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Design and Implementation of an Educational Game for Teaching Chemistry in Higher Education

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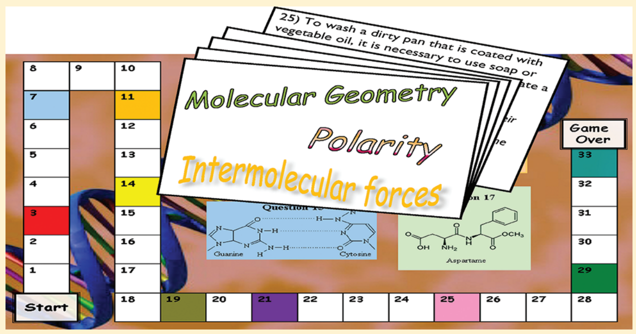
Supporting Information

ABSTRACT: New paradigms in education have led to a need for alternative methodologies in the higher education classroom. An educational game on molecular geometry, polarity, and intermolecular forces for engineering students in a general chemistry course was designed and implemented. The results showed that the game was effective in reconstructing students' knowledge, demonstrating that the games can serve as a useful pedagogical tool in higher education.



KEYWORDS: *First-Year Undergraduate/General, Physical Chemistry, Humor/Puzzles/Games, Noncovalent Interactions, Physical Properties, Student-Centered Learning*

Games are part of our everyday lives throughout the different stages of life (childhood, adolescence, and adulthood). The act of playing is an important process in human development and is vital to the individual's ability to assimilate reality.[1] Games are explicitly recreational, but they can also be of a pedagogical nature when their main objective is to stimulate significant learning.[2] The emotion, attention, and concentration involved in these activities can facilitate the construction of long-term memories, which are intimately linked to significant learning.

Games can be considered educational when they develop cognitive and operational abilities such as problem solving, perception, creativity, and reasoning, which are important for knowledge construction.[2,3] Cognitive skills are related to competence in discriminating between objects, events, or stimuli; identifying and classifying concepts; and applying rules and solving problems.[4] According to Antunes,[2] the operative abilities can be defined as aptitudes or cognitive capacities that enable the individual's understanding and intervention in social and cultural phenomena and that help to build relationships. The use of educational games in the classroom contributes to a more informal environment, facilitating students' experimentation and participation, making them active and cooperative individuals.[5−8]

The implementation of these types of pedagogical tools can even motivate the teacher because this type of activity transforms the teaching−learning process to being almost a recreational activity.[9] In this regard, games also contribute to changing the paradigm of the teacher's performance, encouraging them to broaden their knowledge in order to design the games, as well as to carry out their role as a facilitator in the most efficient way.[10,11]

The use of educational games, mainly for high school students, has frequently been reported in the literature. Russell[12] lists a series of games that can be prepared and utilized in general and organic chemistry classes. Denny et al.[13] suggest that the use of simple puzzles can stimulate students to interact with and enhance their interest in the content, such as the chemical elements of the periodic table. Crute[14] successfully implemented a game of bingo to teach organic chemistry (specifically, the nomenclature of alkanes) to make the practical class more entertaining and interesting. Pieroni et al.[5] also designed and implemented several types of educational games, such as dominoes, cards, word finds, and crossword puzzles, to facilitate students' learning of concepts related to organic chemistry. Soares et al.[15] proposed the use of polystyrene balls arranged in sets that exchange elements to address the concept of chemical equilibrium. These authors noted that better results were obtained when the students were not informed that the activity was associated with chemical equilibrium until the conceptual transposition.

Other examples include the work of Oliveira and Soares,[16] in which a jury was simulated to discuss chemistry concepts; Soares and Cavalheiro,[17] who used the game ludo to discuss concepts related to thermochemistry; and Roque,[18] in which theater was used as a recreational activity to teach students about the history of chemistry.

When teaching chemistry in higher education, however, the design and implementation of games to aid the teaching−learning process is still uncommon. This may be because this level of education in Brazil is still constrained by more traditional

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methods. Globally, however, didactic games in higher education courses have been implemented with some degree of success.[19] In the context of higher education, the main objective of games is to involve students in complex issues or problems that simulate real-world situations, without the undesirable limitations and risks of the real world. The students are challenged to develop representations of relevant knowledge as well as associations in reasoning and strategies for solving problems.

The current paradigms in education have created a need for new teaching and learning methods in the classroom.[20] According to Bazzo and Pereira,[21] engineers are experts in solving problems because they constantly deal with small quantities of information that must be transformed into a useful and well-organized solution. Confronted with this new perspective, a change in the paradigm becomes necessary in relation to new methodologies so that they can be implemented to higher education.

In this context, an educational game related to molecular geometry, polarity, and intermolecular forces was designed and implemented with engineering students in the general chemistry course. This informal activity was proposed as a way to review both conceptual and procedural content on the topics. The usefulness of this teaching tool for knowledge reconstruction in the field of chemistry in higher education was also evaluated. In constructivist and social interactionist approaches to education, reconstructing knowledge involves reviewing or reworking preconceptions through teacher−student and student−student interactions.[22] From this perspective, error has an educational function; when a student makes a mistake in answering a question in the game, he or she is encouraged to reevaluate the answer through hints or additional problematization proposed by the teacher or by the other students.

■ METHODOLOGY

The educational game was designed to fulfill the following criteria proposed by Gredler:[23]

- Winning the game should be more than a matter of luck. The student should win the game as a reward for his or her knowledge of the subject matter.
- The game must provide information relevant to the content; that is, it must show the student which aspects are most important for gaining knowledge, and it must address the subject under study.
- Dynamics of the game must be easy to understand, and the participants must find it interesting.
- Students must not lose points for giving incorrect answers; rather, they should be encouraged to reconstruct knowledge.
- The teacher must be aware that students who demonstrate good knowledge of the subject will not always win the game; thus, the game must be a beneficial exercise in which all students gain some knowledge and content-related skills.

Gredler[23] affirms that a game must take into account educational requirements, redefine previously constructed knowledge, identify failings in the teaching−learning process, carry out content revision, or develop new relationships between the concepts studied. The questions constructed for the game included different cognitive levels, such as knowledge, comprehension, application, and evaluation, based on Bloom's taxonomy.[24,25] Most of the questions aimed to provide an understanding of the relationships between the concepts of molecular geometry, polarity, and intermolecular forces because most students do not realize that these subjects are interrelated.

The game was implemented in a general chemistry class. This class, called class 1, consisted of 19 students, with a vast majority of engineering students.[26] To validate the game as a teaching tool, a class of 29 students was selected, called class 2, also composed mainly of engineering students[27] who were enrolled in the general chemistry course in the same semester as class 1. However, the students in class 2 did not participate in the activity. Prior to the implementation of the game, the subjects of intermolecular forces, polarity, and molecular geometry were presented in a dialogue-type of lecture. The concepts and some examples were discussed with the active participation of students. This methodology was also applied to class 2, in which the game was not implemented. Class 1 was divided into five groups, each with four members. Each group was given a die, 4 playing pieces, the game board (Figure 1), and 27 cards with questions related to molecular geometry, polarity, and intermolecular forces (Figure 2). This subject was chosen because students in previous semesters and classes performed poorly on evaluations.

To play this game, the procedures were similar to those of many other board games:

- All players initially position their playing pieces on the square labeled Start.
- One at a time, each player throws the die and advances the number of squares indicated on it.
- If the player stops on a colored square (represented by the numbers 3, 7, 11, 14, 19, 21, 25, 29, and 33 in Figure 1), the next player (in a clockwise direction) chooses one of the cards (questions) and poses the question to the player who stopped on the colored square. If the player answers correctly, he or she advances the number of squares stated on the card. If the player's answer is incorrect, the student goes back or misses a turn, depending on the directive on the card.
- The player who arrives first at the square labeled Game Over and who gave the highest number of correct answers wins the game.

After the implementation of the game, students were evaluated through a descriptive test that included questions at the cognitive levels that were developed in the game. The validation of the game was performed by comparing the scores obtained by class 1 with those obtained by class 2, who were evaluated with the same descriptive test but did not play the game.

■ RESULTS AND DISCUSSION

The students liked the implementation of the game as suggested by the teacher. An important observation during the game related to the discussions that occurred with each answer. More important than the correct answers to the questions were students' doubts and queries that arose with each question. In their view, in addition to being a novel activity, the game led to greater interaction between classmates.[28] Some students manifested their approval with statements such as, "Thank you for finding a new methodology and for the interaction with the class. The idea is very valid." Another student commented, "It was very good because we could discuss our doubts with members of the group." These statements indicate the importance given by the students to the game as an instructional tool and

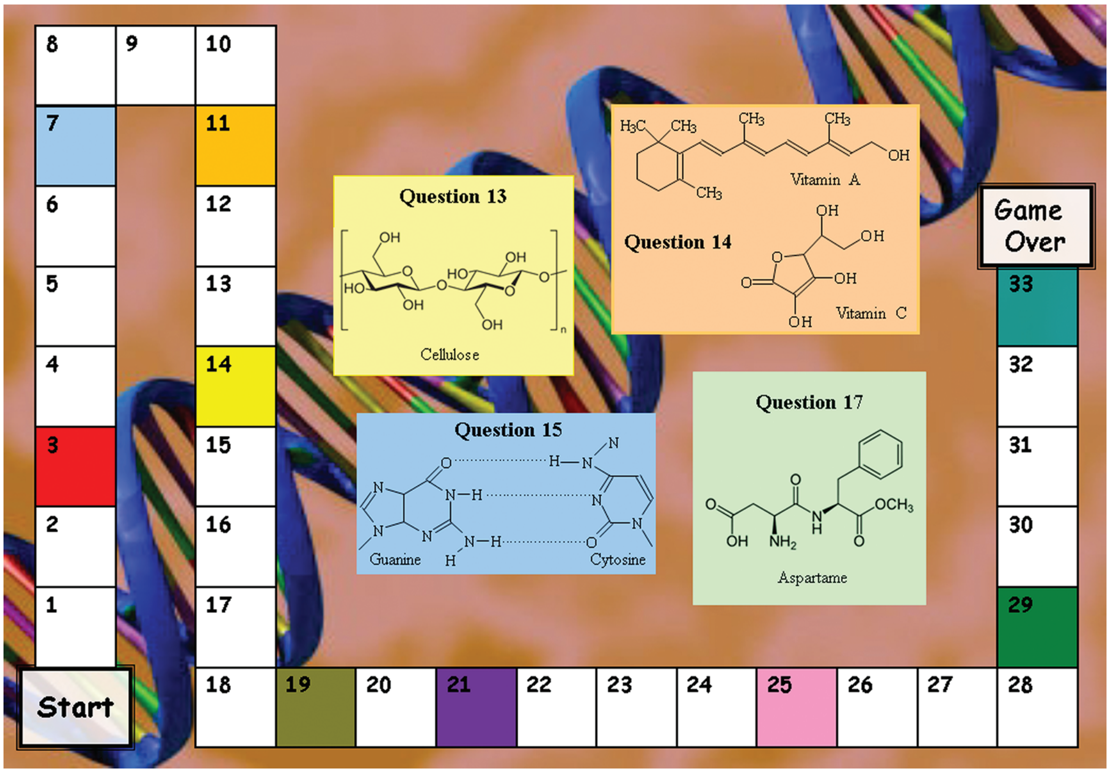

Figure 1. Board game on molecular geometry, polarity, and intermolecular forces.

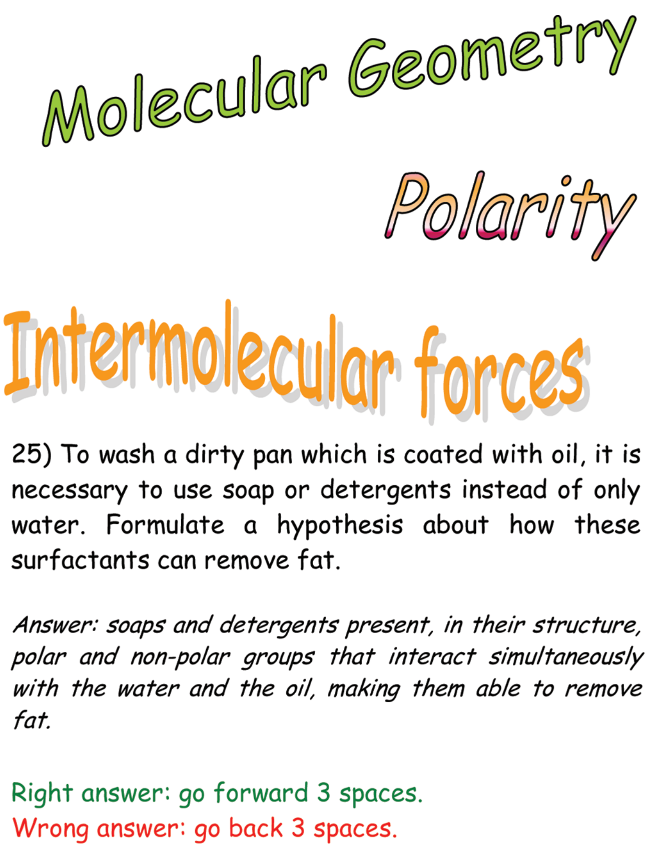

Figure 2. Example of a card used in the game (front and back, respectively).

the results of the game in terms of the discussions and learning of the subjects proposed.

During the week after the game was implemented, an evaluation was conducted on the content, including contextualized questions that were posed in the game. The results were interpreted by comparing the test scores of class 1, in which the educational game was implemented, with the test scores of class 2, which did not participate in the educational game but was administered the same evaluation (Figure 3).

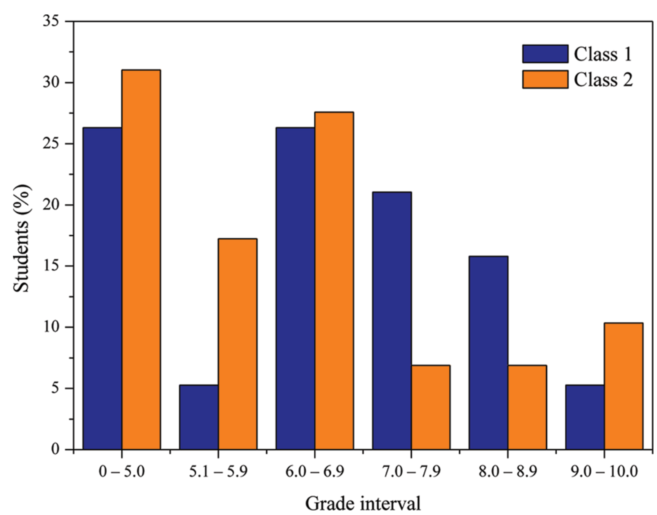

Figure 3. Percentage of students per grade interval.

Twenty-six percent of the students in class 1 obtained a score lower than 5.0 (i.e., achieving less than 50% of the goals of the evaluation), compared to 31% for class 2. Evaluating the performance in terms of a passing grade, that is, a mean score greater than or equal to 6.0, 68% of students in class 1 achieved more than 60% of the proposed objectives, compared with 52%

of students in class 2. In addition, the percentage of students achieving between 70% and 90% of the objectives proposed in the class was higher for the class in which the game was applied (34% and 14% for classes 1 and 2, respectively). These results indicated that, as a teaching tool, the game may have contributed to the better performance of the students in class 1 compared with the students in class 2.

Of greater importance than the grades obtained in the evaluation was the performance of the students in developing discussions related to the questions and, consequently, the reconstruction of knowledge. Participation in the game led to rich discussions between classmates and with the teacher, prompting the students to raise new questions on the subjects, demonstrating their enhanced interest in learning.

The design and implementation of the game as an educational tool also assisted in the development of the teacher's skills,[29] and these abilities affected the way in which the teacher conducted the classes and facilitated student learning. Skills developed by the teacher were related to the following areas:

- the organization and direction of teaching situations as well as the administration of the students' progress, especially with regard to the appreciation of students' errors as tools for the reconstruction of knowledge;
- the development of cooperation between students and simple forms of mutual teaching as students helped each other with questions related to the game;
- enhancing students' engagement in their learning and their work to improve their desire to learn from the game;
- teamwork, because the educational game was not developed and implemented by a single teacher; and
- self-enhancement in the teacher's own training by participating in the design and implementation of the educational tool through study and research on improving teaching practices to provide more meaningful learning for students.

CONCLUSIONS

It can be concluded that the board game, in the form in which it was designed and implemented, was effective in the reconstruction of the students' knowledge. The statements of the students indicated that the game encouraged and aided construction of the concepts proposed. It was also noted that the results of the evaluation were positive because the majority of the students achieved the proposed objectives.

These findings demonstrate that games in higher education can represent a useful pedagogical tool to aid students in the learning process. The development and implementation of this type of pedagogical activity also enabled the teacher to develop the required competencies for a 21st century paradigm of education.

ASSOCIATED CONTENT

Supporting Information

Cards used in the game. This material is available via the Internet at http://pubs.acs.org.

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(27) The student composition in class 2 was 9 from the mechanical engineering major, 7 from the environmental engineering major, 5 from the chemical engineering major, 3 from the control engineering and automation major, 1 from the production engineering major, 1

from the biological sciences major, 1 from the food engineering major, 1 from the degree in teacher chemistry education major, and 1 from the materials engineering major.

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