

“Atomizados”: An Educational Game for Learning Atomic Structure. A Case Study with Grade-9 Students with Difficulties Learning Chemistry

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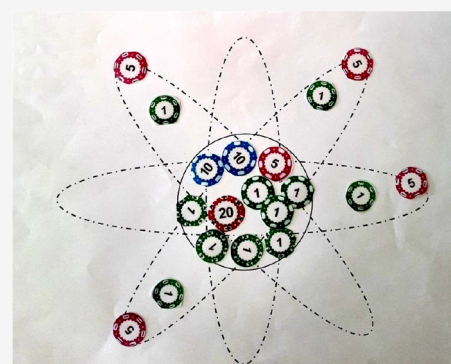


Article Recommendations



Supporting Information

ABSTRACT: Alternative teaching methodologies are required for grade-9 students diagnosed with difficulties learning chemistry. This study examines the progress made in learning atomic structure by 11 Spanish Students Diagnosed with Learning Difficulties (SDLD, experimental group), including those with poor academic performance, specific learning difficulties in reading, writing, and mathematics, attention deficit hyperactivity disorder, and borderline intellectual disability according to the Spanish curriculum. The study was conducted as part of the Program for Improving Learning and Performance (PMAR) and utilized the game “Atomizados”, specifically designed for this purpose. A written test on atomic structure was used to evaluate learning with three learning levels established (naïve, transitional, and informed). The findings indicate that 63.63% of the SDLD (experimental) achieved an informed learning level (understanding the internal structure of the atom) as a result of utilizing a generative learning strategy. The Mann–Whitney U test demonstrated that this learning was statistically significantly greater than that achieved by other students diagnosed with learning difficulties who did not use the game (SDLD control group). No significant differences were found between the SDLD experimental group and two other groups of grade-9 students with no learning difficulties (NSDLD control groups). However, differences were detected between SDLD (control) and NSDLD (control) in favor of the latter groups. The average for these control groups was a transitional level (identifying some elements of the atomic structure) in the best cases. SDLD (experimental) exhibited a very positive perception of the game’s influence on learning chemistry, highlighting its attractiveness, interest, and potential for generating classroom participation.



KEYWORDS: General Public, High School/Introductory Chemistry, Isotopes, Collaborative/Cooperative Learning, Humor/Puzzles/Games, Student-Centered Learning

BACKGROUND

Students Diagnosed with Learning Difficulties in the Chemistry Class

A secondary school chemistry class consists of diverse students with different learning styles, cognitive abilities, physical capabilities or limitations, and disabilities. Taking students’ learning difficulties into account will facilitate the entire learning process.

The study adopts Kirk and Bateman’s¹ definition of “learning disabilities” as “neuro-developmental disorders affecting various types of academic learning in children who are not mentally retarded or impaired by extraneous factors, such as sensory deficits, emotional disorders, or socioeconomic disadvantage”. Learning difficulties encompass a group of disorders that can easily be confused. Students Diagnosed with Learning Difficulties (hereinafter, SDLD) exhibit characteristics such as cognitive process disorders (perception, attention, memory, etc.), neurological problems (minimal brain dysfunction, etc.),

attention deficit hyperactivity disorder, or borderline intelligence.²

The Spanish curriculum integrates learning difficulties into five different groups: academic problems (APs), poor academic performance (PAP), specific learning difficulties (SLDs), attention deficit hyperactivity disorder (ADHD), and borderline intellectual disability (BID). In IQ tests, these students obtain average values for AP, PAP, SLD, and ADHD but are at the lower limit for BID.

Some disorders (ADHD, BID, and SLD) are intrinsic to the student and result from neurological dysfunction affecting fundamental psychological functions for learning such as

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attention, working memory, and learning strategies. Others, such as AP and PAP, may stem from socioeducational and/or teaching factors (inadequate teaching practices or lack of motivation). Learning difficulties may coexist with other disorders (sensory deficiency, intellectual disability, etc.) or extrinsic influences (social and cultural deprivation),² although they are not caused by these conditions.

Program for Improving Learning and Performance (PMAR) for Students Diagnosed with Difficulties Learning

The curriculum in Andalusia (Spain) includes the Programas de Mejora del Aprendizaje y del Rendimiento [Program for Improving Learning and Performance] (PMAR)³ to support students with learning difficulties that are not a result of insufficient studying or effort. These programs enable essential adaptations to the chemistry curriculum, ensuring that SDDL in grades 8 and 9 can successfully complete their compulsory secondary education by promoting individualization and personalization of the teaching-learning process.

The number of SDDL typically enrolled in this program is less than 15, given the student profiles concerned. The PMAR program includes 2 h of chemistry, 4 h of mathematics, and 2 h of biology per week. These SDDL have the same number of class hours in these three scientific subjects as their nonprogram peers but receive personalized attention and use a comprehensive and interdisciplinary working method.

Participants in the PMAR program exhibit several distinct traits, such as grade retention, poor academic performance in chemistry, positive classroom behavior, and a predominant reliance on memorization as their primary learning approach.⁴ Furthermore, they had unresolved subjects from past courses.

In summary, all SDDL in the PMAR program have been diagnosed with one or more learning difficulties (PAP, SLD, ADHD, or BID). The challenges of teaching these SDDL appear early with topics such as the periodic table.

Teaching the Periodic Table and Learning Difficulties

The periodic table is essential for understanding the composition of matter^{5,6} and is widely used as an introductory tool in chemistry education at both secondary and university levels.⁷ However, in the early stages of chemistry learning, its study is complex and includes a large number of concepts that result in serious learning difficulties for many secondary school pupils. Difficulties arise in areas such as identifying chemical elements in daily life, understanding the structure and utility of the periodic table, organizing elements, and recognizing the limitations of the periodic table as a model.⁸

The idea of a chemical element, which is often ambiguously used in literature to refer to different related concepts, underlies many of these difficulties.^{9,10} One major issue arises from the dual interpretation of the definition of a chemical element provided by IUPAC,¹¹ which connects the macroscopic and submicroscopic worlds: "1. A species of atoms; all atoms with the same number of protons in the atomic nucleus" and "2. A pure chemical substance is composed of atoms with the same number of protons in the atomic nucleus. Sometimes this concept is called the elementary substance as distinct from the chemical element as defined under 1, but mostly the term chemical element is used for both concepts".

Indeed, it is in the submicroscopic world that these difficulties become more evident, as shown by some studies concerning the internal structure of the atom. Thus, the study by Suryelita et al.¹² involving grade-10 students from Indonesia revealed that determining the atomic number and mass number for elements

and isotopes and applying them to the calculation of subatomic particles represent learning difficulties. Similarly, studies conducted by Franco-Mariscal^{8,13} with Spanish grade-10 and grade-12 students who received traditional instruction on the periodic table revealed the following findings: (1) Students commonly relied on properties such as metallic or nonmetallic nature, aggregation state, and melting point to differentiate chemical elements, while the atomic number and mass number were less frequently utilized, and (2) only 3% of grade-10 students and 23.6% of grade-12 students accurately calculated the number of protons, neutrons, and electrons in a neutral atom of iron. These findings are worrying and suggest the need for appropriate teaching methods to support their learning.

Although these learning difficulties may be influenced by various factors, such as the teaching methods,¹² curriculum, or the student-teacher relationship, many are inherent to chemistry and prevent some students from exceeding certain learning outcomes. These difficulties become more notable when students' learning abilities, rhythms, and styles require educational actions that facilitate competencies and the achievement of objectives in chemistry.

The Use of Educational Games to Teach the Periodic Table

To help SDDL, strategies that motivate them while increasing student engagement, attainment, and progression in chemistry should be used.¹⁴ Games offer a promising methodology in chemistry education due to their potential for interaction and motivation among students.¹⁵ Furthermore, games provide an interactive learning experience that enhances various skills including collaboration, problem-solving, and strategic thinking.¹⁶

Although the literature contains a number of games for understanding chemical classification and periodic chemical relationships,^{17–20} there are fewer such games focusing on the basic contents required to understand the internal structure of atoms, including the atomic number, mass number, subatomic particles, atomic orbital, or the difference between an element, ion, or isotope. The games covering these topics include bingo^{21,22} or domino,²³ which help in learning the chemical relationships between valence, atomic number, and chemical symbol.

Another interesting game that aims to reinforce the recognition of atomic orbitals by radial distribution functions and three-dimensional isosurface is BingOrbital.²⁴ This bingo is played in class as a retrieval practice tool, following an inquiry-based learning activity on atomic orbitals,²⁵ encouraging students to recall information from memory rather than relying solely on notes or textbooks.

In addition, the recent literature suggests that games, which include tactile learning methods, promote encoding of new concepts into memory^{26,27} and may be appropriate as a teaching tool for students who learn best through "hands-on" activities on a wider scale.²⁸ Some examples of this include three-dimensional models for visualizing and conceptualizing intermolecular forces²⁸ or 3D printing, which is used in many chemistry-education settings, such as the learning of periodic trends.²⁹

The learning strategy that students apply when learning via games depends on their instruction. The literature review by Franco-Mariscal et al.^{30,31} identified two types of educational games for learning the chemical elements, each employing different learning strategies. The first type focuses on memorization of chemical names, symbols, and their positions in the periodic table using mnemonic strategies with the purpose

of remembering content (including encoding, organization, and association).³² Examples include word-forming games,^{33–35} crosswords,³⁶ drawings,³⁷ songs,³⁸ and card games.^{19,39,40} The second type emphasizes understanding and use of the periodic table. Such games use generative learning strategies as they must help students to conceptualize, understand, and apply some in-depth aspects related to this subject and therefore imply reasoning and changes at a deeper and more significant level. Generative learning strategies are based on the SOI model (Select, Organize, and Integrate), allowing learners to create their own output, such as a summary or a drawing.⁴¹ Examples include games related to the environmental presence of elements,^{42,43} macroscopic properties,⁴⁴ atomic models,⁴⁵ atomic properties,^{21,22} and periodicity.²³

The study by Franco-Mariscal and Oliva,⁴⁶ which explored various games associated with the periodic table, revealed that the most frequently employed learning mechanism in educational games, as depicted in Figure 1, has the potential to stimulate students' interest and foster a more profound comprehension of the concepts being taught.⁴⁷

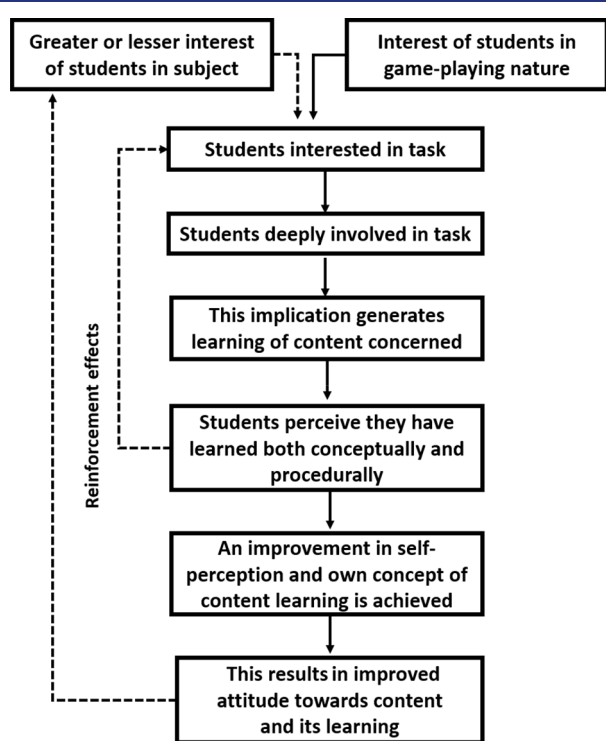


Figure 1. Mechanism that students may be following during learning situations involving educational games.

In this framework, we present the learning outcomes of the game “Atomizados”, specifically designed to learn about atomic structure in secondary education. The novelty of this study is that it presents a case study with Spanish SDDL studying chemistry as part of the PMAR and compares the outcomes with those obtained for another SDDL group who did not use the game and for two groups of students with no learning difficulties (NSDDL) who were taught by traditional instruction. This study will contribute to the relatively unexplored area of teaching SDDL.⁴⁸

METHODS

Purpose of the Investigation and Hypothesis

The study performed is a case study and proposes the following research questions:

- Research Question 1 (RQ1): What level of learning is achieved with the “Atomizados” game in Spanish grade-9 SDDL?
- Research Question 2 (RQ2): How is the learning acquired by SDDL who did not use the game?
- Research Question 3 (RQ3): How is the learning acquired by SDDL with respect to NSDDL from the same year who followed a traditional instruction and did not use the game?
- Research Question 4 (RQ4): What perceptions did SDDL manifest when using the game?

The study is grounded on the following hypotheses: (1) The “Atomizados” game can facilitate the learning progress in grade-9 SDDL; (2) this learning is greater compared to a group of SDDL who did not use the game; (3) this learning is comparable to that of a group of NSDDL in the same year who received traditional instruction without using the game; (4) “Atomizados” is able to generate motivation and interest in SDDL in regard to the internal structure of the atom.

Context and Participants

The sample for this study comprises four groups: an experimental group and three control groups.

Experimental Group. The participants in the experimental group were 11 Spanish grade-9 (third year of compulsory secondary education in Spain) SDDL from a public secondary school in Malaga (Spain) located in a neighborhood with a medium-low socioeconomic level compared to the city average. 54.5% were male and 45.5% female, aged between 15 and 17 years. These students were enrolled in the PMAR program during the 2020–2021 academic year for SDDL, which is why the sample is relatively small. Further details regarding the participants' diagnoses and characteristics can be found in the Supporting Information. This group was selected to determine the efficacy of the chemistry-related game in SDDL and to favor classroom dynamics other than blackboard teaching, which are not recommended for this type of student.

Control Groups. This study includes an SDDL control group and two NSDDL control groups.

The SDDL control group comprised 9 grade-9 SDDL from the same secondary school. These students followed the PMAR program during the subsequent academic year (2021–2022) and had comparable learning difficulties to students from the previous year (see Supporting Information) but did not use the game. Among the participants, 44.44% were male and 55.55% were female with ages ranging from 15 to 17 years.

The NSDDL control groups comprised 21 grade-9 NSDDL students from the same secondary school. These students followed traditional instruction and did not use the game. Of these, 57.2% were male and 42.8% were female with ages between 14 and 15 years. These students belonged to two groups: A ($N = 8$) and B ($N = 13$). The limited number of students in each group can be attributed to the circumstances of the COVID-19 pandemic during the 2020–2021 year, when in-person schooling was conducted with strict limitations on group sizes.

The teacher for the experimental group (first author) was different from that for the three control groups. However, all

teachers adhered to the same curriculum timeline, employed the agreed-upon evaluation criteria, and possessed similar research backgrounds and years of teaching experience. Consequently, any potential influence on the results stemming from different instructors is deemed to be minimal.

Data Collection and Analysis

Two instruments were used for data collection: a written test in which students applied their understanding and a questionnaire regarding the perceptions of students regarding their learning from the game. The written test was used in the experimental and the three control groups to compare the understanding acquired by SDLD (with and without game) and NSDLLD. The perceptions questionnaire was exclusively administered to the experimental group.

Written Test. Students were asked to complete the properties (Z, A, protons, neutrons, electrons) of five atoms or ions using the information provided (Table 1). SDLD and NSDLLD received the test with the same information on the chemical elements.

Table 1. Written Test

atom	symbol	Z	A	protons	neutrons	electrons
oxygen	O ²⁻		16			10
nitrogen	¹⁴ ₇ N					
phosphorus	P				16	15
rubidium	Rb ¹⁺	85		37		
calcium	Ca	20	40			

The task analysis was performed quantitatively, establishing the number of correct answers for each student and calculating the frequency and percentage of students at each level, the mean and the mode. Those questions lacking all of the adequate information were considered to be answered incorrectly. To establish different levels of learning, the results were grouped into three categories:

- Informed level: The student demonstrates a comprehensive understanding of the internal structure of the atom with four or five correct answers.
- Transitional level: The student recognizes some elements of the internal structure of the atom with three correct answers.
- Naïve level: The student lacks knowledge regarding the elements of the internal structure of the atom. This corresponds to two, one, or no correct answers.

U Mann–Whitney test was performed to compare these three levels for the different groups and to detect possible statistically significant differences between the three control groups and between the experimental and each control group as this test is suitable for small samples.⁴⁹

Questionnaire of Assessment of Students' Perceptions Concerning the Use of Educational Games. The questionnaire validated by Franco-Mariscal et al.^{50,51} and applied in other studies was also used here to anonymously evaluate students' perceptions.⁵² The first part of the questionnaire,⁵⁰ based on a Likert scale, comprises 13 items where students can indicate their level of agreement or disagreement with various statements. The second part⁵¹ involves an assessment of the "Atomizados" game. As open questions, students were asked to indicate what they had learned about chemistry and the best and worst aspects of the game. The

qualitative analysis adopted a collaborative and iterative approach, involving the creation of codes (and subcodes) to identify common ideas within portions of text from students' responses.⁵³ This coding process enabled the establishment of a category system and determination of the frequency of the appearance for each category. The closed questions evaluated the game on a scale of 0 to 10 points and different aspects of the game using a Likert scale. These questions were analyzed quantitatively due to their structured nature and limited scale.

THE EDUCATIONAL GAME "ATOMIZADOS" AND ITS IMPLEMENTATION

Learning Goals and Strategies for the Game

The board game "Atomizados" is indicated for chemistry students in grade-9 or higher. Its aim is to promote learning of the internal structure of the atom, covering various topics included in the Spanish chemistry curriculum for that school year, namely, subatomic particles, atomic number, mass number, isotope, ion, and development of the atomic model. "Atomizados" is a tactile, card- and chip-based learning activity that helps students visualize protons, neutrons, and electrons, a strategy we might rightly expect to benefit students with disabilities.^{26–28} Table 2 lists the cognitive and knowledge dimension and learning outcomes according to Bloom's revised taxonomy model.⁵⁴

Table 2. Cognitive and Knowledge Dimension and Learning Outcomes for the "Atomizados" Game

cognitive and knowledge dimension	learning outcomes for the students: upon playing the game, students can...
Remember + Factual	List the subatomic particles
Remember + Conceptual	Recognize the relationship between subatomic particles
Analyze + Procedural	Characterize the internal structure of the atom
Understand + Metacognitive	Predict the existence of ions and isotopes
Analyze + Conceptual	Differentiate between atom, ion, and isotope
Apply + Procedural	Construct the Rutherford nuclear model for neutral atoms using a template and cards Construct the Rutherford nuclear model for ions and atomic species from neutral atoms using a template and tokens
Evaluate + Metacognitive	Reflect the periodic table as an organizational structure for chemical elements

"Atomizados" uses a generative learning strategy which prompts learners to apply Mayer's Selection, Organizing, and Integrating (SOI) memory model.⁴¹ According to this model, learners go through three processes during productive learning: (a) Selection, learners select the most important ideas from the information source (the periodic table), (b) Organizing, the selected important ideas are placed in context and organized into a coherent structure that establishes links between the new subject matter and prior knowledge (constructing an atom), and (c) Integrating, the new information is integrated into knowledge schemes in long-term memory, or existing knowledge schemata are updated based on the new information.⁴¹

Description and Rules of the Game

The aim of the game is to determine the subatomic particles in different atoms and construct the Rutherford model for those atoms. The game, which is recommended for four players, comprises a board, player table, atomic model scheme, two dice,

pieces, ancillary material, and timer (Figure 2), as described in greater detail below.

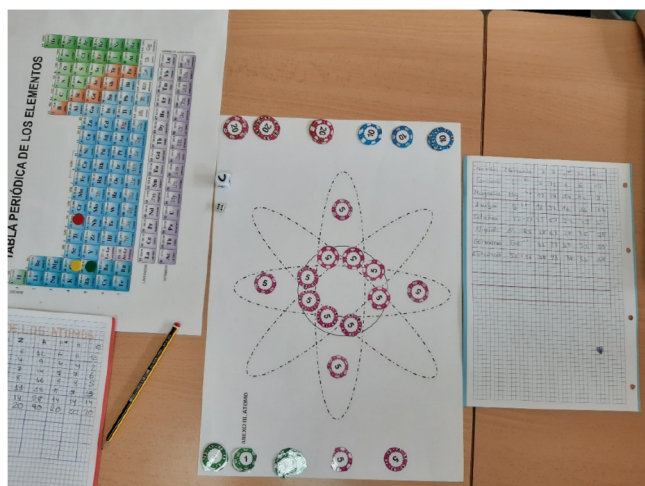


Figure 2. Materials for the "Atomizados" game.

- **The board:** This comprises the current periodic table, in which the atomic number (Z) and atomic weights of the various elements are represented.
- **Player table:** A table prepared by each player in their notebook in which they record the information for each atom including name, symbol, Z , A , number of

constituent particles (protons, neutrons, electrons) and its neutral, isotopic, or ionic (cationic or anionic) nature.

- **Atomic model scheme:** Piece on which the student should construct a Rutherford nuclear model to represent the corresponding atom (Supporting Information).
- **Dice:** There are two types:
 - (1) Move die: A traditional, six-sided die that is used to move around the board.
 - (2) A subatomic particle die: A six-sided die with the following information: N (neutral, 1 side), I (isotope, 1 side), C (cation, 2 sides), and A (anion, 2 sides). This die was made using a commercial white die that could be written on using a permanent marker.
- **Cards:** There are two types.
 - (1) A movement piece for each player. Board game pieces were used (Figure 2).
 - (2) Subatomic particle pieces. Plasticized pieces to represent the Rutherford nuclear model. Each piece contains a value (1, 5, 10, and 20) and a charge (positive, negative, or neutral) (Supporting Information). The intention was to place particular emphasis on the charges of the subatomic particles; therefore, a color code was assigned to the quantity rather than to the specific particle. This approach helps players grasp the nature of the particles without relying on their color for identification.
- **Timer:** This is used to control the time for each turn if the players decide to play this way.

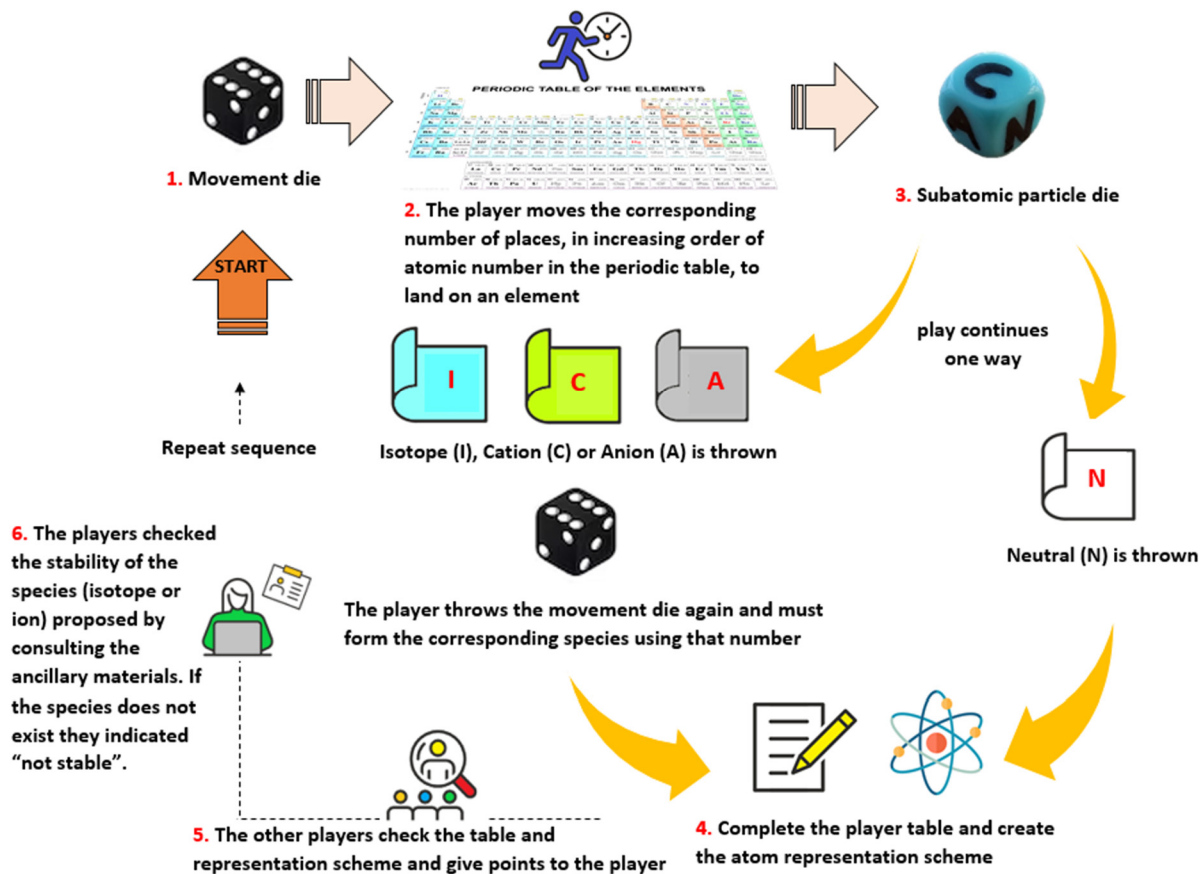


Figure 3. Playing sequence.

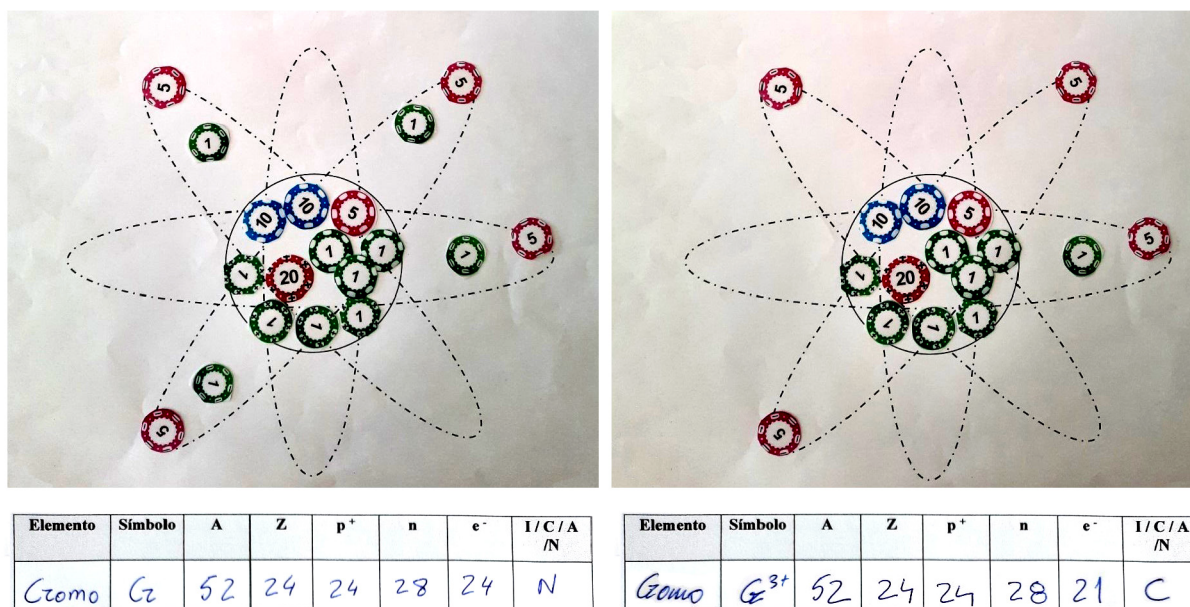


Figure 4. Player table and atomic model scheme for Cr (left) and Cr³⁺ (right).

- *Ancillary material:* Device with Internet access to consult the existence of the isotope proposed on the IUPAC Web site⁵⁵ or the stability of the ion on an educational website⁵⁶ to consult stable ions for chemical elements.

How to Play. Two groups are formed in the classroom. The board (periodic table) is placed at the center of the table, and each player puts their movement piece on the hydrogen element. The atomic model scheme is displayed next to the board with ten pieces of each type of subatomic particle available on the sides so that each player can construct the atomic model during their turn.

During their turn, each player must complete two tasks:

- Task 1: Correctly complete the player table with all the properties of an element (neutral atom, isotope, or ion) using the information provided by the dice.
- Task 2: Construct the Rutherford nuclear model to represent that atom using the atom representation scheme and particle pieces.

A score of half a point is awarded for successfully completing each task. Games can be played with or without the timer. If the timer is used, the time available for each player to complete the tasks during their turn is predetermined. Three difficulty levels can be established: 3, 2, and 1 min. Additionally, it is essential to agree on the number of turns to be played. As an example, this activity was conducted with 2 min playing times, groups of four players, and a 1 h session, resulting in six turns to complete each game.

Playing Sequence. Figure 3 provides a summary of the playing sequence, while a more detailed description can be found in the [Supporting Information](#).

Figure 4 shows an example of the player table and atom representation scheme for a neutral chromium atom (left) and the corresponding +3 cation (right).

Implementation in the Classroom

The game was implemented in the classroom as part of a teaching-learning sequence on the structure of matter in six 1 h sessions held in March 2021. The SDLD had no prior understanding of atomic structure, as it was being covered for

the first time in that academic year, as established in the Spanish curriculum.⁵⁷

In the first session, the experimental group teacher provided an explanation of the internal structure of the atom and the characteristics of the subatomic particles. This included an overview of the historical evolution of atomic models, emphasizing the aspects that remained unchanged (constituent particles) and the changes that occurred leading to the current atomic model (nature and location of subatomic particles). The purpose of this explanation was to ensure that SDLD are aware that the Rutherford model is an important milestone in the evolution of atomic models as it proposes the existence of a central nucleus in the atom and places the subatomic particles for the first time.

In the second session, the teacher introduced the game, explaining its objectives, rules, and specific chemical concepts that students should learn from it. It was clarified that the game uses the Rutherford nuclear model, where electrons orbit the nucleus in circular orbits similar to that of planets in the solar system. Additionally, it was briefly mentioned that modern chemists use the quantum mechanical model, which describes electrons as an electron cloud. The Rutherford model was chosen for this game instead of the current model as only the former is included at the Spanish secondary school curriculum⁵⁷ and because this analogy has major advantages in regard to introducing new concepts in general chemistry.⁵⁸ The game promotes a learning mechanism based on the understanding and use of the periodic table.

Under supervision from the teacher, various games were played as examples with different difficulty levels. Initially, the board was limited to the second period in the periodic table to apply students' understanding to elements containing a smaller number of particles. Subsequently, ions and isotopes were introduced without increasing the number of elements.

During sessions three–six, heterogeneous groups (in terms of sex and academic performance) were formed to play using the entire periodic table. After explaining the rules, the SDLD played autonomously, while the teacher supervised each round, resolving any doubts regarding chemical concepts or rules and

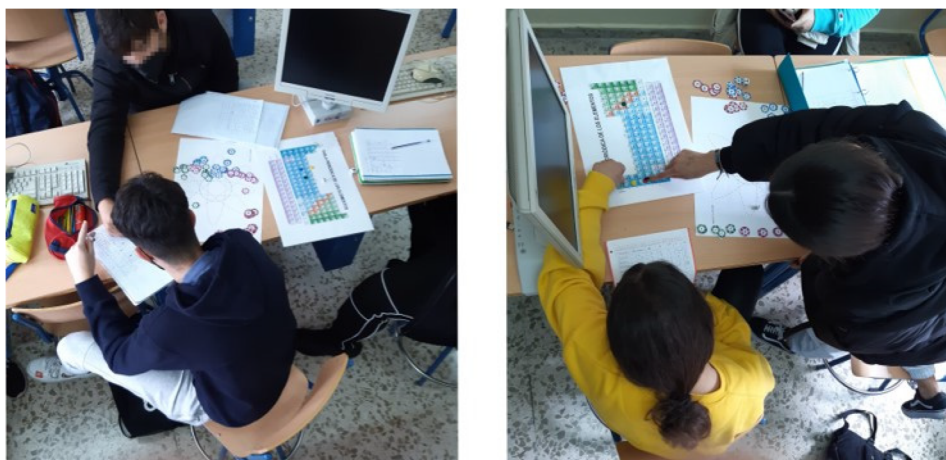


Figure 5. Students from the experimental group playing in the classroom.

checking the results recorded in the players' tables. Figure 5 illustrates various SDLD activities in the classroom.

The control groups covered these topics during the same number of sessions. The first session was identical, while the remaining sessions consisted of traditional instruction based on blackboard teaching and exercises. These sessions involved calculating the constituent particles using the Rutherford model based on completion of the table subsequently used for the written test (Table 1), as well as atom representation schemes (elements containing a smaller number of particles for session 2, ions for session 3, isotopes for session 4, and elements, ions, and isotopes for sessions 5 and 6). Both the experimental and control groups performed the same tasks, but the control groups received data provided by the teacher for determining elements through mathematical operations, while the experimental group obtained data randomly through the game itself. Finally, since the SDLD had previously employed games for learning and had acquired a fluid game dynamic, using the game to practice problem-solving did not require more time than a didactic blackboard teaching method.

FINDINGS

Assessment of Learning

The findings reveal that the experimental group demonstrated greater progress in understanding the internal structure of the atom compared with the three control groups. Figure 6

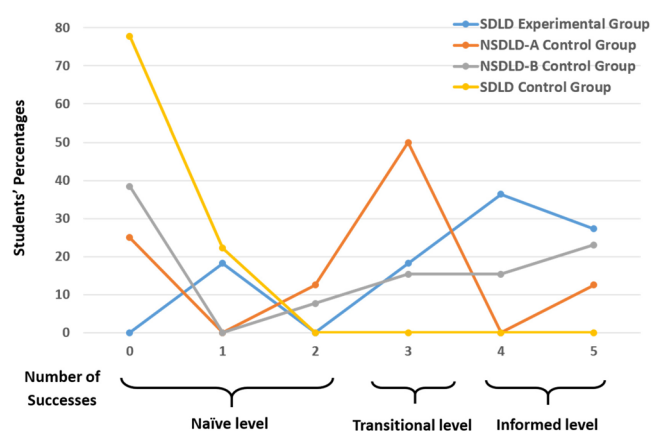


Figure 6. Learning levels achieved by each group.

illustrates the comparison of learning levels among the different groups, indicating that the majority of students in the experimental group reached the informed level. In contrast, all SDLD in the control group remained at the naïve level, while the NSDLD from the two control groups achieved lower levels (transitional level for group A and naïve level for group B).

The Mann–Whitney U test (see Supporting Information) confirms the existence of statistically significant differences ($p < 0.05$) between the experimental group and the SDLD control, favoring the first group, thus highlighting the effect of the game on learning. Similarly, significant differences were found between the two NSDLD groups and the SDLD control, in favor of the former, as would be expected given the student profile. However, no significant differences were found between NSDLD-A and NSDLD-B, suggesting similar performance between these two groups.

Students' Perceptions

Figure 7 presents the percentages obtained for each item in the perceptions of chemistry using the games questionnaire for each option on the Likert scale.

The percentages for each point on the Likert scale were calculated for each item. An analysis was then carried out by grouping the percentages of students who agreed or strongly agreed with positive items and the percentages who disagreed and strongly disagreed with negative items.

The overall analysis of questionnaire items (see the footnote in Figure 7) shows a positive perception for SDLD (experimental group) with all items exhibiting percentages higher than 54.5%. A detailed analysis of each area in the questionnaire is provided below.

Influence of the Game on Learning: 63.7% of students considered that using the game improved their perceptions of studying chemistry (item 1). Similarly, 81.8% felt that “Atomizados” enhanced the learning process (item 3), whereas 81.9% indicated that the game made the content more interesting (item 5). Moreover, the game appears to improve the motivation to study chemistry for 54.6% SDLD (item 7). However, it should be noted that 63.7% found that the chemistry content was difficult despite being presented as a game (item 2).

Use of the Game to Encourage Classroom Participation: In the second area, most SDLD agreed that the game successfully promoted their individual engagement (72.8%, item 8) but not their ability to work as a team (90.9%, item 9). As such, our aim is to improve the game by incorporating new rules to provide

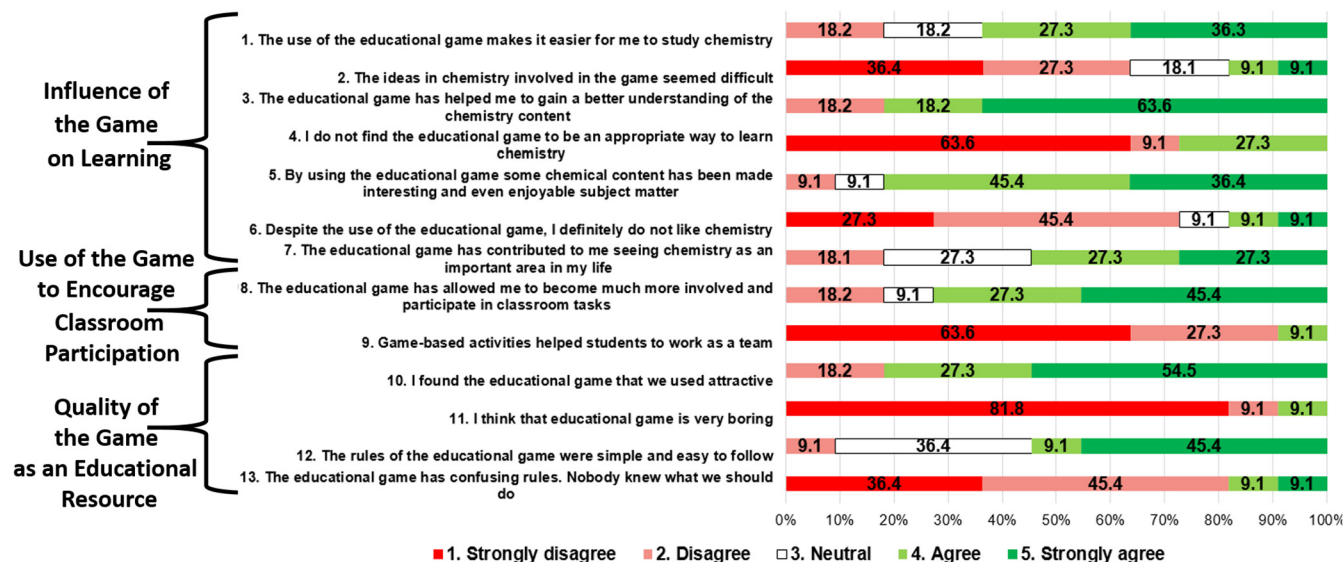


Figure 7. Results of the perceptions of chemistry using a games questionnaire.

opportunities to SDDL to solve tasks collaboratively, even though this may impact certain positive aspects of the game, such as “playing in a group with companions”, being seen more as a competition rather than a cooperative task.

General Qualities of the Game: Around 81.8% of SDDL stated that the game was attractive (item 10) and not at all boring (item 11), whereas 81.9% noted that the rules were not confusing (item 13).

Evaluation of the “Atomizados” Game

Students gave the game an average score of 8.9/10, thus showing that it was well received by the participants.

The answers given to the question about what they had learned can be grouped into two categories using the codes established: “atom” (and subcategory “subatomic particles”) and “game”. The main category (9/11 SDDL) relates to the acquisition of chemistry-related learning. Some SDDL (3/9) expressed their learning using more accurate terms related to the internal structure, specifically naming subatomic particles (“I have learned a lot about the difference between protons and electrons”), whereas the majority (6/9) used more general expressions (“I have learned about atomic structure”, “...a lot about atoms”). The minor category (2/11 SDDL) concerned the rules of the game (“I have learned how to play”).

Around 63.64% of students considered “Atomizados” to be an easy or very easy game to play: 72.72% found it useful, 100% found it attractive or very attractive, and 81.82% found it very interesting (Figure 8).

The closed question (qualities of the game) was analyzed by calculating the percentages obtained for each point on the Likert scale.

Regarding the positive aspects of the game, they indicated that “the best was playing in groups with my classmates” or “building the atom with the pieces”. Only a few negative aspects were mentioned, such as “the worst was having to wait for my turn”, which indicates their overall interest and implication in the game.

CONCLUSIONS

The results of this study suggest that the “Atomizados” game promotes the learning of atomic structure and enhances the

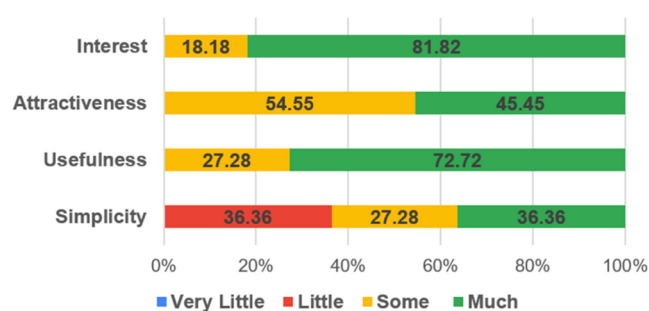


Figure 8. Aspects of the game appreciated by students.

understanding of constituent particles, ions, and isotopes among SDDL in the PMAR program (RQ1). 63.63% of the students achieved an informed level of understanding. The experimental group’s progress can be attributed to the generative learning strategy (Figure 1). The SDDL’s significant interest in the game, as evident in their perceptions, contributed to their improved understanding of the atom. This level of learning achieved presents statistically significant differences with respect to an SDDL control group that did not use the game (RQ2), the majority of whom reached only a naïve level.

No significant differences were found between the SDDL experimental and the two NSDDL groups, but differences were detected between the SDDL control and the two NSDDL groups, in favor of the last groups (RQ3).

Moreover, SDDL had a very positive perception of the influence of the game on chemistry learning, highlighting its attractiveness, interest, and potential for generating participation in the classroom as its most important aspects (RQ4).

However, research has certain limitations. One of these relates to the small size of the experimental group due to the specific characteristics of SDDL. Another limitation was finding control groups with a similar number of NSDDL in the same school for comparisons as these are not common in Spanish schools. However, this limitation was addressed during the COVID-19 pandemic when the number of students in other classes was reduced, resulting in an equal number of students in both the control and experimental groups.

The findings indicate that not starting with the latest models is not necessarily a drawback as they have helped to motivate SDDL, starting from simpler models and aiming to subsequently introduce the current complexities.

In the future, we plan to assess the effectiveness of “Atomizados” as a chemistry learning tool for NSDDL. Our intention is to introduce some improvements in this new implementation. These include using a three-color scheme for the particle type (proton, electron, neutron) to clearly distinguish the subatomic particles. Additionally, after the game, students will use a more realistic atomic scheme. Thus, the orbits in the Rutherford model will be replaced by orbital diagrams, which will help us understand the internal structure of the atom and the historical evolution of atomic models.

■ ASSOCIATED CONTENT

SI Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00614>.

Characteristics of the SDDL participants in the research, most relevant diagnosis and learning difficulties (PDF; DOCX)

Materials for the game: Atomic model scheme and subatomic particle pieces (PDF; DOCX)

Instructions and game sequence (PDF; DOCX)

Statistical analysis, frequency, and percentage of students who resolved the written test adequately by learning level (PDF; DOCX)

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Notes

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