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Time Bomb Game: Design, Implementation, and Evaluation of a Fun and Challenging Game Reviewing the Structural Theory of Organic Compounds

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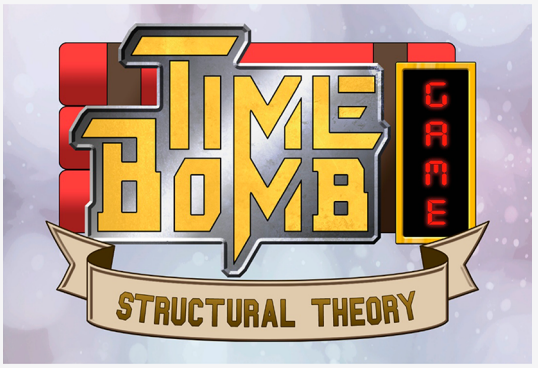
Supporting Information

ABSTRACT: This report provides information about a free-of-charge, trilingual (Portuguese, Spanish, and English) game-based application that engages high school and undergraduate students in reviewing the structural theory of organic compounds in a challenging way. In Time Bomb Game, students must disarm a time bomb on their own by correctly answering random questions from a database with 621 questions. Students and professors have tested and evaluated the app, and the results revealed that the game design, content, playability, and usefulness are helpful as a complementary didactic tool to provide students with the required theoretical knowledge.



KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Organic Chemistry, Humor/Puzzles/Games, Molecular Properties/Structure*

INTRODUCTION

In the late 19th and early 20th centuries, significant discoveries about the nature of atoms placed theories of molecular structure and bonding on a more secure foundation, which provided the conceptual basis for the structural theory of matter by suggesting that substances are defined by a specific arrangement of atoms.[1−6]

Mastery of the structure of organic compounds is crucial to understand as the organic molecules interact and react to each other. For this reason, usually, introductory organic courses teach the structural theory of organic compounds as a beginning chapter.[7]

Unfortunately, this subject is considered by many students as one of the most challenging subjects, having abstract concepts that may be challenging to grasp, and often involving learning activities that require ingenuity and higher problem-solving skills. However, regardless of how students view the abstractness of the subject, they are compelled to take it because it is a part of the curriculum and is considered a major topic.[8]

As chemistry educators, it is important to recognize these difficulties and to use different teaching strategies to enhance the students' learning experience in the classroom, as well as to provide viable and relevant resources for self-directed study. One such approach includes integrating smartphones and mobile apps into the course curriculum and classroom instruction.[9,10]

The present generation of students is adopting smartphones and appears to be using them regularly because these devices are multifunctional computers serving as video players, game systems, browsers, music players, and navigation systems, and they have many valuable capabilities that have tremendous potential for use in chemical education.[11−15]

There are hundreds of applications that can be downloaded at no charge, or purchased for just a few dollars, but there is no free app in a game format that is able to cover the structural theory of organic compounds in Portuguese, English, and Spanish languages.

In past years, we have focused our research on the design of computer games that have been engaging students in reviewing different chemical concepts[16−20] more recently in game-based applications.[16,17] The student satisfaction and the findings of the assessment of the learning motived us to design a new game-based app for helping students review the structural theory of organic compounds in a challenging and fun way.

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PLAYING THE GAME

We developed a game-based application named Time Bomb Game for Android[21] and IOS[21] devices using the Unity Platform.[22] It is a trilingual (Portuguese, English, and Spanish), free-of-charge, dynamic, and easy-to-play game that allows students to review the structural theory of organic chemistry. We designed the game so that students win the game when they disarm a time bomb with their knowledge and not as a matter of luck.

To begin, the player clicks on the biggest button located at the center of the main screen (Figure 1a). From the main screen, it is also possible to check the ranking of the players (Gallery of Heroes), to change the game settings, or to read the game rules. When play is initiated, two screens sequentially appear to set up the game parameters by selecting the selected groups of topics (Figure 1b) that determine the subjects of the questions that appear during the game and choose one of three possible game modes, which determine the difficulty of the game (Figure 1c).

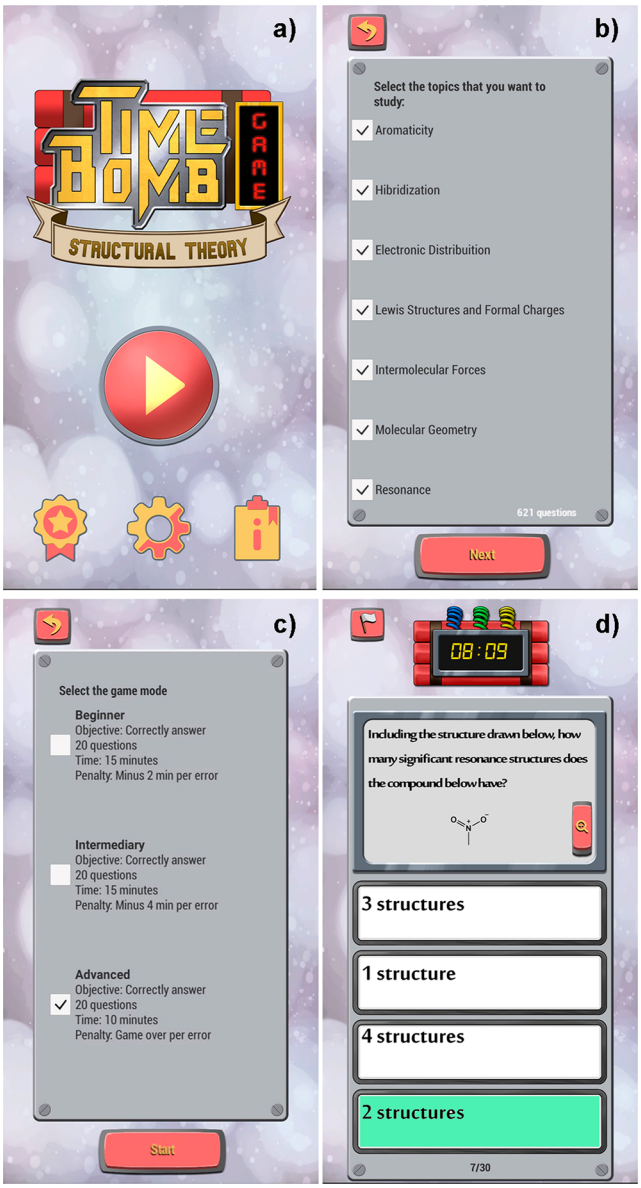

Figure 1. (a) Main screen of the game where a player can (b) select topics of interest, (c) select a game mode, and (d) answer a question.

In all modes, the player must correctly answer 20 multiple-choice questions to disarm the time bomb. However, each mode has a level of difficulty. In the beginner and intermediate modes, the player has 15 min to disarm the bomb, and the time available to complete the mission is reduced by 2 and 4 min, respectively, every time the player answers incorrectly. In the third mode (advanced), the player must disarm the bomb in 10 min with no incorrect answers.

When the player responds correctly (Figure 1d), a new question appears on the screen, and the number of correct answers is summed up on the bottom of the screen. If an incorrect answer is selected, the game indicates that the chosen alternative is wrong by making it red. The time is reduced, and a new question appears on the screen.

When the mission is completed, the player wins, and a game-over screen appears in which they can check the total number of questions answered on each topic along with the number of hits. Players can share scores on various social media platforms by clicking on the button on the top right of the screen (Figure 2a). In addition, players can register their data in a "Gallery of Heroes" by clicking on the "Heroes" button (Figure 2a), or even to check all answered questions (Figure 2b) by clicking on the "Feedback" button (Figure 2a), which will present all answered questions with the correct alternative highlighted in green. After that, for each question, the player can access a short comment (Figure 2c) to know why the alternative indicated as correct is the correct one by clicking on the Question Mark (?) button located at the bottom of the Figure 2b.

On the other hand, when a player fails to disarm the time bomb, the application simulates an explosion through a sound, and an image that resembles a cracked screen appears (Figure 2d). From this screen, players have the same postgame action options described above, except they cannot register their data in the Heroes Gallery.

EVALUATORS' OPINIONS

Student evaluators of the Time Bomb Game included 203 undergraduate students of Introductory Organic Chemistry (U) from six different courses (Agronomy, Food Engineering, Fishery Engineering, Chemical Engineering, Pharmacy, Dentistry, and Zootechnics) from our university, and 76 high school students (H). A total of 35 chemistry professors (P) tested and evaluated the Time Bomb Game; these included 7 professors from our own university and 28 professors from other Brazilian universities.

All opinions regarding the application were obtained using a printed survey containing 13 statements. Responses using a Likert-type scale[23] are shown in Figure 3 for four areas of interest: design, content, playability, and usefulness. In general, the responses to the 13 statements showed high levels of agreement ("agree" and "agree totally") from those surveyed. Therefore, we believe that the game is dynamic, fun, and easy-to-play and has an attractive design able to capture the attention of the player. The questions are clear and well-elaborated and adequately cover the content seen in the classroom. Moreover, students agree that the game is an innovative didactic tool that can help them review structural theory.

In general, the responses on the 13 statements (see the Supporting Information) presented received a high level of agreement (agree and agree totally) from those surveyed. Therefore, in general, we believe with reasonable accuracy that the Time Bomb Game has an attractive design that captures the attention of the player and makes it easy to play/review the

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Figure 2. (a) Congratulations screen. (b) Checking the answers of the questions. (c) Questions comment. (d) Failure screen.

content seen in the classroom through questions that are clear and well-elaborated. Moreover, the game is a dynamic and fun way to help students to review the structural theory of organic compounds. Therefore, the application is an excellent educational tool that can complement the traditional materials, such as books, in the student learning process.

The Time Bomb Game has also been very favorably evaluated by professors and students who left positive comments and some suggestions for improvement in the evaluation form. A selection of comments from professors and students (translated here into English by the authors) demonstrates the pedagogical value of the app.

- "The game is a great initiative, well designed and has good questions. It will certainly help students to review the content for which it is intended. However, I think there are some improvements in design." [professor from UECE]

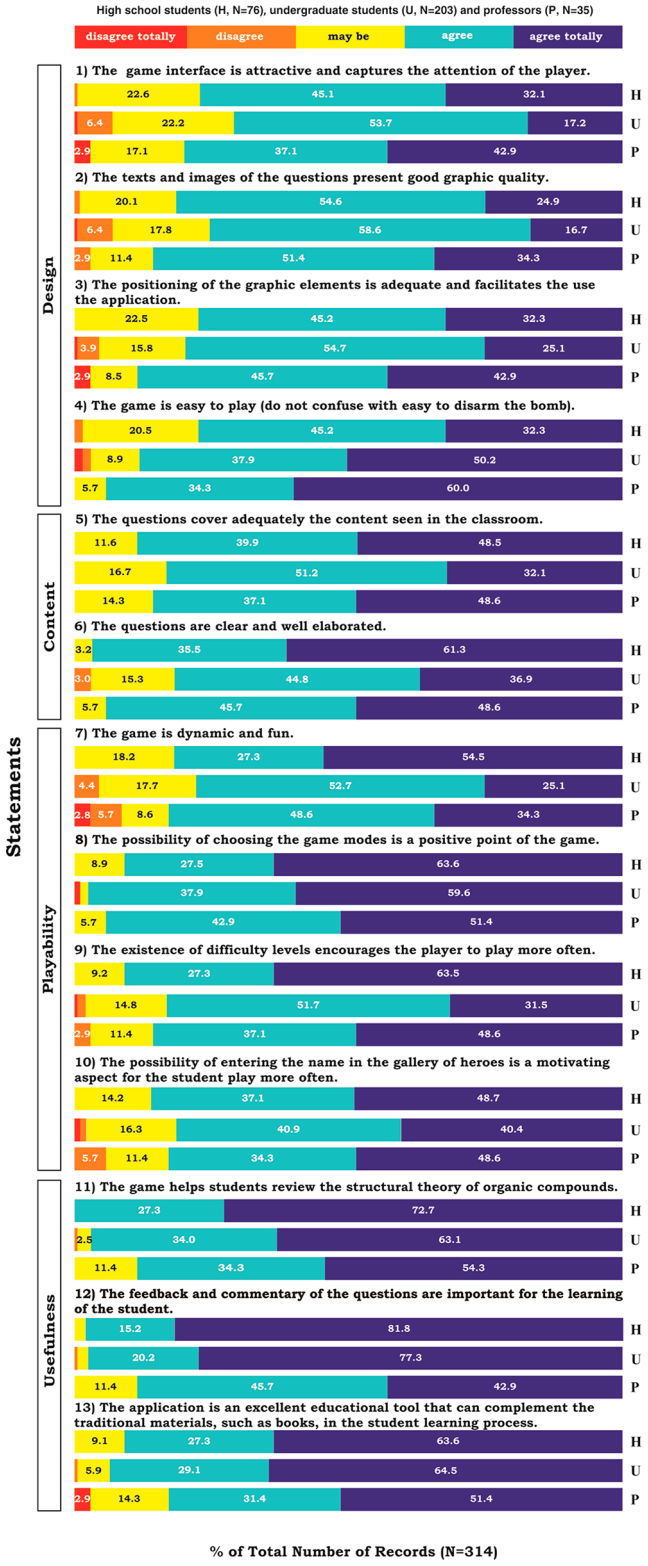

Figure 3. Survey results showed the distribution of Likert scores for evaluators' responses by survey statement.

- "Excellent tool, putting comments for each of the issues certainly was an excellent idea and certainly is a very important factor." [professor from IFCE]
- "The game is wonderful, creative, with smart questions and answers. Also, it catches the attention of the player and motivates him to continue playing it to disarm the

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bomb. The creators and mentors of the game are to be congratulated." [professor from UnB]
- "It's a great game, which makes it much easier to learn and review content." [Pharmacy student]
- "Congratulations to the developers of the game! I particularly felt much helped." [Food engineering student]
- "Great way to fix the content, because you can play the app any time and be learning the subject." [Agronomy student]

The development of the Time Bomb Game is continually based on user feedback from students and professors who evaluated the first version of the application. Although the vast majority of comments were positive, some suggestions for improvement were related to design. On the basis of these suggestions, we asked students how the new version should be designed. From their responses, we redesigned the application entirely, which is presented in this report and has received better evaluations.

EVALUATION OF THE INSTRUCTIONAL ROLE OF THE GAME

The evaluation was carried out with 110 12th grade students from Governador Adauto Bezerra High School in Fortaleza-Brazil. Three classes were randomly chosen as two experimental groups (EG, 76 students) and one control group (CG, 34 students).

The following hypothesis was tested: There is a significant difference between student learning of structural theory of organic chemistry supplemented with the application (EG) as a complementary educational tool as compared to student learning by a traditional lecture with textbooks, whiteboards, and slideshow presentations (CG).

The experimental study was conducted using a controlled pretest and posttest with 20 multiple-choice questions that were each designed to analyze the effect of the instructional role of the developed game on the learning of structural theory organic compounds at the high school level. (See the Supporting Information.)

Pretest and Posttest

The pretest was administered to all three groups (1 control and 2 experimental) in the classroom before any lecture about the structural theory of organic chemistry. This test aimed to verify the students' knowledge about the subject.

The posttest was also administered to all three groups in the classroom after all groups had had seven traditional lectures of 50 min each covering the following topics:

- Aromaticity
- Hybridization
- Electronic distribution
- Lewis structures and formal charges
- Intermolecular forces
- Molecular geometry
- Resonance

Both experimental and control groups had the same lectures with the same teacher. However, there was a significant difference: the two experimental groups had access to the app between both tests while the control group did not play the game at any time.

The aim of this posttest was verifying whether there was a significant difference between students' learning of structural theory of organic compounds via use of the application as a complementary teaching tool and students' learning by traditional lectures. The posttest was similar to the pretest and asked students to answer questions that covered the topics seen in the classroom. The students had 50 min to respond to both tests.

Statistical Analysis

A *t*-test for paired samples was used to determine whether there was a statistical increase in the number of correct questions of each group between the pre- and posttest (Table 1).

Table 1. Comparison of Student Performance Relative to Use of the Application

	Students' Average Scores[a]		
Group (*N*)	Pretest	Posttest	Av Score Differences
EG 1 (38)	7.8 ± 3.5	11.5 ± 4.9	3.7[b]
EG 2 (38)	7.9 ± 4.2	12.2 ± 5.0	4.3[b]
CG 1 (34)	6.5 ± 3.3	7.6 ± 4.0	1.1[c]

[a]The scores have a range of 0−20. [b]$p < 0.0001$. [c]$p = 0.0911$.

There was a significant statistical increase in the number of correct questions in the experimental groups ($p = 0.0000$); however, there was no difference in the control group ($p = 0.0911$). This increase has different magnitudes among the groups ($p = 0.0022$). The differences were more considerable between the EG1 than in the CG ($p = 0.0067$), and between the EG2 than in the CG ($p = 0.0009$), and there were no significant differences between the EG1 and EG2 ($p = 0.5269$) (Tables 2 and 3).

Table 2. One-Way ANOVA on Test Performance between the Experimental and Control Groups

Variation	Sum of Squares	dF	MS	*F* Value	*p* Value
Between groups	205.5	2	102.8	6.498	0.0022
Error	1692.4	107	15.8		
Total	1897.9	109			

Table 3. *Post hoc* DMS Test for Independent Samples for Comparing the Differences of the Number of Correct Answers between the Groups

Differences between Groups	Av Score[a] Difference	SD	*p* Value
EG1 − CG	2.61	0.945	0.0067
EG2 − CG	3.19	0.933	0.0009
EG2 − EG1	0.58	0.913	0.5269

[a]The scores have a range of 0−20.

Groups EG1 and EG2 had no significant difference in the increase in the average number of questions with correct answers between the posttest and the pretest. Still, these had a more substantial difference when compared to the CG control group.

Therefore, on the basis of the previous statistical analysis, we can conclude that the use of the application by students as a complementary educational tool contributes to the improvement of students' learning.

CONCLUSIONS

The new generation of chemistry students is growing up in the modern era of electronic devices and is more engaged with learning activities when smartphones are used in the classroom

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as new technologies, and multimedia presentations naturally attract young students.[11,24,25] Therefore, students will be the leading force in the adoption of chemistry apps that are in continuous growth in user base along with the increasing adoption of mobile computing technologies in the classrooms by educators.[26]

There are many possibilities to use mobile applications as tools for learning basic sciences successfully. The Time Bomb Game is an example of a useful didactic resource to promote understanding of the basic concepts of the structural theory of organic compounds, allowing students to review these concepts through a fun game designed to achieve this aim. Due to its intuitive and interactive features, the learning process is a ludic process that allows students to review the content taught in the classroom and possibly help them to improve their performance in the exams.

However, to enhance the educational experience, educators should treat these educational applications merely as a helpful tool since the apps alone cannot address all the obstacles that the students face in the process of learning.

The apps should not replace the educators' role in leading the learning process. Chemistry mobile apps should be combined organically with other pedagogical tools such as conventional paper media, live demonstrations, and even old-school lecturing to reach educational goals.[26]

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.9b00571.

Survey, pretest, and posttest (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

The Android version of the Time Bomb Game is available at https://play.google.com/store/apps/details?id=com.A11v1r15.TimeBombST, and the iOS version is available at https://apps.apple.com/us/app/time-bomb-game/id1456069569 (both accessed Nov 30, 2019).

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