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STR120: A Web-Based Board Game for Aiding Students in Review of the Structural Theory of Organic Compounds

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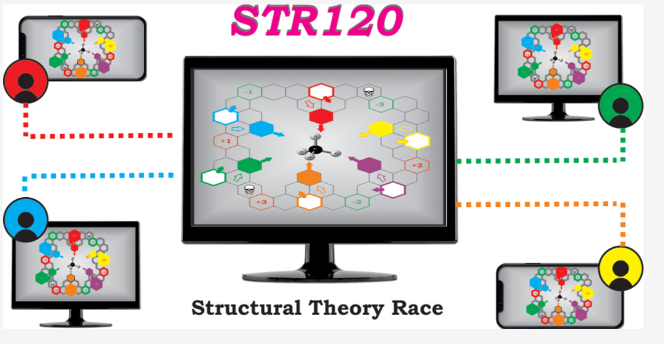

ABSTRACT: This paper provides information about a multilingual (Portuguese, English, Spanish, Italian, and French) virtual card game for computers and smartphones. Facing the disruption caused by the Covid-19 pandemic, this game allows students to play remotely or face-to-face with friends in a fun and cooperative environment and review the topics related to the structural theory of organic compounds simultaneously. Brazilian and Italian undergraduate students played and evaluated the game positively. Also, learning assessments revealed that the game promotes learning equivalent to the traditional solving-problem classes. Therefore, the game is a playful alternative method to the conventional educational strategies for reviewing the content related to the structural theory of organic compounds in a fun way in a collaborative environment in which the students discuss the answer to each question.

KEYWORDS: *First-Year Undergraduate/General, Organic Chemistry, Computer-Based Learning, Humor/Puzzles/Games, Molecular Properties/Structure*

■ INTRODUCTION

In 1972, the Organic Subcommittee developed an outline of topics that defined "standard" two-semester organic chemistry course content. The course should begin with some issues related to the structural theory of organic compounds, such as the chemical bond and the geometry of molecules, the electronic structure of organic molecules, resonance, and molecular orbital theory.[1] Usually, introductory organic courses teach the structural theory of organic compounds as the beginning chapter because mastering the structural theory of organic compounds is crucial to understand various other contents, such as intermolecular forces, organic acids and bases, and organic reactions.

Many studies have reported that learners consider the structural theory complex and abstract due to understanding macroscopic observations based on the microscopic world of molecules.[2−17] These students' difficulties have motivated the educators to develop innovative teaching approaches like game-based learning tools to help them overcome their challenges in learning topics related to the structural theory of organic compounds.[18−28]

However, educators must remember that today's students have changed radically. They are no longer the people our educational system was designed to teach in the past. The arrival and rapid dissemination of digital technologies in the last decades of the 20th century make today's students—Digital Natives—think and process information fundamentally differently from their predecessors. These differences go far further and more profound than most educators suspect or realize.[29] Therefore, we need to learn to communicate in the language and style of students and reconsider our methodology and content.

A good way can be adapting materials to the language of Digital Natives, as using games for reviewing content taught in the classroom instead of the traditional problem-solving class seems to be a good method. For example, games are excellent educational tools that allow students to learn complex content in fun activities, promoting cooperation between students and the consequent collective learning. Educational games can be exceptional learning methods because they attract students to participate continuously in activities.[30,31] After all, they can motivate and engage students by promoting interaction and

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were evaluated positively in learning and enrichment of socialization and collaboration.[32]

In the past several years, researchers have increasingly developed and used games at all levels, from high school to university (Table S2, Supporting Information). They have published ninety-three papers on educational games and their positive impacts on students' learning in many areas of chemistry. However, only 15 of them focus on a few topics related to structural theory or intermolecular forces.[33−47] Only the *Time Bomb Game* covers all subjects, but it is an application not focused on promoting students' interaction.[33]

Thus, this lack of virtual card games that specifically address the content related to the structural theory of organic compounds motivated us to design *STR120*. It is a game that allows students to review the content taught in the classroom while playing remotely in an activity that could bring them together, driving them to discuss and learn playfully.

■ THE GAME

STR120, *Structural Theory Race*, is a multilingual (Portuguese, English, Spanish, and French), free-of-charge, dynamic, and easy-to-play game that allows students to review concepts related to the structural theory of organic compounds in a fun, virtual, and collaborative environment (Figure 1). Participants can play it remotely or face-to-face using personal computers, notebooks, tablets, or smartphones.

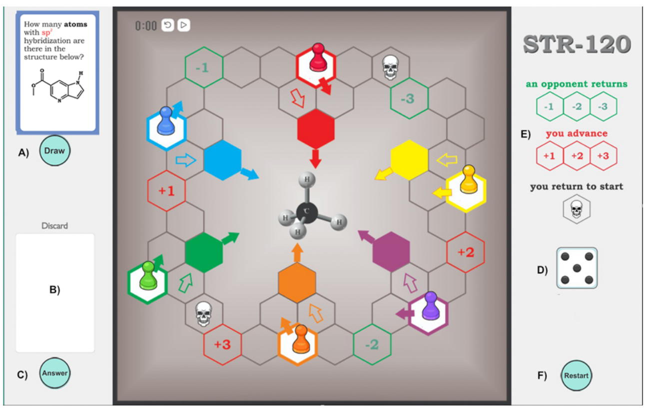

Figure 1. Game screen.

The game was developed using the *Playingcards* platform,[48] and the game comprises one board, six players' pieces, one die, and 120 cards. The cards show statements on their front. On their back, the cards present the answers and a short explanation (Figure 2). The questions cover topics related to the structural theory of organic compounds, such as hybridization, covalent bond, geometry, formal charge, intermolecular forces, inductive effect, resonance, and aromaticity.

Playing the Game Remotely—Rules

(1) To start the game, a player must click on the "Draw" button (Figure 1A) to draw a card and move it to the discard pile (Figure 1B). Position the cursor over the card (PC) or press the screen with your finger (smartphone) to enlarge the card.

(2) Afterward, they answer the question and click on the "Answer" button (Figure 1C) to flip the card and reveal the correct answer.

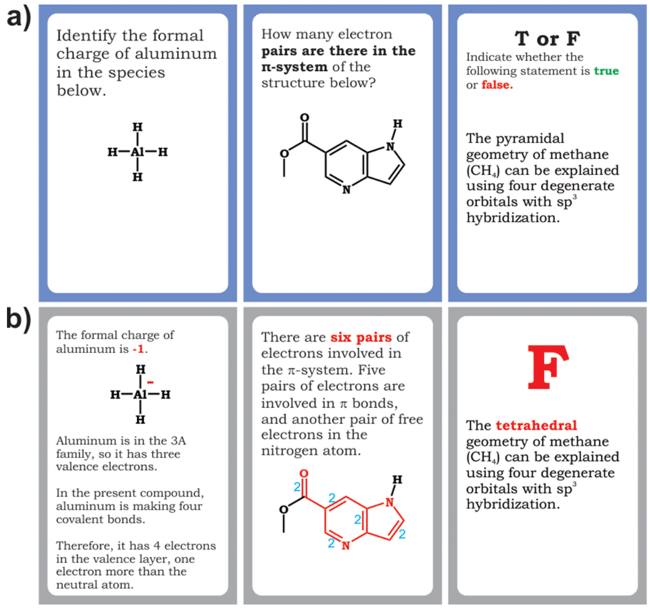

Figure 2. Examples of cards: (a) front and (b) back.

(3) If the player has responded correctly, they click on the die (Figure 1D) to define the number of spaces that will move their piece on the track, where there are seven special spaces that define different pieces' movements on the board. The movement of players' pieces is not automated, and therefore, players must similarly move their pieces like they do when playing a physical board game.

(4) On the board, there are six special spaces (Figure 1E). If the player's piece stops at one of these spaces, the player must move their piece or the opponent's piece according to the commands below and pass the turn to the next player.
- −1: an opponent's piece returns one space.
- −2: an opponent's piece returns two spaces.
- −3: an opponent's piece returns three spaces.
- +1: a player's piece advances one space.
- +2: a player's piece advances two spaces.
- +3: a player's piece advances three spaces.
- Skull image: player's piece returns to the start position.

(5) The next player follows the steps described above. The game follows this dynamic until the first player walks the entire track (33 spaces) and reaches the center of the board.

(6) To restart the game, the player must click on the "Restart" button (Figure 1F).

Players can play the game in public or private rooms by following the instructions below. Twenty groups in Brazil and another ten groups in Italy played the game and evaluated the educational possibilities of using the game. They spent 63 min on average per match.

Accessing Public Rooms

To make playing more accessible, we created one room for each language, through which users can access them directly (Table 1). However, it is crucial to keep in mind that other users may also access the same room. Then, we recommend groups create private rooms to play.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 1. Direct Links to Access the Games in Public Rooms

Language	Link
English	https://playingcards.io/bxrvcy
Portuguese	https://playingcards.io/ezjgqa
Spanish	https://playingcards.io/mdde5s
French	https://playingcards.io/5akx6r
Italian	https://playingcards.io/va2y9m

Setting to Play—Private Rooms

To create private rooms, players must observe the following instructions:

(1) Download the game from the links available (Table 2) to a folder on your computer.

Table 2. Direct Links to Download the Games

Language	Link
English	https://tinyurl.com/yckv4sp4
Portuguese	https://tinyurl.com/3pvhwhhv
Spanish	https://tinyurl.com/twku55t8
French	https://tinyurl.com/538xz8ps
Italian	https://tinyurl.com/25ec6vz6

(2) Access the address https://playingcards.io/import.

(3) Drop the .pcio file previously downloaded to your computer on the gray field, or click on the button below the gray field to select the .pcio file from your computer.

(4) In both cases above, wait for the uploading of the file. That can take a few minutes.

(5) When the .pcio file is uploaded completely, a pop-up comes up with the "Enter" button.

(6) Then copy the Share Room Code—the code on the white field on the top of the pop-up. This code must be shared with the students who will play together in that room: https://playingcards.io/code.

(7) After, click on the "Enter" button on the pop-up. After that, the game is ready to go.

(8) Finally, the students will need to use a communication platform (WhatsApp, Zoom, Google Meet, Microsoft Teams, etc.) to maintain a conversation during the matches.

■ ASSESSMENT OF LEARNING IN BRAZIL

Additional General Information

Although there were many organic chemistry classes in our department, we chose two classes with the same professor. Thus, we can compare the results of the exams because the professor was not a variable in the study.

We randomly chose the classes that would be the experimental and control groups; i.e., we did not select the classes based on any personal reason or preference to validate the method.

The participants in the study in Brazil were second-semester undergraduate students from the Federal University of Ceará. All were 18−19 years old and were enrolled in the Introductory Organic Chemistry Course for the first time.

Before the meeting online with the professor, the students from both groups watched two video classes at home when they wanted to. The videos covered topics related to the structural theory of organic compounds, such as hybridization, covalent bonds, geometry, formal charge, intermolecular forces, inductive effect, resonance, and aromaticity.

The methodology used to assess learning took 4 weeks—two classes per week, and all classes had a 100 min duration.

An online problem-solving class (Figures 3 and 4) is a class where the students, in small groups, solve problems from the

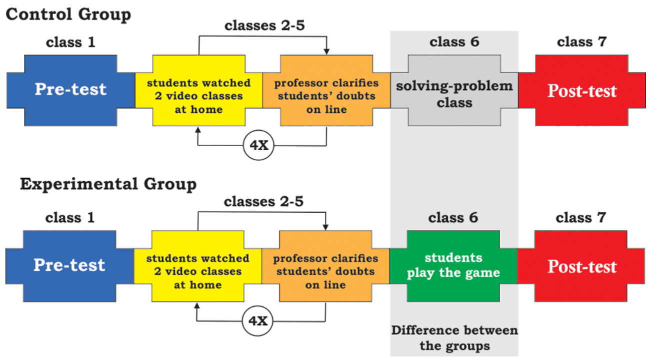

Figure 3. Methodology used in Brazil to assess the instructional role of the game.

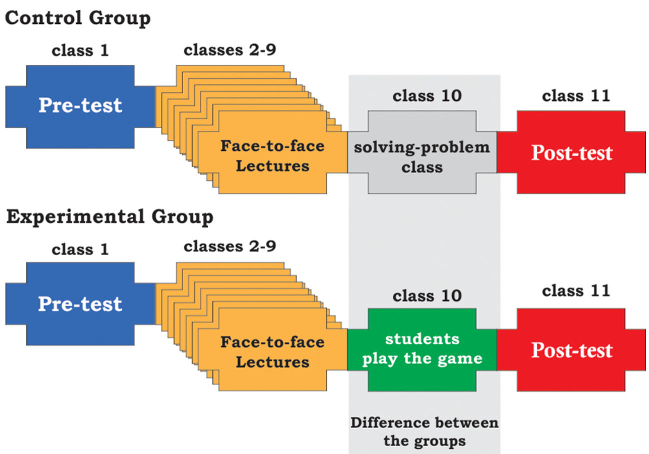

Figure 4. Methodology used in Italy to assess the instructional role of the game.

textbook. The number of exercises varied for each group. The limiting factor was the time (100 min). Therefore, each group solved the maximum number of exercises in that time. The problems solved were those present in the textbook Organic Chemistry, by David Klein.[49]

Pre-Test and Post-Test

The assessment of learning in Brazil was an experimental study conducted with controlled pre-tests and post-tests with 25 multiple-choice questions, which analyzed the effect of the instructional role of the game on the learning of the structural theory of organic compounds at the college level. Both tests had a duration of 100 min.

In Brazil, we randomly chose one class composed of 21 s-year Pharmacy undergraduate students (12 males and nine females) to be the experimental group (EG), whose students played the game as a strategy to review the content discussed in the classroom. On the other hand, we chose another class composed of 20 s-year Pharmacy undergraduate students (12 males and eight females) to be the control group (CG), whose students took a traditional problem-solving class. All the students were from the Federal University of Ceará in Brazil.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 3. Comparison of Brazilian Student Performance Relative to the Participation in the Game versus Participation in the Problem-Solving Class

	Students' Average Scores[a]					
	Pre-Test[b]		Post-Test[c]		Average Score Differences[d]	
Group (N)	Game	Problem-Solving	Game	Problem-Solving	Game	Problem-Solving
Experimental (21)	0.2 ± 0.4		4.9 ± 1.7		4.7[b]	
Control (20)		0.2 ± 0.4		5.0 ± 1.6		4.8[c]

[a]The scores have a range of 0−10. [b]p = 0.9315. [c]p = 0.9297. [d]p = 0.9461.

The study proposed to test the following question: is there any difference between learning of structural theory of organic compounds between the experimental and the control groups?

Initially, a pre-test was administered to the two groups (control and experimental) before any lecture about the structural theory of organic compounds. This test aimed to verify the students' knowledge about the subject.

After, all students from both groups watched two video lectures that covered the topics related to the structural theory of organic compounds at home. They clarified their doubts with an online meeting with the professor for 100 min. This sequence took place four times.

To review the content presented in the video lectures and discussed with the professor, the experimental group played the game in class 6. In contrast, the control group partook in an online problem-solving class in which the students, in small groups, solved problems from the textbook.

Finally, a post-test was administered to all students from both groups. Figure 3 illustrates the methodology used to assess the instructional role of the game in Brazil.

Statistical Analysis

To assess the instructional role of the game, we compared the students' average score differences between the pre-test and the post-test (Table 3).

The findings showed that the game promoted similar learning to the traditional solving-problem class. There was no statistically significant difference in students' average scores between the control and experimental groups. However, all twenty-one students who played the game (EG) provided verbal feedback saying they preferred to play it instead of participating in conventional problem-solving. In comparison, 20 students who participated in the problem-solving activity (CG) said they would like to play the game.

■ ASSESSMENT OF LEARNING IN ITALY

The assessment of learning in Italy also was an experimental study conducted with controlled pre-tests and post-tests with the same 25 multiple-choice questions each. Both tests had a duration of 100 min. The experiment also analyzed the effect of the instructional role of the game on the learning of the structural theory of organic compounds at the college level in Italy.

However, it is important to highlight that the experiment was carried out at different times in the two countries. In Brazil, the study was carried out during the Covid-19 pandemic, while in Italy, the study was carried out after the return of face-to-face activities.

Pre-Test and Post-Test

In Italy, the study was conducted with a class composed of 86 first-year Biotechnology undergraduate students from the Università Degli Studi di Genova. All were 19−20 years old and were enrolled in the Introductory Organic Chemistry Course for the first time. All students attended an Introductory Inorganic Chemistry Course in the first semester, where some general issues related to the structural theory of matter were already introduced. The same pre-test used with Brazilian students was administered to the class before any lecture about the structural theory of organic compounds. This test aimed to verify the students' knowledge about the subject, which was partially covered by the Inorganic Chemistry course previously attended by the students.

Shortly after the pre-test, the class was divided into two homogeneous groups (experimental and control), i.e., groups that were heterogeneous within but homogeneous among themselves, and therefore comparable. To do this, a kick-off questionnaire was administered in which information was collected regarding (a) learning, such as the school of origin, the grade achieved in the inorganic chemistry exam, and the average grade in the exams passed; (b) sociocultural aspects, such as the city/region of origin or participation in extracurricular activities; and (c) soft skills, such as possessing language/computer certifications or participating in cooperative experiences. The information collected was used as conflict variables in Grumbler's algorithm (https://scholar.harvard.edu/msparrow/grumbler), and through the web app Team Metrics (https://www.edutainmentformula.com/web-app/team-metrics/) the two groups were generated. After that, the experimental group (EG) had 42 students (16 males and 26 females), and the control group (CG) had 44 students (13 males and 31 females).

The class followed the lessons related to the structural theory of matter that, being transversal to different topics ranging from hybridization of carbon atom to aromaticity, lasted a total of 16 h (eight 2 h classes, three times a week). At the end of this period, the class was divided into the two previously created groups, in which the EG participated in the STR-120 game, while the CG participated in a traditional problem-solving class. Both activities lasted 2 h and were supervised by the same instructors. The traditional problem-solving class was based on the textbook Organic Chemistry, by David Klein[49] (same as Brazil). Finally, all the students participated in the post-test (also same as Brazil), consisting of 25 multiple choice questions similar, but not equal, to the ones used in the pre-test.

Figure 4 illustrates the methodology used to assess the instructional role of the game in Italy, and like in Brazil, the study proposed to test the following question: is there any difference between learning of structural theory of organic compounds between the experimental and the control groups?

Statistical Analysis

Again, to assess the instructional role of the game, the student's average score differences were compared between the pre-test and the post-test (Table 4).

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 4. Comparison of Italian Student Performance Relative to the Participation in the Game versus Participation in the Problem-Solving Class

	Students' Average Scores[a]					
	Pre-Test[b]		Post-Test[c]		Average Score Differences[d]	
Group (N)	Game	Problem-Solving	Game	Problem-Solving	Game	Problem-Solving
Experimental (42)	5.7 ± 1.0[a]		6.3 ± 1.2[c]		0.6[b]	
Control (44)		5.7 ± 1.2[b]		5.9 ± 1.3[d]		0.2[c]

[a]The scores have a range of 0−10. [b]p = 0.9476. [c]p = 0.2290. [d]p = 0.2316.

We observed that the Italian students had better performances in the pre-test than the Brazilian students. We already expected the better Italian students' performances in the pre-test because they had partially seen the content covered in the game in another course in the previous semester.

Again, there was no statistically significant difference between the students' average scores in the control and experimental groups. Thus, the findings showed that the game promoted learning similar to a traditional solving-problem class.

■ EVALUATION OF THE GAME—STUDENTS' OPINIONS

According to Mark Rosewater,[50] all games should have certain aspects to attract the players. The author summarized these aspects into ten categories: goal, rules, interaction, catch-up feature, inertia, surprise, strategy, flavor, hook, and fun. Then, 60 undergraduate students from the Federal University of Ceará (in Brazil) and sixty-two undergraduate students from the Università Degli Studi di Genova (in Italy) played and evaluated the game. All students were enrolled in Organic Chemistry courses at their universities and attended lectures covering the same content covered in the game before playing the game.

Afterward, they evaluated if the game had entertainment and educational aspects by responding to two electronic surveys containing ten statements, adopting a Likert-type scale[51] (Figures 5 and 6). In addition, the students also rated the game (by attributing a score from 0 to 10), evaluating it as an educational tool for reviewing the topics related to the structural theory of organic compounds.

It is important to mention that 19 other Brazilian Dentistry undergraduate students tested the game and evaluated it. However, they did not participate in the assessment of learning described above because they had another professor. This fact may result in a methodological failure.

Based on the students' high level of agreement (totally agree and agree) with the statements provided, we can affirm that the STR120 possesses all aspects to attract the players. We also believe the game is an exciting tool that allows students to review the contents related to the structural theory of organic chemistry in a fun way.

Regarding the game rating, the average rating from Brazilian students was 9.3 ± 0.9, and that from Italian students was 8.0 ± 1.1. These high scores show that the Brazilian and Italian students approved the game as an educational tool for reviewing the topics related to the structural theory of organic compounds.

Finally, the students also commented on their experiences of using the game remotely, which, in general, was very positive for their learning. Below, there are three of these comments (translated into English by the authors):

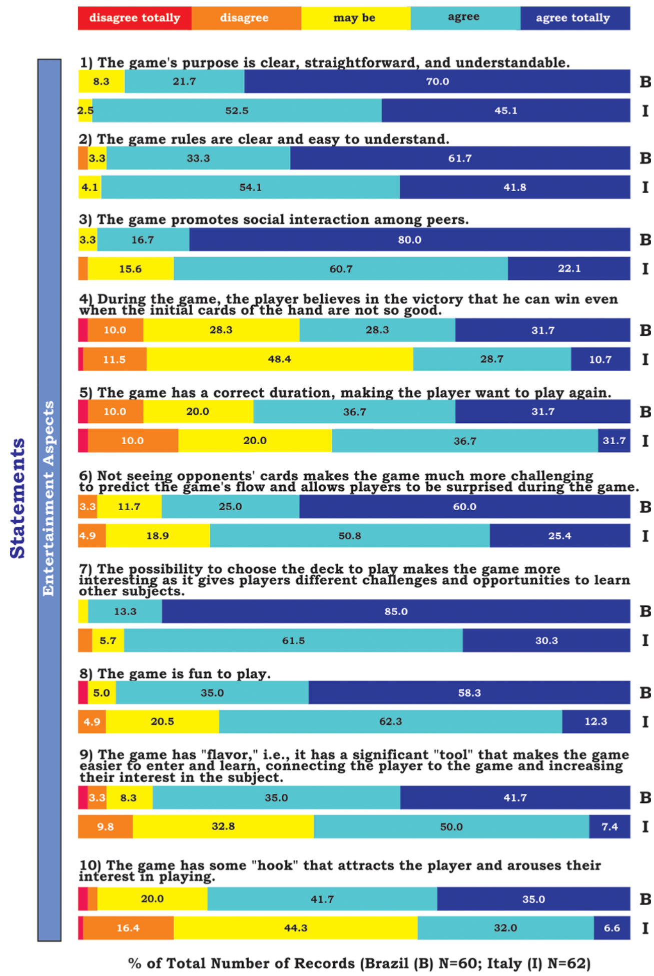

Figure 5. Entertainment aspects—distribution of students' responses to survey statements after playing the STR120 game [N = 60 Brazilian students (B); N = 62 Italian students (I)]. The percentages represent students' responses on a five-point Likert-type scale that ranges from "disagree totally" to "agree totally".

> *"Easy rules, direct questions, promotes interaction between students, indicates mistakes and successes instantly, dynamic learning process."*
>
> *"It is easy to learn, reviews topics covered in class, makes the student want to play again, gathers and entertains colleagues. Best game, for that matter."*
>
> *"In a distance education scenario, it is fundamental for interaction and promoting interaction between students. In addition, it is possible to learn and ask questions from fellow gamers. It is fantastic!"*

Although almost all the comments have been positive, some students left suggestions to improve the game. Some of these comments are below.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

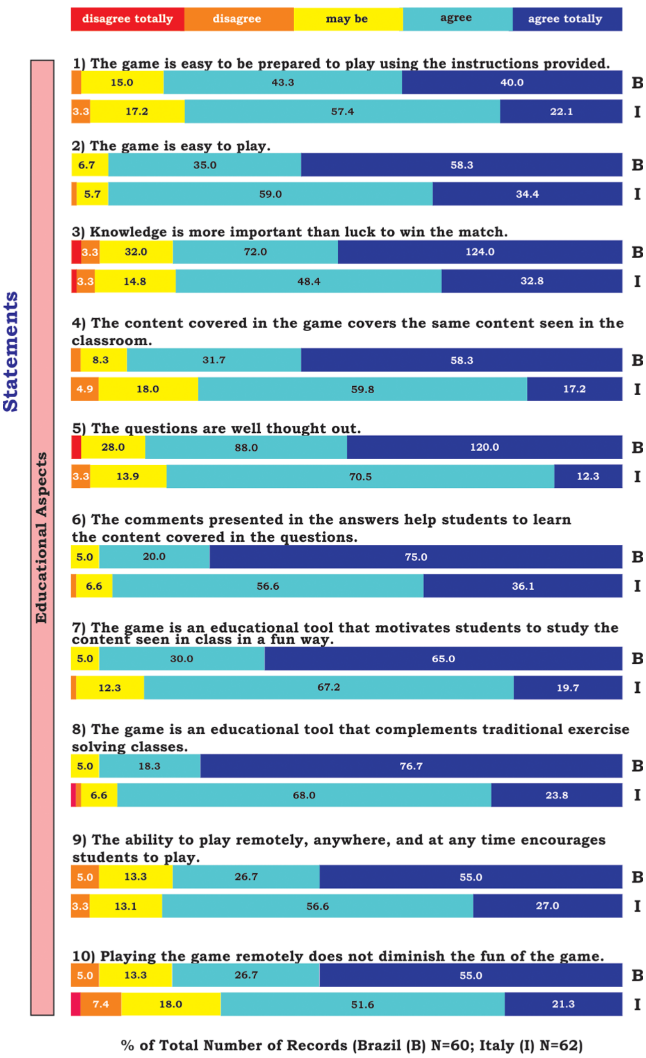

Figure 6. Educational aspects—distribution of students' responses to survey statements after playing the STR120 game [N = 60 Brazilian students (B); N = 62 Italian students (I)]. The percentages represent students' responses on a five-point Likert-type scale that ranges from "disagree totally" to "agree totally".

"I do not believe it has any significance, maybe relying on luck to win. But I think more important than winning is reviewing the content more nicely and that the game fulfills."
"The surprise factor contributes to the fun, but it is a little unfair because luck defines a little more who's the winner at the end than knowledge of it, but I think it is pretty cool about that. Also, expanding the number of players could be a game improvement option."
"The skulls are not very nice, especially for the green and yellow, which are the most harmed as they can fall into it when they are very close to winning."

FINAL CONSIDERATIONS AND FUTURE WORK

Some educators were not born into the digital world but have become fascinated by and adopted many or most aspects of the new technology—Digital Immigrants. Usually, the educator always retains, to some degree, their foot in the past and resists changes. Consequently, Digital Immigrant instructors speak an outdated language and struggle to teach a population that speaks an entirely new language. Therefore, we need to learn to communicate in the language and style of students and reconsider our methodology and content. Educational games are excellent tools that can aid Digital Immigrants instructors in communicating themselves with today's students and allow them to learn complex content in fun activities, promoting cooperation between students and the consequent collective learning.

Our previous experience in designing and implementing educational games allows us to claim that educational games speak today's students' language. STR120 presented in this paper is another example. It is a good alternative to traditional problem-solving for reviewing content related to the structural theory of organic compounds classes. Based on the evaluation of students and the findings of the assessment of learning, the STR120 can contribute to Digital Immigrants communicating better with their Digital Native students.

Although the students' learning benefits are equivalent to those obtained from a conventional problem-solving class, the game provides students with an alternative way to review the content covered in the game. In addition, the playfulness of the game allows students to review content in a fun way in a collaborative environment in which students discuss each of the questions answered.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00389.

Tutor guide to create private rooms, surveys, and pre- and post-tests (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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J. Chem. Educ. XXXX, XXX, XXX−XXX