Game to teach Organic Chemistry in Virtual Reality

Iris Gabriela Pereira Rodrigues
Instituto Superior Técnico, Lisboa, Portugal
October 2018

Abstract
This paper describes the work conducted to develop a game in Virtual Reality to teach Organic Chemistry. Other educational games were analysed to identify their strengths and weaknesses and the importance of games and Virtual Reality technologies in education were studied to obtain guidelines on how to approach the implementation of this game. The manipulation of objects was also studied because it is extremely important in Virtual Reality and it takes a central focus in this game because the player will be manipulating atoms and molecules. To help with this component, the Leap Motion sensor was used alongside the HTC Vive. The game development, which includes mechanics and gameplay, was done in three iterations. Two tests were performed at the end of the first two iterations, one test per iteration, and a final test was performed at the last iteration with high school students.

The results showed that the approach of using VR is viable for teaching Organic Chemistry.

Keywords: Virtual Reality, Organic Chemistry, Manipulation, Leap Motion

1. Introduction
There are more and more educational games that can have an impact in several fields of studies. However, it is not easy to create a good educational game, because it needs to have a balance between two aspects, teaching and entertainment, in order to have a game that has greater chances to achieve its goals. Virtual Reality is also being taken into account since it provides a platform where learners can be fully immersed in a virtual world allowing them to perform actions that they couldn’t do in real life.

This project aims to improve and complement the traditional methods of teaching Organic Chemistry. With Virtual Reality, it is possible to create a game that adds interactivity and immersion to the traditional methods, thus enabling the students to better understand the more difficult subjects. This technology comes with the challenge of how the interaction with objects should be performed. To help with this aspect, this project also makes use of the Leap Motion which tracks the user’s hands, enabling the use of the hands to perform the manipulations in the virtual world.

2. Background
2.1. Domain
The domain present in the educational game that was developed focus on the basic knowledge that a high school student should acquire about Organic Chemistry. This knowledge consists on information about the organic molecules, their nomenclature, structural drawings, 3D structure, class and formula.

2.1.1 Discipline topics
Since the target audience of this project are high school students it was necessary to know and understand what is taught in high school about Organic Chemistry. From this initial research the discipline topics focus on the bonding, structure and nomenclature of organic molecules, the fundamental groups, isomerism, organic bases and acids and reaction mechanism. These are the overall goals in Organic Chemistry courses, however they will not all be learning objectives in the game that will be developed. This will be further explained in the Implementation section.

2.2. Virtual Reality and Games in Education
To understand how Virtual Reality can be used in education, it is necessary to understand how humans learn and improve their skills and capabilities. According to the constructivist theory by Piaget a person learns in real life by doing and improves his skills through practice on realistic tasks, meaning that there must be active learning to have improvement. Since humans learn by having experiences and by interacting with their environment, Virtual Reality becomes a clear choice to create educational games. When creating a VR game or tool, there are three aspects to consider: immersion, interactivity and multi-sensory feedback [1]. Immersion means being enveloped or surrounded by the environment and the key benefit of this component is that en-
sures the feeling that one is really in the virtual world. Interactivity is the ability to control events in the virtual world using one’s body movements and having the world generate responses to them, and multi-sensory feedback allows the simulation to be more believable and engaging because the information is derived from several senses making it more redundant which reduces potential ambiguity and confusion. These features make VR a great option to use in educational games, because it means that a student can be put in a depicted world, interact with it, generate solutions to problems presented and have responses from the world to those actions, all within a safe environment.

There are studies that show that games have a positive impact in changes in perception, attention and spatial cognition. From the results of those studies, we can assume that games can have an impact in teaching, but creating an useful and fun educational game is not an easy task. There must be a balance between the educational purpose and the entertainment aspect for the game to improve learning and be engaging at the same time. Kili [5] proposes a model that links gameplay with experiential learning to facilitate flow experience. The base of this model are the challenges based on educational objectives provided in the game, and through a cycle of attempts of the player and feedback from the game, active experimentation is induced. From this, it is possible to see a parallel between this model and the constructivist theory.

There are 5 strategies to design Virtual Reality Learning Environments [3] that one can use. This paper will focus on problem based learning which is a learner-centered approach. It allows students to observe the simulated situation, motivate them to learn and solve problems adequately through the immersive interactive environment [3].

2.3. Chemistry games and applications
Most chemistry games, that exist to date, are more commonly card games or boardgames. There aren’t many video games that focus on Chemistry, there are more applications and tools. The main applications and games analyzed and the conclusions taken from them are:

- Groupica[2] (game) - shows how to correlate elements to their group families;
- Elemental Periodica[2] (game) - uses the information about an element for the players to find out what element it is and what is it’s name;
- MolyPoly[7] - depicts how gestures can be used to interact with molecules with the help of a manipulation panel.

2.4. Objects manipulation in Virtual Reality
The interaction with objects within the virtual world is an important issue to tackle, it has a direct effect in the immersive feeling of the virtual environment, thus impacting the whole experience. In the game developed, the interaction with objects (atoms and molecules) is extremely important, and for that reason it is necessary to understand how to manipulate objects in a virtual world. The most important aspect to implement this component is the technique that should be used.

2.4.1 Manipulation techniques
There are several techniques that can be used for manipulating objects but one aspect that they all must have is that they should provide the means to accomplish at least one of the three basic manipulation tasks: object selection, object positioning and object orientation. Poupyrev and Ichikawa created a taxonomy which categorizes the different methods of virtual objects manipulation available at the time by analyzing their characteristics[4]. They defined two major metaphors for the techniques: exocentric and egocentric. In this project the focus will be on the techniques from the egocentric metaphor.

Although there are many techniques used for manipulation of objects, there are two major categories: Virtual hands - provides direct manipulation capabilities by resembling the user’s real hand in a virtual space. This method is intuitive and natural due to the direct control of objects based on analogies from the real world, but the user is restricted to the physical reachable area around him; Virtual pointers - can expand the reachable area by allowing the user to cast a ray at a distant object that enables the user to pick it, grab it and interact with it. Because of the ray cast, this technique requires relatively less effort to perform any manipulation to the object. Although this is an easier technique to use and more efficient, it can be subjected to inaccuracy due to hand jitter and the Heisenberg effect.

Figure 1: Example of a classical virtual hand

For this project, the classical hand will be mostly used for the manipulation of objects, since they will

all be close to the players, and he won’t have a large space to move around on.

2.4.2 Feedback

One important aspect regarding the manipulation of objects in Virtual Reality is the feedback that is given to the player when he performs different actions in the virtual world. The best type of feedback that can be used in a VR game or application is haptic feedback, which allows the user to have the sensation of touching a virtual object by simulating some features of the object such as: hardness, weight, inertia, surface contact geometry, smoothness and slippage. However, the hardware that was available to use in this project didn’t have haptic feedback, making it necessary to find an alternative whose results should be as close as possible to the results of using haptic feedback.

Most games and applications rely on visual and auditory feedback which, comparing to haptic feedback, are a low-cost type of feedback. The visual and auditory sensorial channels have a one-way, information-only flow, which means that they only collect and analyse information coming from the environment but have no interaction with it. Also, these two senses are allocated to relatively large areas in the sensory cortex, suggesting that visual and auditory displays have the potential of presenting haptic feedback with good results [6]. For this reason, the chosen replacement for haptic feedback was the combination of auditory and visual feedback.

3. Implementation

3.1. Idea

After researching and also talking to a high school Chemistry teacher, the defined domain of the game includes the nomenclature, structural drawings and functional groups of organic molecules.

The several parts of the domain are integrated in the different game modes available on the game. There were two main game modes defined which were the Normal and the Speed Run modes. Both use the domain in its full scope, meaning that they have different types of challenges related to each part of the domain. These game modes will be detailed in section 3.1.3. There were also four sub game modes that focus on the different types of challenges that the game has, which means that each mode only presents one type of challenge. Therefore these sub game modes are Build, Complete, Transform and Multiple Choice. These types of challenges will be described in section 3.1.2.

The game mechanics used in all the game modes are the same, making it easy for the player to switch between modes without having to adapt to different mechanics. The player can create molecules by connecting the atoms and manipulate the created molecules.

3.1.1 Learning goals

One of the most relevant components to define are the learning goals which must clearly define what the users should learn about the domain through the game. This means that the game must provide the means to reach the learning objectives. The final learning goals defined are:

- Recognize and name the major functional groups (hydrocarbons, carboxylic acids, haloalkanes, alcohols, aldehydes and amines)
- Recognize the functional group a molecule belongs to
- Know the nomenclature of the molecules
- Correlate molecular structure with the nomenclature
- Correlate conventional drawings of molecular structures with their 3D structure

3.1.2 Challenges

There are four different types of challenges that the player is faced with, which are:

- Build molecule from scratch knowing some information about it (Build) - the player has to connect the atoms to build the molecule with only a piece of information about. This information can be anything about the molecule, it can be the structure, the name, the functional group it belongs to or the formula;
- Complete a given molecule knowing some information about it (Complete) - this challenge is very similar to the Build challenge, the difference is that instead of building the molecule from scratch, the player has a partially built molecule that he must complete, considering the information that is given;
- Multiple choice question (Multiple choice) - in this challenge the player has to answer a question about the molecule that is placed in front of him. The question has 3 possible answers and the player has to look at the molecule and figure out what the correct answer is. Transform a molecule into another (Transform) - for this challenge, the player is faced with a complete molecule and information about the molecule that he must achieve. The objective is to transform the given molecule into a molecule that corresponds to the information that is given. This information can be the name, the functional group, the formula or the structure of the intended molecule.

One of the things that was discussed with the Chemistry teacher were how the exercises applied in this subject solidify the concepts that the students learn. It was clear that the same type of exercise
can be used for different concepts. This means that the same challenge can be used for different learning objectives, making them versatile.

3.1.3 Gameplay

As it was previously said, there are two main game modes, Normal and Speed Run, that use the domain in its full capacity.

The Normal mode is a slow-paced game mode and focus on the player having time to learn and absorb the knowledge. In this mode, there are 50 levels and each level has different challenges. The difficulty for this mode increases according to the number of learning objectives the level tackles. The first 20 levels tackle a distinct learning objective at a time, meaning that there are 4 levels per learning goal. The order of the learning objectives is equal to the order in which the students learn the different concepts in class. The next 15 levels mix two learning objectives and the last 15 levels mix three learning objectives. Besides this evolution, the challenges within each level also get increasingly difficult with what they ask the player to do.

The Speed Run mode is a fast-paced game mode and it emulates a quiz, where the player has a time limit to complete all the challenges he is faced with. In this mode, there are 10 levels, each level with 5 challenges that the player must solve as fast as they can. All the levels tackle a distinct learning objective at a time, meaning that there are two levels per learning goal. The first level of each learning goal has easier challenges and the second level has harder challenges. This means that the difficulty for this mode isn’t has high has the Normal mode, particularly for the levels.

3.1.4 Scoring System

The scoring system of the game is based on two measures: number of attempts and number of moves.

In the Normal mode, the skill of the player is measured in number of moves for the challenges Build, Complete and Transform because these challenges force the player to manipulate the atoms and interact with the molecule to solve them. For this reason, it makes sense to count the number of moves that the player performs until he reaches the desired molecule. For a Multiple Choice challenge the player is rated by the number of attempts he makes until he selects the correct answer.

In the Speed Run mode the skill of the player is measured only in time, since the only thing that matters is how fast the player can finish all the levels.

3.2. Technical implementation

The game was developed in three iterations: the first one focused on implementing the core mechanics, the second was needed to improve some of those initial mechanics, and finally, the third one had the main objective of implementing the gameplay components (levels and challenges) and some extra elements.

One of the most important aspects implemented in this stage was the relationship between an atom and a molecule as objects in the game 2. When two atoms are connected, a bond is created between them and a molecule is formed. Every molecule has a pivot, which is a gear that is used in the manipulations techniques to help the play interact with the molecules. The position of the pivot is the mean of all the atoms position with an offset on the x axis, which means the pivot appears always to the right of the molecule.

3.2.1 Core mechanics

The core mechanics were implemented in this stage, which are connecting atoms, translating and rotating molecules. For connecting atoms, there were two methods implemented, one that was based on distance and another that was based on touches. The method based on touches (nicknamed Tapping method) consisted on grabbing two atoms, one in each hand, and touch the atoms together. Each time the atoms touch each other, while the player is grabbing them, the type of bond increases, from single to triple bond. When it reaches the triple bond and the atoms touch each other again, it circles and goes back to a single bond. The technique based on distance starts the same way as the Tapping method, but after the atoms touch each other once, the player has to define the bond he wants to create by moving the atoms away or closer to each other. The closest the atoms are, the stronger is the bond type and the farthest the weaker is the bond.

To move the molecule into a different position, the player could use two different ways. One method was to grab one of the atoms of the molecule...
and move it to the desired location and the rest of the atoms would be dragged along. The other method was to grab the pivot with his left hand, and move it, which would make the whole molecule move without losing its shape.

There were three different rotation methods implemented:

- **Automatic rotation** - the player grabs the pivot of the molecule with his right hand and define the axis around which the molecule should rotate with his left hand. He can set one of two axes, the X-axis and Z-axis, through two distinct hand gestures which vary according to the method being used (showed in figure 3). After the pivot is grabbed and the axis set, the molecule rotates on its own.

- **Rotation with wrist control** - the player also needs to define the axis around which the molecule should rotate through the same gestures shown in the figure 3. The rotation of the molecule is controlled by the rotation of the right wrist, this means that the player has to grab the pivot with his right hand and while grabbing it, he must rotate his wrist to rotate the molecule.

- **Rotation with atom** - the player has to grab the pivot with his right hand and grab one atom of the molecule with his left hand, and then he has to move the atom around what would be the centre of the molecule. When he begins to move the atom, the pivot moves to the centre of the molecule. This way the player has a visual reference of where it is, making it easier to understand how he must move the atom to rotate the molecule around the central point. As the atom is moved around the pivot, the whole molecule follows its movement, making it rotate around the pivot.

**Figure 3:** Hand gestures for setting the rotation axis (each method is represent in each row).

From the results of the testing phase of the first iteration, the conclusion was that the preferred technique to connect atoms was the Tapping method and that for translating a molecule, both techniques were adequate for different scenarios. Two of the rotation techniques implemented, Rotation with Wrist Control and Rotation with Atoms, needed to be improved but they were the most preferred methods. Although the users chose the Automatic Rotation has their preferred technique, the most of them mentioned that they only picked it because it was the one that was working with less problems, not because they liked it better. For this reason, the Automatic Rotation method was discard, and the focus on the second iteration was to improve the other two techniques and test them again.

### 3.2.2 Gameplay

The gameplay components that were implemented consist on the levels, which include all the different challenges, and the ranking and evaluation systems of those challenges. One objective was to create the levels in a flexible way, allowing for easy changes in them without tempering with the code. This was made through text files that are parsed by the system and that can be easily changed. They have a specific structure that must respected in order to be loaded correctly.

The challenges have their own specific name that must be used. Each challenge has it’s own structure because each has different components that have to be provided, as it is shown in the figure 4. These structures must be respected for the level to be loaded with no problems.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> : multiple choice</td>
<td>&gt;What is the name of the molecule?</td>
</tr>
<tr>
<td></td>
<td>&gt;a. CH4</td>
</tr>
<tr>
<td><strong>2</strong> : build</td>
<td>&gt;2-methylbutane</td>
</tr>
<tr>
<td><strong>3</strong> : complete</td>
<td>&gt;alcohol</td>
</tr>
<tr>
<td><strong>4</strong> : transform</td>
<td>&gt;methane</td>
</tr>
</tbody>
</table>

**Figure 4:** Example of tasks with their specific structure

For some of the challenges it is necessary to present a molecule to the player, and for this reason, the game needs to have a database with the molecules that should be loaded in those tasks. The database is a collection of text files, each of them correspond to one molecule, which has several information about the molecule such as: the position it should appear, the different atoms that it has and the bonds that exist between the atoms.

### Checking challenge completion

Besides those type of files, there are also another type that represent a molecule only through the
bonds that it has (figure 5). This type of files is used to compare molecules with each other and those files are used to check if the player completed a task correctly, specifically a Complete, Build or Transform task where they have to assemble a specific molecule.

Figure 5: Example of file used to compare a molecule to another

The way this comparison is made is through the bonds that the molecule created has, since that is the information that is stored in these files. Because they are text files, the simplest way to compare it with the created molecule, is to have a string with the same information about all the bonds the molecule has. Then the comparison is made between the text file and that string.

The evaluation of the Multiple Choice task is more direct since it is only necessary to check if the answer that the player chose is a match to the correct answer provided in the task description.

Scoring system
In this phase of development, the two types of scoring of the different tasks were implemented. As was explained in section 3.1, these types of ranking are Number of Attempts and Number of Moves.

The Number of Attempts is only used with the Multiple Choice tasks, so the point system is specific to this task. This correlation is: First attempt - 3 points; Second attempt - 2 points; Third attempt and up - 1 point;

For the Number of Moves, it was necessary to define what should be considered a move. The actions that are counted as moves are bonding two atoms, breaking a bond, picking a new atom, throwing a molecule or an atom to the trash and remove all molecules or all atoms from the scene. To get the maximum points, the player must solve the task with the minimum moves necessary which depends on the molecule he needs to complete, build or transform and the starting point of the task. For the Complete and Transform task, the starting point is the partial molecule that is placed in front of the player, and for the Build task, the starting point is empty. For this reason, the minimum number of moves is defined at the start of each task, because the value depends on the specifications of the challenge.

The figure 6 shows how the points are given according to the number of moves the player makes to solve the task.

Figure 6: Correlation of the number of points the player receives with the number of moves he makes.

Due to a tight schedule between the beginning of the final testing phase and the final decision on how to distribute the points for this scoring method, it wasn’t possible to fully implement the calculations necessary to automatically obtain the minimum number of moves for each case. They had issues, where the resulting value of minimum moves didn’t correspond to the actual value, due to the way the required information is obtained. For this reason, for the final tests the minimum number of moves of each task were hard coded, in order to have both scoring methods tested.

Audio and visual feedback
Audio and visual feedback were extremely important in this project to compensate the lack of haptic feedback.

The first visual feedback added was an yellow outline to the atoms that it is displayed when the player grabs them. It was also added an extra outline in red to indicate when the player couldn’t connect two atoms together. This red outline appears when a player touches two atoms together where at least one of them doesn’t have anymore available bonds to make. It was also implemented a representation of the number of bonds that an atom can make. These are represented by small spheres around the atom, and each time the player makes a bond with that atom, the correspondent number of spheres disappears.

Lastly, for audio feedback there were different sounds played for different actions. The actions that had audio feedback were: when an atom is grabbed, when the atoms touch each other while the player is grabbing them, when a bond is formed, when a bond is broken, when something is thrown in the trash, and when a button is pressed.

4. Results
In the final test the user was asked to perform several tasks and then fill a questionnaire. The challenges the user had to perform were to complete the tutorial and also the Normal game mode. This game mode was thought out to have 50 different levels, but for these tests, it was reduced to
4 levels. These 4 levels are detailed in the figure 9 which shows the challenges they had and the learning goals they tackle.

| Level 1 | (Know the nomenclature of molecules) |
| Challenge 1 - Build a CH4 molecule | Challenge 2 - What is the name of the molecule? (2,2-dimethylbuthane) |

| Level 2 | (Correlate conventional drawings of molecular structures with their 3D structure) |
| Challenge 1 - Complete the molecule knowing it’s structure (2,2-dimethylbutahne) | Challenge 2 - Build the molecule from the structure (CH3COOH) |

| Level 3 | (Recognize the functional group a molecule belongs to and knowing the names of functional groups) |
| Challenge 1 - Transform the molecule into a haloalkane. | Challenge 2 - Complete the molecule knowing it is an alcohol |

| Level 4 | (Correlate molecular structure with the nomenclature) |
| Challenge 1 - Transform the molecule into a 3-methylpentane. | Challenge 2 - What molecule is this? (Ethylene) |

Figure 9: Correlation of the levels with the learning goals.

The challenges used in the test were shown to a high school chemistry teacher to make sure that the content of the challenges was correct.

4.1. Users Sample
This test was performed by 25 users, 8 were high school students ranging from 16 to 18 years old, and the remaining 17 were college students ranging from 18 to 26 years old. The high school students were from the 11th grade and they had Organic Chemistry lessons in the previous school year, which means that they had knowledge about the domain that they had learned recently. The college students hadn’t been in contact with any aspect about Organic Chemistry for several years, so they didn’t remember most of the subjects that were approached in the game. For this reason, while they were performing the test, they had a printed sheet available to them with general concepts explained that they needed to know to solve the challenges.

4.2. Problem description
In order to understand if the game created fulfils its main objective, the results of the tests need to show three different points. One is that the students can easily manipulate the atoms and perform the tasks with ease. Two is that they have fun while they are enhancing their knowledge on Organic Chemistry. And finally three is that the content is accurate to what it is taught in schools. Another relevant aspect is that the tests should show that the levels can be easily changed by the teachers according to what they want the students to practice.

4.3. Experimental method
On this test, the logging technique was used to record information concerning each challenge and level posed to the user. The number of moves, the number of attempts and the points that the user made in each challenge since they were the methods used to attribute a score to the user.

The questionnaire used was based on the Game Experience Questionnaire (GEQ) \(^2\) and the VR Sickness Questionnaire \(^3\), but it also had 3 more specific questions about the challenges and 2 questions about the scoring methods. The questions about the challenges were made regarding each type of challenge that the user had to tackle: Build, Transform, Complete and Multiple Choice. They asked the user to rank in a linear scale how much did he like to use them, how much fun they were and how interesting. The questions about the scoring methods asked the users how fair the methods were and how pressured they felt using them.

4.4. Logs
The number of moves and attempts that the users made to solve each challenge were compared to the respective optimal number of moves and attempts. The optimal number of moves corresponds to the minimum number of moves to solve a challenge, and the optimal number of attempts is always one.

From the results of the analyses of the number of moves and number of attempts (figures 10 and 11), it is possible to say that the high school students had an overall better performance than the college students. This was expected because the high school students had learned Organic Chem-


\(^3\)http://w3.uqo.ca/cyberpsy/docs/qaires/SSQ_va.pdf [accessed: 7/10/2018]
The expected difficulty in each challenge was fairly close to the actual difficulty displayed by the users. However, there were some challenges were issues with the implementation caused big values that could have been much lower had those problems not existed (they are further explained in section 5). For this reason, the users were forced to restart the molecule, being careful not to join two molecules, and thus making a lot more moves than what was expected.

4.5. Questionnaire

From the analyses of the section of the questionnaire about Game Experience (figure 12), the conclusions are that the users had a positive experience with the game. They felt immersed in it and they felt skillful while playing it. This can indicate that the mechanics implemented helped in making the users feel competent. Another important aspect is the game flow, which had high values, meaning that the users felt that the game had a smooth progression.

The Challenge aspect of the game had the lowest scores which isn’t necessarily a bad sign. These values aren’t surprising because the challenges are based on Organic Chemistry and they aren’t very complex, which means that anyone with a basic to moderate level of knowledge on this subject can easily solve the challenges. Given that the high school students had had revisions on the domain prior to the test, and that the college students had information about the subject available to them, it is reasonable that the game wasn’t considered extremely challenging.

The Post-Game module results also indicate that the overall experience was positive, with little negative aspects and tiredness from the users.

4.6. Observations

All the high school students had fun while playing the game, some of them even said it at the end of the test. They also seemed focused on solving the challenges and were concentrating on finding out the answer without any help. Most of the users from the college sample had fun and enjoyed playing the

---

Figure 10: Results of the analyses of the number of moves and number of attempts recorded on levels 1 and 2.

Figure 11: Results of the analyses of the number of moves and number of attempts recorded on the levels 3 and 4.

Figure 12: Results of the analyses of the GEQ section of the questionnaire.

Figure 13: Results of the analyses of the VR Sickness section of the questionnaire.
game. Some of them were really focusing and trying to find out the correct answer by themselves without any help, except from the information that they had available to them. Half of the users mentioned at the end of the test that the game made it more fun to learn about this subject compared to the traditional method.

4.7. Interview to a Chemistry teacher
In order to have the point of view of a teacher, an interview was made to a high school chemistry teacher.

Q: What advantages and disadvantages the game has comparing to the traditional teaching methods on Organic Chemistry?
A: It’s more appealing to solve the exercises through the game than through paper and pencil, however it requires more time to solve them.

Q: How would you use the game in a class about Organic Chemistry?
A: In a classroom, it is possible to have 30 students simultaneously. If the game is used in a laboratory class, there can be 15 students at maximum. We would have to have the necessary equipment to have all those students playing the game at the same time. If the school has a room with all the required equipment, it makes the process easier.

Q: Does the game help to approach Organic Chemistry in a more entertaining way?
A: Yes. Without a doubt, it is a good method to cement the knowledge in a fun way.

By analyzing the answers given by the teacher, the game might be a good tool to be used in the classroom to help teach Organic Chemistry, since it might be able to bring fun and entertainment in learning the subject.

5. Conclusions
5.1. Results
The most important achievement present in this work is the creation of a functional educational game which is fun and entertaining to play. Although it was only implemented a small version of the Normal game mode, all the proposed mechanics in the concept were implemented as well as the most crucial audio and visual feedback. The levels and the different challenges were implemented as they were thought out with the additional flexibility, which wasn’t tested with users, but it enables them to change the challenges as they see fit. This would be used by the teachers, so that they could change the levels and challenges according to what they were teaching in each class.

The results obtained were overall very good. All the users enjoyed playing the game, and it was visible the potential the game as in a class room environment and the impact in learning Organic Chemistry, particularly in the users with little knowledge. The need to solve the challenges correctly and gain the maximum number of points made them invested in learning the concepts needed by themselves and understand about the domain. In the case for the high school students, it was possible to see that they were applying the knowledge that they already had, and when they made a mistake, they analyzed why it was wrong and were able to understand how to correct it and solve it. Even though there were problems during the tests, the users still felt comfortable with the mechanics and they didn’t have difficulties in understanding how to manipulate the molecules and atoms.

5.2. Future Work
There are several aspects that would enhance the game if they were implemented, but there are two that would be the most beneficial. The first one is implement the possibility to join two molecules together, because not being able to do this is a major flaw in the game, and it takes away a bit of freedom on how the players can interact with molecules. The second would be to implement a tool that would enable the teachers to design and create the levels for the game with a user friendly interface, and it would automatically create all the necessary text files for the game to load the levels correctly. This would be very beneficial because they could customize the game at their own will, according to what they want or need their students to learn at a specific class. The game would become more flexible and dynamic to be used in the classrooms.

Acknowledgements
I would like to acknowledge the board of Agrupamento de Escolas Raúl Proença for the help and collaboration in the final tests. Without their help, it would have been impossible to have made these tests and they made the entire process as simple as possible. I would also like to give a special thanks to Prof. Antónia Gomes from Agrupamento de Escolas Raúl Proença, for the help in understanding the domain of the game in depth, as well for the time spent and collaboration in preparing the final tests. And also for participating in the test and answer a questionnaire about it. I would also like to acknowledge my dissertation supervisor Prof. Rui Prada for his insight, support and sharing of knowledge that has made this Thesis possible. Last but not least, a special thanks to everyone from the Laboratório de Jogos at Instituto Superior Técnico who helped throughout this entire process, gave me advice and lend me a helping hand whenever I needed.

References


