approaches" case studies

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

(EDU2013-41952-P), funded by the Spanish Ministry of Economy and Finance through its 2013 research call.

■ REFERENCES

(1) Schmidt, H. J.; Baumgärtner, T.; Eybe, H. Changing ideas about the periodic table of elements and students' alternative concepts of isotopes and allotropes. *J. Res. Sci. Teach.* **2003**, *40* (3), 257−277.
(2) Scerri, E. R. *The Periodic Table. Its Story and Its Significance*; Oxford University Press: New York, 2007.
(3) Demircioğlu, H.; Demircioğlu, G.; Çalik, M. Investigating the effectiveness of storylines embedded within a context-based approach: the case for the periodic table. *Chem. Educ. Res. Pract.* **2009**, *10*, 241−249.
(4) Ben-Zvi, N.; Genut, S. Uses and limitations of scientific models: the periodic table as an inductive tool. *Int. J. Sci. Educ.* **1998**, *20* (3), 351−360.
(5) Linares, R.; Izquierdo, M. La tabla periódica en el Journal of Chemical Education a través del siglo XX. *Tec. Epist. Did.* **2007**, *21*, 7−23.
(6) Scerri, E. R. A review of research on the history and philosophy of the periodic table. *J. Sci. Educ.* **2011**, *12* (1), 4−7.
(7) Taber, K. S. Ideas about ionisation energy: A diagnostic instrument. *Sch. Sci. Rev.* **1999**, *81* (295), 97−104.
(8) Taber, K. S. Understanding ionisation energy: Physical, chemical and alternative conceptions. *Chem. Educ. Res. Pract.* **2003**, *4* (2), 149−169.
(9) Linares, R. *Elemento, átomo y sustancia simple. Una reflexión a partir de la enseñanza de la tabla periódica en los cursos generales de química*. Doctoral dissertation, University of Barcelona, Barcelona, Spain, 2004.
(10) Talanquer, V. Common sense chemistry: A model for understanding student's alternative conceptions. *J. Chem. Educ.* **2006**, *83* (5), 811−816.
(11) Talanquer, V. Explanations and teleology in chemistry education. *Int. J. Sci. Educ.* **2007**, *29*, 853−870.
(12) Talanquer, V. Pensamiento intuitivo en química: Suposiciones implícitas y reglas heurísticas. *Ens. Cienc.* **2010**, *28* (2), 165−174.
(13) Taber, K. S.; Tan, K. C. D. Exploring learners' conceptual resources: Singapore a level students' explanations in the topic of ionisation energy. *Int. J. Sci. Math. Educ.* **2007**, *5* (3), 375−392.
(14) Franco-Mariscal, A. J.; Oliva-Martínez, J. M. Dificultades de comprensión de nociones relativas a la clasificación periódica de los elementos químicos: la opinión de profesores e investigadores en educación química. *Rev. Cien.* **2012**, *16* (2), 53−71.
(15) Franco-Mariscal, A. J.; Oliva-Martínez, J. M. Evolución en el alumnado de la idea de elemento químico a lo largo del bachillerato. *Rev. Eureka Ens. Div. Cienc.* **2013**, *10* (3), 353−376.
(16) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Almoraima Gil, M. L. Understanding the idea of chemical elements and their periodic classification in Spanish students aged 16−18 years. *Int. J. Sci. Math. Educ.* **2016**, *14* (5), 885−906.
(17) Bayir, E. Developing and Playing Chemistry Games To Learn about Elements, Compounds, and the Periodic Table: Elemental Periodica, Compoundica, and Groupica. *J. Chem. Educ.* **2014**, *91* (4), 531−535.
(18) Kurushkin, M.; Mikhaylenko, M. Chemical Alias: An Engaging Way to Examine Nomenclature. *J. Chem. Educ.* **2015**, *92* (10), 1678−1680.
(19) Orlik, Y. *Chemistry: Active Methods of Teaching and Learning*; Iberoamerica Publ: Mexico, 2002.
(20) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Bernal-Márquez, S. Una revisión bibliográfica sobre el papel de los juegos didácticos en el estudio de los elementos químicos. Primera parte: Los juegos al servicio del conocimiento de la Tabla Periódica. *Educ. Quím* **2012**, *23* (3), 338−345.
(21) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Bernal-Márquez, S. Una revisión bibliográfica sobre el papel de los juegos didácticos en el estudio de los elementos químicos. Segunda parte: Los juegos al servicio de la comprensión y uso de la Tabla Periódica. *Educ. Quím.* **2012**, *23* (4), 474−481.
(22) Tan, K. C. D.; Chee, Y. S. Playing games, learning science: promise and challenges. *Austr. J. Educ. Chem.* **2014**, *73*, 20−28.
(23) Šulcová, R.; Zákostelná, B.; Reslová, M. Didactical games for chemical education. In *Teaching and Learning Science at All Levels of Education*; Cieśla, P., Michniewska, A.; Eds.; Peadagogical University of Kraków: Kraków, 2014; pp 47−50.
(24) Goodale, T. L.; Godbey, G. C. *The Evolution of Leisure: Historical and Philosophical Perspectives*; Venture Publishing: State College, PA, 1988.
(25) Huizinga, J. *Homo ludens: A Study of Play-Element in Culture*; Routledge: London, 2000.
(26) Bakhtin, M. *Rabelais and His World*; Indiana University Press: Bloomington, IN, 1984.
(27) Chazan, S. *Profiles of Play: Assessing and Observing Structure and Process in Play Therapy*; Jessica Kingsley Publishers: London, 2002; p 19.
(28) Henricks, T. S. Play as ascending meaning: Implications of a general model of play. In *Play Contexts Revisited*; Reifel, S., Ed.; Ablex Publishing Group: Stamford, 1999; pp 257−277.
(29) Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L.. From game design elements to gamefulness: defining "gamification". *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*; ACM: New York, 2011; pp 9−15.
(30) Caillois, R. *Man, Play, and Games*; University of Illinois Press: Chicago, 2001.
(31) Dempsey, J. V.; Haynes, L. L.; Lucassen, B. A.; Casey, M. S. Forty simple computer games and what they could mean to educators. *Sim. Gam.* **2002**, *33* (2), 157−168.
(32) Salen, K.; Zimmerman, E. *Rules of Play: Game Design Fundamentals*; MIT Press: Cambridge, 2004.
(33) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Almoraima Gil, M. L. Students' perceptions about the use of educational games as a tool for teaching the periodic table of elements at the high school level. *J. Chem. Educ.* **2015**, *92* (2), 278−285.
(34) Cannon, R.; Newble, D. *A Handbook for Teachers in Universities and Colleges*; Kogan Page: London, 2000.
(35) Lieberman, J. N. *Playfulness: Its Relationship to Imagination and Creativity*; Academic Press: New York, 1977.
(36) Vygotsky, L. S. The role of play in development. In *Mind in Society*, Cole, M., Trans.; Harvard University Press: Cambridge, 1978; pp 92−104.
(37) Bruner, J. Juego, pensamiento y lenguaje. *Persp.* **1986**, *16* (1), 79−85.
(38) Torres, C. M. El juego: una estrategia importante. *Educ. Rev. Venez. Educ.* **2002**, *6* (19), 289−296.
(39) Belanich, J.; Sibley, D.; Orvis, K. L. *Instructional Characteristics and Motivational Features of a PC-Based Game (ARI Research Report 1822)*; U.S. Army Research Institute for the Behavioral and Social Science: Alexandria, VA, 2004.
(40) Ebner, M.; Holzinger, A. Successful implementation of user-centered game based learning in higher education: An example from civil engineering. *Comp. Educ.* **2007**, *49* (3), 873−890.
(41) Erhel, S.; Jamet, E. Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Comp. Educ.* **2013**, *67*, 156−167.
(42) Driver, R.; Oldham, V. A constructivist approach to curriculum development in science. *Stud. Sci. Educ.* **1986**, *13*, 105−122.
(43) Osborne, J. Teaching critical thinking? New directions in science education. *Sch. Sci. Rev.* **2014**, *352*, 53−62.
(44) Blanco-Lopez, A.; España-Ramos, E.; González-Garcia, F. J.; Franco-Mariscal, A. J. Key Aspects of Scientific Competence for Citizenship: A Delphi Study of the Expert Community in Spain. *J. Res. Sci. Teach.* **2015**, *52* (2), 164−198.
(45) Blanco, A. Relaciones entre la educación científica y la divulgación de la ciencia. *Rev. Eureka Ens. Div. Cienc.* **2004**, *1* (2), 70−86.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

(46) Mondeja, D.; Zumalacárregui, B.; Martín, M.; Ferrer, C. Juegos didácticos: útiles en la educación superior? *Rev. Electr. Dir. Form. Prof. Min. Educ. Sup. Rep. Cub.* **2001**, *6* (3), 65−76.
(47) España, E.; Rueda, J. A.; Blanco, A. Juegos de rol sobre el calentamiento global. Actividades de enseñanza realizadas por estudiantes de ciencias del Máster en Profesorado de Secundaria. *Rev. Eureka Ens. Div. Cienc.* **2013**, *10* (Extra), 763−779.
(48) Squire, K. Video Games in Education. *Int. J. Intell. Gam. Sim.* **2003**, *2* (1), 49−62.
(49) Annetta, L. A.; Minogue, J.; Holmes, S. Y.; Cheng, M. T. Investigating the impact of video games on high school students' engagement and learning about genetics. *Comp. Educ.* **2009**, *53* (1), 74−85.
(50) Wayer, N.; Crippen, K.; Dawson, K. Design and enactment of online components during four blended learning courses. *J. Onl. Learn. Res.* **2015**, *1* (2), 219−239.
(51) Prensky, M. Computer games and learning: Digital game-based learning. *Hand. Comp. Game Stud.* **2005**, *18*, 97−122.
(52) Egenfeldt-Nielsen, S.; Smith, J. H.; Pajares, S. *Understanding Video Games: The Essential Introduction*; Routledge: New York, 2013.
(53) Gee, J. P. *What Video Games Have To Teach Us about Learning and Literacy*; Palgrave/McMillan: New York, 2003.
(54) Yager, R. E.; Penick, J. E. Analysis of the current problems with school science in the USA. *Eur. J. Sci. Educ.* **1983**, *5*, 463−459.
(55) Koballa, T. R. Attitude and related concepts in science education. *Sci. Educ.* **1988**, *72*, 115−126.
(56) Reid, D. J.; Hodson, D. *Science for All*; Casell: London, 1989.
(57) Pintrich, P. R.; Marx, R. W.; Boyle, R. A Beyond cold conceptual change: the role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Rev. Educ. Res.* **1993**, *63* (2), 167−199.
(58) Vázquez-Alonso, A.; Manassero-Mas, M. A. La elección de estudios superiores científico-técnicos: análisis de algunos factores determinantes en seis países. *Rev. Eureka Ens. Div. Cienc.* **2015**, *12* (2), 264−277.
(59) Piaget, J. *La formation du symbole chez l'enfant: imitation, jeu et rêve, image et representation*; Delachaux et Niestlé: Paris, 1970.
(60) Piaget, J.; Inhelder, B. *The Psychology of the Child*; Basic Books: New York, 1984.
(61) Sarquis, J.; Sarquis, M.; Williams, J. *Teaching Chemistry with Toys*; Learning Triangle Press: New York, 1995.
(62) Granath, P. L.; Russell, J. V. Using games to teach chemistry. 1. The old prof card game. *J. Chem. Educ.* **1999**, *76* (4), 485−486.
(63) Russell, J. V. Using games to teach Chemistry. 2. CHeMoVEr board game. *J. Chem. Educ.* **1999**, *76* (4), 487−488.
(64) Chimeno, J. How to make learning chemical nomenclature fun, exciting, and palatable. *J. Chem. Educ.* **2000**, *77* (2), 144−145.
(65) Talanquer, V. Recreating a periodic table: A tool for developing pedagogical content knowledge. *Chem. Educ.* **2005**, *10*, 95−99.
(66) Franco-Mariscal, A. J. How Can We Teach the Chemical Elements to Make the Memorization Task More Enjoyable? *Foundations of Science* **2014**, *19* (2), 185−188.
(67) Martí-Centelles, V.; Rubio-Magnieto, J. ChemMend: A Card Game To Introduce and Explore the Periodic Table while Engaging Students' Interest. *J. Chem. Educ.* **2014**, *91* (6), 868−871.
(68) Joag, S. D. An Effective Method of Introducing the Periodic Table as a Crossword Puzzle at the High School Level. *J. Chem. Educ.* **2014**, *91* (6), 864−867.
(69) Zaragoza Ramos, E.; Orozco Torres, L. M.; Macías Guzman, J. O.; Núñez Salazar, M. E.; Gutiérrez Gonzalez, R.; Hernández Espinosa, D.; Navarro Villarruel, C. L.; de Alba Ritz, M.; Villalobos Diaz, R. A.; Gómez Torres, N. A.; Cerda Vazquez, R. I.; Gutiérrez Hernandez, A. D.; Pérez Avina, K. A. Estrategias didácticas en la ensẽnanza-aprendizaje: lúdica en el estudio de la nomenclatura química orgánica en alumnos de la Escuela Preparatoria Regional de Atotonilco. *Educ. Quím.* **2016**, *27* (1), 43−51.
(70) Helser, T. L. Elemental Zoo. *J. Chem. Educ.* **2003**, *80* (4), 409.
(71) Franco-Mariscal, A. J. Elemental Chem Lab. *J. Chem. Educ.* **2008**, *85* (10), 1370−1371.
(72) Franco-Mariscal, A. J.; Cano-Iglesias, M. J. Playing with the 50 States and the Chemical Elements. *Geog. Teach.* **2007**, *4* (2), 10−12.
(73) Franco-Mariscal, A. J.; Cano-Iglesias, M. J. Elemental B-O-Ne-S. *J. Chem. Educ.* **2011**, *88* (11), 1551−1552.
(74) Mattern, D. L. Elemental anagrams revisited. *J. Chem. Educ.* **1995**, *72* (12), 1092.
(75) Tubert, I. Crucigrama elemental. *Educ. Quím.* **1998**, *9* (6), 379.
(76) Franco-Mariscal, A. J.; Oliva-Martínez, J. M.; Bernal-Márquez, S. An educational card game for learning families of chemical elements. *J. Chem. Educ.* **2012**, *89* (8), 1044−1046.
(77) Hara, J. R.; Stanger, G. R.; Leony, D. A.; Renteria, S. S.; Carrillo, A.; Michael, K. Multilingual mnemotecnics for the Periodic Table. *J. Chem. Educ.* **2007**, *84* (12), 1918.
(78) Hernández, G. Jugando con símbolos. *Educ. Quím.* **2006**, *17* (2), 187−188.
(79) Hernández, G. Respuestas a jugando con símbolos. *Educ. Quím.* **2006**, *17* (3), 404−405.
(80) Lehrer, T. The elements. *On Tom Lehrer in Concert, More Songs by Tom Lehrer, and an Evening Wasted with Tom Lehrer*; Reprise Records: New York, 1959.
(81) Saecker, M. E. Periodic table presentations and inspirations. *J. Chem. Educ.* **2009**, *86* (10), 1151.
(82) Franco-Mariscal, A. J. Exploring the Everyday Context of Chemical Elements: Discovering the Elements of Car Components. *J. Chem. Educ.* **2015**, *92* (10), 1672−1677.
(83) Linares, R. Las maravillas ocultas en la tabla periódica. *Enseñanza de las Ciencias, Extra VIII Congreso Internacional sobre Investigación en Didáctica de las Ciencias*; University of Barcelona: Barcelona, Spain, 2009; pp 2725−2733.
(84) Feinstein, H. I. Elemental trivia. *J. Chem. Educ.* **1982**, *59* (9), 763.
(85) Wilbraham, A. C.; Stanley, D. D.; Matta, M. S. *Laboratory Manual for Prentice Hall Chemistry (Student ed.)*;Pearson Education, Prentice Hall Inc.: NJ, 2005.
(86) Franco-Mariscal, A. J. La lotería de átomos. *Alamb. Did. Cienc. Exp.* **2006**, *50*, 116−122.
(87) Tejeda, S.; Palacios, J. Chemical elements bingo. *J. Chem. Educ.* **1995**, *72* (12), 1115−1116.
(88) Oliva-Martínez, J. M. Comparando la tabla periódica con un calendario: posibles aportaciones de los estudiantes al diálogo de construcción de analogías en el aula. *Educ. Quím.* **2010**, *6*, 13−22.
(89) Kelkar, V. D. Find the symbols of elements using a letter matrix puzzle. *J. Chem. Educ.* **2003**, *80* (4), 411−413.
(90) Franco-Mariscal, A. J. Aprendiendo química a través de autodefinidos multinivel. *Educ. Quím.* **2008**, *19* (1), 56−65.
(91) Franco-Mariscal, A. J. *El juego educativo como recurso didáctico en la enseñanza de la clasificación periódica de los elementos químicos en educación secundaria*. Doctoral dissertation, University of Cádiz, Cádiz, Spain, 2011.
(92) Roth, K. J. Science teachers as researchers. In *Handbook of Research on Science Education*; Abell, S. K., Lederman, G., Eds.; Routledge: New York, 2007; pp 1203−1259.
(93) *Beyond 2000: Science Education for the Future*; Millar, R., Osborne, J., Eds.; King's College, School of Education: London, 1998.
(94) OECD. *PISA 2009. Assessment Framework. Key Competencies in Reading, Mathematics, and Science*; OECD: Brussels, 2009.
(95) Leach, J.; Scott, P. Designing and Evaluating Science Teaching Sequences: An Approach Drawing upon the Concept of Learning Demand and a Social Constructivist Perspective on Learning. *Stud. Sci. Educ.* **2002**, *38*, 115−142.
(96) Franco-Mariscal, A. J. La búsqueda de los elementos en secundaria. *Alamb. Did. Cienc. Exp.* **2007**, *51*, 98−105.
(97) Franco-Mariscal, A. J. Diseño y evaluación del juego didáctico "Química con el mundial de Brasil 2014" [Design and evaluation of the educational game "Chemistry in 2014 Brazil World Cup"]. *Educ. Quim.* **2014**, *25* (E1), 276−283.
(98) McNaught, A. D.; Wilkinson, A. *IUPAC Compendium of Chemical Terminology, (The gold book)*. 2a ed.; Royal Society of Chemistry Blackwell Science: Cambridge, UK, 1997.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX

(99) UNESCO. *New UNESCO Source Book for Science Teaching*; United Nations Educational Scientific and Cultural Organization: Paris, France, 1973.
(100) Béguyer De Chancourtois, A. E. Vis tellurique. *C. R. Acad. Sci.* **1862**, *54*, 757−761, 840−843, 967−971.
(101) Calatayud, M. L.; Carbonell, F.; Carrascosa, J.; Furió, C. J.; Gil, D.; Grima, J.; Hernández, J.; Martínez, J.; Payás, J.; Ribó, J.; Solbes, J.; Vilches, A. *La construcción de las ciencias físico-químicas*; Nau Llibres: Valencia, Spain, 1990.
(102) Sagan, C. The lives of the stars. In *Cosmos, a Personal Voyage*; Andorfer, G., McCain, R., Prods., 1980.
(103) Lucena, M. *WebQuest "Un viaje al interior de la nada"*, 2004. http://iesaguilarycano.com/dpto/fyq/webquest1/index.html.
(104) Franco-Mariscal, A. J. Elemental, ganemos el Mundial! *Aul. Innov. Educ.* **2006**, *156*, 87−96.
(105) Haber-Schaim, U.; Gendel, P.; Kirksey, H. G.; Pratt, H. A.; Stair, H. *Introductory Physical Science (IPS)*, 9th ed.; Science Curriculum Inc.: Lakewood, CO, 2010.
(106) Ormrod, J. E. *Human Learning Theories, Principles, and Educational Applications*; Merrill: Columbus, OH, 1990.
(107) Pelcastre, L.; Gómez, A. R.; Zavala, G. Actitudes hacia la ciencia de estudiantes de educación preuniversitaria del centro de México. *Rev. Eureka Ens. Div. Cienc.* **2015**, *12* (3), 475−490.

DOI: 10.1021/acs.jchemed.5b00846
J. Chem. Educ. XXXX, XXX, XXX−XXX